Semiconductor Equipment, Manufacturing, and Materials

Dataquest
Perspective

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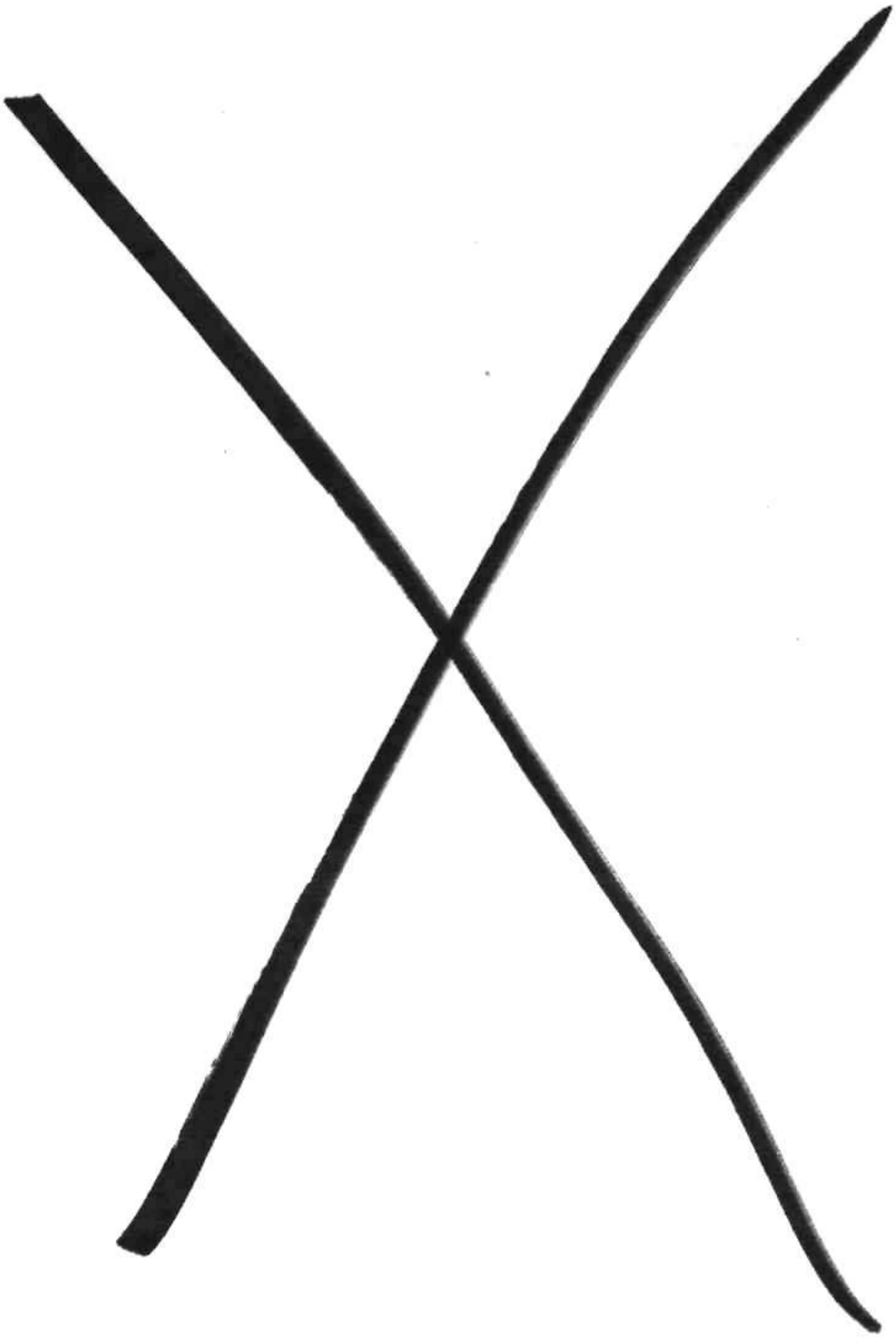

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Semiconductor Equipment, Manufacturing, and Materials

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In This Issue...

In this issue of Dataquest Perspective, we present a special focus on the global silicon wafer market. The articles in this issue address the different regional trends both from a macro viewpoint and an industry viewpoint. This document also includes our most current forecast for all the major silicon wafer segments including prime, epitaxial, and test and monitor wafers on a regional basis.

Market Analysis

Mixed Reviews for the United States

Many semiconductor companies are weathering the stagnant economic climate hanging over the U.S. economy. Device companies with products targeting the PC market are benefiting from the 20 to 25 percent unit growth in PCs in 1992. However, not all IC vendors are participating in this upturn. Device makers with products going into the mainframe/midrange computer markets, consumer applications, and military applications have reported a range of results for 1992, from marginally up to significantly down.

We now anticipate that silicon wafer unit demand (millions of square inches) in the United States will grow 5.0 percent in 1992 (see Table 1 in "Regional Unit Silicon Wafer Consumption Forecasts," elsewhere in this issue). The growth rate for silicon wafers is considerably lower than the growth rate of U.S. semiconductor revenue as reported by WSTS, about 15 percent revenue growth in 1992. The difference in growth rates is because of the increase in high-priced MPU sales in the overall U.S. revenue mix. Consequently, a higher average selling price had more of an impact on the 15 percent revenue growth rate than did the increase in units.

Winners and Losers

The primary beneficiaries of this trend are microprocessor makers AMD, Intel, and Motorola. These three companies' sales of devices shot ahead this year. In the last quarter alone, all three companies' revenue jumped in the range of 20 to 25 percent year-to-year. Epi wafer demand in 1992 has also surged, up 22 percent (see Table 2 in "Regional Unit Silicon Wafer Consumption Forecasts," elsewhere in this issue), since both Intel and AMD built their microprocessors using epi wafers.

The prime, test, and monitor wafer market in the United States saw much more sedate growth in 1992, up only 2.0 percent (see Table 3 in "Regional Unit Silicon Wafer Consumption Forecasts," elsewhere in this issue). The growth of this segment reflects the more modest sales gains made in many of the non-PC-related device applications. An application particularly hard hit was the mainframe/midrange systems market. Amdahl, Digital Equipment, and IBM all recorded dismal sales in a year widely heralded to be the beginning of a cyclic upturn for large system manufacturers. The weak system market translated into poor sales for captive device operations and external chip suppliers selling product into this computer segment.

Consequently, silicon wafer vendors' 1992 performance in the United States will depend heavily on which accounts they supplied. For example, the surge in epi demand left OTC, SEH, and Wacker scrambling to bring up additional ASM epi reactor capacity. These vendors supply Intel, which has only qualified ASM epi systems to date. On the other hand, the weak demand for wafers at IBM is expected to impact vendors, such as MEMC, which are primary suppliers.

Forward to 1993 and Beyond

Dataquest believes that the U.S. silicon wafer market will continue to be driven by system applications, especially PCs and workstations, and by network applications. Lower prices will continue to fuel unit sales of PCs and workstations. In addition, the growth of graphics-based applications utilizing the power of a new-generation of MPUs will increase the demand for silicon wafers. Finally, in the communications segment, the trend to a distributed computing architecture by many U.S. businesses will remain as a major driver in device growth.

But in 1993, the PC and workstation business will remain the primary driver and silicon wafer demand will again be tied closely to unit shipments of these systems. We expect the steady improvement in the U.S. economy over the next several years to gradually increase the demand for devices in other applications such as auto and consumer electronics. We anticipate a more broad-base recovery in the electronic food chain by 1994. Consequently, we expect silicon usage to grow 7.3 percent in 1994 and to have a 5.8 percent compound annual growth rate from 1992 to 1996.

Our view on the mainframe/midrange market is that the current downturn is a secular rather than a cyclic shift. Our current silicon forecast assumes that demand for semiconductors in this segment will decline over the five-year-forecast horizon.

Table 1
1992 Fab Closings

Company	City	State	Technology	Geometry (Microns)	Wafer Size (Inches)
Unisys Components Group	Rancho Bernardo	CA	BIP MOS	1.5	4
Micrel Semiconductor	San Jose	CA	DMOS BIP	1.0	4
Motorola	Mesa	AZ	BIP BiCMOS	0.5	4
AMD	Santa Clara	CA	BIP M2	1.5	4
Signetics (to Close)	Orem	UT	BIP	2.0	4
Xicor	Milpitas	CA	CMOS MOS	2.0	4
Hewlett-Packard	Palo Alto	CA	CMOS	0.5	4
LSI Logic (to Close)	Edmonton, Alberta		CMOS	1.5	6

Source: Dataquest (November 1992)

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Dataquest's five-year forecast for silicon is modest when compared with historical levels. Our silicon forecast mirrors the slower macroeconomic environment that we believe the U.S. economy will experience through 1996.

There are also trends on a micro level contributing to the slower growth of silicon wafer demand. First, the United States has the oldest semiconductor fab infrastructure, and we believe that the rate of fab closures will continue at a steady pace because of obsolescence (see Table 1). Second, we expect the rate of investment by foreign companies in U.S. fab capacity to decrease. The decline in Japanese investment in U.S. fabs will be especially notable. Finally, we believe that U.S. device companies will continue to pursue high-value-added niche applications concentrating on design and using overseas foundries to manufacture the devices.

By Mark FitzGerald

Japan's Recovery Problematic

The current economic slide in Japan has hit the Japanese electronic industry hard. Asset deflation in the financial sector of the economy, both in equities and real estate, has spilled over into the industrial sector. Weak end markets in the computer and consumer segments has caused device demand to decline sharply, about 10 percent according to current WSTS data. We expect silicon usage in 1992 to drop 8.5 percent (see Table 1 in "Regional Unit Silicon Wafer Consumption Forecasts," elsewhere in this issue).

End-Use Markets Deteriorate

Miserable business confidence and constrained capital spending budgets have eroded the demand for computer systems, the largest end-use application for semiconductors, especially in the mainframe market. MITI's August production data, the latest as of press time, shows mainframe sales off 23 percent in August year-to-year and down 22 percent from July. With banks, financial institutions, and manufacturers all cutting capital budgets, it is unlikely that this segment will recover in 1993. PC production was down 1 percent year-to-year and off 23 percent from July.

In addition, consumer electronic sales have hit the skids as export market and domestic demand still remain weak. MITI's August data show most product segments off sharply, including camcorders, VCRs, TVs, and home appliances. Video disk players and digital audio disk players bucked the trend, showing solid growth in production year-to-year, though not strong enough to offset declines in the other product segments. Inventories of consumer goods continue to increase, though seasonal factors may be at work here.

Forward to 1993

We have decreased our projections for the growth of silicon wafer demand in Japan since our forecast one year ago. We now estimate that silicon demand will have a 6.0 percent compound annual growth rate through 1996, down from the year-ago forecast of 7.8 percent. As the Japanese economic problems unfold, the impact on the Japanese semiconductor industry is proving more severe than our earlier assumptions.

Our estimate is that silicon demand will edge [illegible]p slightly in 1993. Our forecast growth rate is [illegible] percent in 1993, versus a decrease of 8.5 per[illegible] in 1992. Though we believe that the silicon [illegible]e has bottomed, we cannot identify any [illegible]ajor driving factors that will cause demand to bounce back in 1993.

The five major Japanese device companies—Fujitsu, Hitachi, Mitsubishi, NEC, and Toshiba—are all facing steep declines in revenue and profits in their information/communications equipment, consumer electronic goods, and semiconductor groups.

We believe that weak semiconductor demand is because of further production control by Japanese consumer electronic manufacturers and sluggish domestic demand for data processing equipment, including mainframes and PCs. Furthermore, we expect little improvement in the domestic demand for these goods in 1993.

Because the lion's share of these five companies' semiconductor sales is in Japan and a significant portion of their domestic sales is to captive end-use operations (see Table 1), we believe that the major Japanese semiconductor makers will only see a moderate upturn in 1993. Overseas markets will remain a bright spot for these companies because demand for MOS memory products will continue to improve. But, because of the relatively small size of the export market, we do not believe that this opportunity will completely offset the weak domestic market.

We believe that the structural problems built up in the Japanese economy will take time to work themselves out. Especially hard hit by the deflation of assets will be capital spending by Japanese businesses. As a result, demand for data processing equipment, including computers and office automation equipment, is expected to lag over our five-year forecast period. Because this is the largest end-use application for semiconductors in Japan, accounting for 42 percent of semiconductor usage, we are not optimistic about semiconductor production snapping back.

Consumer applications, which account for 29 percent of semiconductor usage in Japan, also face future challenges. The most immediate problem is the lack of any major new product driving demand for semiconductors as the VCR did in the 1980s. Furthermore, shifts in technology used in consumer products threaten to disrupt the vertical integration of large Japanese consumer electronic companies such as Matsushita and Sony. Key technologies required for future consumer products such as personal communicators, multimedia equipment, and HDTV will be software, microprocessors, and memory devices. Because Japanese companies lead in only one of these technologies, it is not clear how the domestic semiconductor industry will benefit as these products move to market.

External forces that threaten to weaken the demand for silicon wafers in Japan also are building. Mounting trade surpluses with the United States and a more protectionist stance by the Clinton administration may result in the United States being more aggressive in pushing for access to the Japanese semiconductor market.

The downturn in the demand for silicon wafers could not have come at a more awkward time for Japanese wafer vendors. Many companies have just completed a round of investment in

Table 1
1991 Semiconductor Sales (Revenue in Millions of Dollars)

	Worldwide Revenue	Percent Captive	Percent DRAM	Percent Japan
Fujitsu	2,705	29.0	18.6	73.0
Hitachi	3,765	20.0	17.6	68.2
Mitsubishi	2,303	27.0	22.4	65.7
NEC	4,774	26.0	15.6	72.9
Toshiba	4,202	15.0	22.8	58.0

Source: Dataquest (November 1992)

200mm wafer production lines. As one might well expect, this new capacity is not being used extensively because many semiconductor companies have put on hold their 200mm fab plans. Prices for the large-diameter wafers are under pressure and threaten to prevent companies from earning a return on their investment.

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The uncertainty in the Japanese electronic market has caused us to be more cautious about the growth of silicon usage. Even so, one should not underestimate the influence that the Japanese electronics market has on the global electronics food chain and the semiconductor industry in particular. It is difficult to ignore a market that will process 46 percent of the world's silicon in 1993, by our estimates. The sheer size of the electronic market will guarantee that the Japanese semiconductor remains a dominant force in the global industry.

By Kunio Achiwa and Mark FitzGerald

European Slump

Business activity in Europe remains difficult. Economic activity in Germany is falling off, the United Kingdom continues to be in recession, Spain's growth rate is slowing, and Northern Europe's economy is quite depressed. As we commented in our previous forecast document, the European economy is unarguably the biggest drag on silicon demand.

The fact that growth of silicon usage is almost entirely dependent on investment made by non-European companies is perhaps the most alarming trend. With the completion of the Mietec Alcatel facility in 1993, there will be no new green-field investment in front-end production fabs undertaken by domestic European companies (see Table 1). If the semiconductor investment climate in the United States and Japan remains stagnant, then U.S. and Japanese companies may well rethink their planned investment in Europe, further cutting into our forecast growth for European silicon consumption.

A deterioration in European device manufacturers' competitiveness is also causing us to be more cautious in forecasting silicon wafer usage. The three largest Europe-based companies—Philips, SGS-Thomson, and Siemens—continue to lag Asian, Japanese, and U.S. companies in design of devices and development of semiconductor process technology. The current downturn in capital spending at these companies suggests that the competition issue will not turn around any time soon.

European Company Performance

Philips has been particularly hard hit by the slowdown in consumer electronic demand. The company delayed introduction of its digital compact cassette player (DDC) until the end of the year. Even so, we do not expect this product to generate much demand for semiconductors. Other systems under development are HDTV and new compact disc systems. Introduction of these products is too far off to have much of an effect on device production for our forecast period. Philips' early device investment in

Table 1
Planned European Investment

Company	Country	Device	Technology	Geometry (Microns)	Wafer Size (Inches)
Production Begins 1993					
Intel	Ireland	MPU	BiCMOS	0.5	8
Mietec Alcatel	Belgium	ASIC	CMOS	0.5	6
National Semiconductor	Scotland	Lin	BIP		6
SGS-Thomson	France	ASIC	CMOS BiCMOS	0.5	8
Production Begins 1994					
Fujitsu	United Kingdom	DRAM	CMOS	0.5	6
Mitsubishi	Germany	DRAM	CMOS	0.8	6

Source: Dataquest (November 1992)

China over the long term may be the key to the rejuvenation of this company's semiconductor operations.

Siemens has cut back sharply on the production of semiconductors in Europe. The company closed three fabs in Germany during 1991 and continued to cut employees in 1992 at its semiconductor operations. The partnership strategy Siemens is now pursuing suggests that access to leading-edge device technology is more critical than adding manufacturing capacity. A de-emphasis on manufacturing will most certainly result in a decline in silicon wafer demand.

The third major European company, SGS-Thomson, continues to struggle with profitability problems. The company is moving ahead with plans to invest in a submicron, 200mm process technology. A research/pilot line is scheduled for completion in 1993. However, the French and Italian governments, the primary source of capital for SGS-Thomson, are struggling to lower their national budget deficits. If fiscal conservatism continues to be part of these governments' political agenda, then the governments' continued support of SGS-Thomson could be threatened.

On a more positive note, telecommunications devices will remain a strong area for European companies such as Siemens and Mietec Alcatel. The underdeveloped communications infrastructure of the eastern European countries means that demand for telecommunications gear will remain strong for the remainder of the decade.

Foreign Companies Lead the Way

Our forecast growth for the European silicon market, 6.9 percent compound annual growth rate through 1996 (see Table 1 in "Regional Unit Silicon Wafer Consumption Forecasts," elsewhere in this issue), is tied closely to spending on new fabs and expansions of existing facilities by non-European companies such as Fujitsu, Intel, Mitsubishi, Motorola, NEC, and National Semiconductor. Especially noteworthy is Intel's investment in a new line in Ireland. We expect epi wafer demand to grow 16 percent in 1993 and surge another 35 percent in 1994, based largely on Intel's requirements.

Previously, we were more optimistic about Japanese companies spurring the demand for silicon wafers in Europe. But as domestic problems in Japan have mounted over the last year, we have turned more cautious. Only Fujitsu and Mitsubishi plan facilities in 1994, and there is even a possibility that these may be delayed. On the other hand, NEC is spending additional money to expand its facilities in England.

Texas Instruments is now ramping its Avezzano, Italy facility, helped by the upturn in the U.S. memory market. Consequently, TI's silicon usage should also increase in 1993. National is closing several bipolar lines in Santa Clara, California and moving production to a new line in Scotland.

Dataquest Perspective

Though the formation of a unified Europe is certainly not the compelling reason for investing in new fabs that many foreign device makers thought it would be several years ago, we believe that it may yet prove to be a boon to Europe-based semiconductor production and to the demand for silicon consumption. Certainly, the end-use market demand is there. The main problem is that a major upturn is not on our five-year-forecast horizon, which extends through 1996.

By Mark FitzGerald

Asia/Pacific Rolls On

The 1992 growth of silicon consumption is surpassing our expectations. Our current estimate is that unit consumption will be up 24 percent in 1992, and we are forecasting a further increase of 14 percent in 1993 (see Table 1 in "Regional Unit Silicon Wafer Consumption Forecasts," elsewhere in this issue). The five-year compound annual growth rate (CAGR) through 1996 is estimated to be 14.2 percent, which is twice the growth rate of any other region in the world.

Koreans Lead

The phenomenal growth in silicon consumption in Asia/Pacific in 1992 is tied directly to the Korean DRAM producers. DRAM revenue at the three major Korean device makers shot ahead in 1992 (see Table 1). We believe that global demand for DRAMs will remain strong through 1993, pushing up silicon unit demand in Asia/Pacific another 14 percent. A major uncertainty surrounding our forecast is the recent dumping tariffs placed on the Korean DRAM vendors.

In spite of the tariffs, major Korean suppliers continue to add production capacity, but are asking at the same time whether they can maintain their market share growth by selling at higher prices forced on them by the U.S. government. Major users, which have a substantial interest in the eventual outcome in the resolution of this issue, so far are silent. They all recognize that it was only the Koreans that limited the Japanese DRAM hegemony that developed in the late 1980s, but are likewise sympathetic to the interest of U.S. suppliers.

Table 1
Korean DRAM Sales (Millions of U.S. Dollars)

	1992 Revenue	1992 Growth Rate (%)
Samsung	1,173	32
Goldstar	525	130
Hyundai	422	127

Source: Dataquest (November 1992)

Our forecast assumes that the Koreans will hold the market share gains they have won and further penetrate western markets. However, it is unlikely that the size of the market share gains achieved in 1992 will be repeated in 1993.

Perhaps the biggest obstacle to the long-term growth of the silicon wafer market is the strong hand of the Korean economic planners. The government has favored the high-technology sector to the exclusion of other sectors of the economy. This policy has resulted in a capital spending boom on new semiconductor capacity. But such a strategy is risky, considering the heavy dependence on device exports to pay for this investment. In our opinion, a more balanced semiconductor industry in Korea, where end-use applications such as PCs thrived, would be a more solid foundation on which to build a domestic semiconductor industry.

Other Countries also Prosper

The new fab lines being built in this region (see Table 2) suggest that the dominance of Korea in this region will wane. Plans to construct fabs in

Table 2
New Fabs Planned for Asia/Pacific

Company	Country	Year Planned	Products	Geometry (Microns)	Wafer Size (Inches)
Goldstar	South Korea	1993	16Mb DRAM 4Mb SRAM	0.5	8
Mosel/Vitelic Corporation	Taiwan	1993	4Mb DRAM	0.6	6
NEC China	China	1993	Telecom consumer ICs	2.0	6
Semiconductor Complex	India	1993	LSI	3.0	6
Tech Semiconductor Singapore Ltd.	Singapore	1993	16Mb DRAM	0.6	8
Wuxi Microelectronics Corporation	China	1993	Telecom ICs	3.0	5
Hitachi	Malaysia	1994	1Mb DRAM, 4Mb DRAM	0	6
Hua Yue Microelectronics Company	China	1994	NA	1.0	6
Mimos	Malaysia	1994	NA	1.5	6
Mosel/Vitelic Corporation	Taiwan	1994	16Mb DRAM	0.5	8
Samsung	South Korea	1994	4Mb 16Mb DRAM	0.6	8
Syntek	Taiwan	1994	NA	0	6
United Microelectronics	Taiwan	1994	SRAM	0	8

NA = Not available
Source: Dataquest (November 1992)

China, Malaysia, Singapore, and Taiwan suggest that these countries increasingly will play a more important role in the growth of the Asia/Pacific semiconductor industry.

Taiwan's market-driven economy in many respects is much healthier than is Korea's. Though its silicon consumption is much smaller than Korea, its semiconductor industry is better balanced. Taiwan has a thriving computer market, which provides device makers a domestic market for their product. As a result, we forecast silicon demand to grow at 8.3 percent CAGR through 1996.

However, the real star performer in terms of growth in silicon consumption will be the group of countries that fall under the rubric Rest of World (ROW). We estimate that silicon consumption for this group will push ahead at a 22.3 percent CAGR. Countries to benefit from this growth will be Singapore, Malaysia, India, and China. Much of the growth in the ROW category will be fueled by investment and technology transfers from Japanese, U.S., and to a lesser extent European companies.

Dataquest Perspective

The Asia/Pacific region remains the most vibrant in terms of growth rates in silicon consumption. However, we do expect some rotation in the growth of silicon consumption away from the current leader, Korea, to those countries just beginning to build their industrial infrastructures. The ultimate growth opportunities will be China and India because of the sheer size of the market. But political turmoil, fragile legal systems, and underdeveloped infrastructures make the timing of these opportunities difficult to gauge.

By Mark FitzGerald

Regional Unit Silicon Wafer Consumption Forecasts

This section includes Dataquest's most recent forecasts of regional unit silicon wafer consumption. The seven tables detail unit consumption in the four major regions of the world: the United States, Japan, Europe, and Asia/Pacific. Individual forecasts of the major product segments such as prime, epitaxial, and test and monitor wafers are included.

Table 1
Forecast of Captive and Merchant Silicon* and Merchant Epitaxial Wafers
(Units: Millions of Square Inches)

	1991	1992	1993	1994	1995	1996	CAGR (%) 1992-1996
United States	611	642	678	728	761	806	5.8
Growth (%)	-4.5	5.0	5.7	7.3	4.6	5.8	
Japan	1,046	957	995	1,086	1,140	1,209	6.0
Growth (%)	5.4	-8.5	4.0	9.1	5.0	6.0	
Europe	208	200	197	217	241	261	6.9
Growth (%)	-11.7	-4.0	-1.5	10.5	11.0	8.0	
Asia/Pacific-ROW	194	241	274	310	366	410	14.2
Growth (%)	7.5	24.0	14.0	13.0	18.0	12.0	
Total	2,059	2,039	2,145	2,341	2,509	2,684	7.1
Growth (%)	0.5	-1.0	5.2	9.2	7.2	7.0	

Note: Columns may not add to totals shown because of rounding.
*Includes prime, test, and monitor wafers
Source: Dataquest (November 1992)

Table 2
Forecast of Merchant Epitaxial Wafer Consumption
(Units: Millions of Square Inches)

	1991	1992	1993	1994	1995	1996	CAGR (%) 1992-1996
United States	92	112	126	137	147	157	8.9
Growth (%)	4.0	22.0	12.5	9.0	7.0	7.0	
Japan	104	100	103	107	111	116	3.7
Growth (%)	11.6	-3.5	2.5	4.3	4.0	4.0	
Europe	20	21	24	33	38	42	19.6
Growth (%)	7.4	2.3	16.7	35.0	17.0	11.0	
Asia/Pacific-ROW	7	8	9	10	13	17	21.3
Growth (%)	43.5	17.9	16.7	11.7	27.9	30.0	
Total	222	240	262	287	309	332	8.4
Growth (%)	9	8.2	8.8	9.7	7.8	7.4	

Note: Columns may not add to totals shown because of rounding.
Source: Dataquest (November 1992)

Table 3
Forecast of Merchant and Captive Silicon* Wafer Consumption
(Units: Millions of Square Inches)

	1991	1992	1993	1994	1995	1996	CAGR (%) 1992-1996
United States	520	530	553	591	615	649	5.2
Growth (%)	-5.9	2.0	4.3	6.9	4.0	5.5	
Japan	942	857	893	979	1,029	1,093	6.3
Growth (%)	4.8	-9.0	4.2	9.7	5.1	6.2	
Europe	188	179	172	185	203	218	5.1
Growth (%)	-13.3	-4.6	-3.6	7.1	9.9	7.4	
Asia/Pacific-ROW	188	233	265	300	353	393	14.0
Growth (%)	6.6	24.0	13.9	13.0	17.7	11.3	
Total	1,837	1,799	1,883	2,054	2,199	2,352	6.9
Growth (%)	-0.4	-2.1	4.7	9.1	7.1	7.0	

Note: Columns may not add to totals shown because of rounding.
*Includes prime, test, and monitor wafers
Source: Dataquest (November 1992)

Table 4
Forecast of Captive Silicon* Wafer Consumption
(Units: Millions of Square Inches)

	1991	1992	1993	1994	1995	1996
United States	70	70	70	70	70	70
Japan	40	40	40	40	40	40
Europe	5	5	5	5	5	5
Asia/Pacific-ROW	0	0	0	0	0	0
Total	115	115	115	115	115	115

*Includes prime, test, and monitor wafers
Source: Dataquest (November 1992)

Table 5
Forecast of Merchant Silicon* Wafer Consumption
(Units: Millions of Square Inches)

	1991	1992	1993	1994	1995	1996	CAGR (%) 1992-1996
United States	450	460	483	521	545	579	5.9
Growth (%)	-4.7	2.3	4.9	7.9	4.6	6.2	
Japan	902	817	853	939	989	1,053	6.5
Growth (%)	5.7	-9.4	4.4	10.1	5.3	6.5	
Europe	183	174	167	180	198	213	5.2
Growth (%)	-12.4	-4.8	-3.7	7.3	10.2	7.6	
Asia/Pacific-ROW	188	233	265	300	353	393	14.0
Growth (%)	6.6	24.0	13.9	13.0	17.7	11.3	
Total	1,722	1,684	1,768	1,939	2,084	2,237	7.4
Growth (%)	0.7	-2.2	5.0	9.7	7.5	7.3	

Note: Columns may not add to totals shown because of rounding.
*Includes prime, test, and monitor wafers
Source: Dataquest (November 1992)

Table 6
Forecast of Merchant Test and Monitor Wafer Consumption
(Units: Millions of Square Inches)

	1991	1992	1993	1994	1995	1996	CAGR (%) 1992-1996
United States	90	92	97	104	109	116	5.9
Japan	180	163	171	188	198	211	6.5
Europe	37	35	33	36	40	43	5.2
Asia/Pacific-ROW	38	47	53	60	71	79	14.0
Total	345	337	354	388	418	449	7.4

Source: Dataquest (November 1992)

Table 7
Forecast of Merchant Prime Wafer Consumption
(Units: Millions of Square Inches)

	1991	1992	1993	1994	1995	1996	CAGR (%) 1992-1996
United States	360	368	386	417	436	463	5.9
Growth (%)	NA	2.3	4.9	7.9	4.6	6.2	
Japan	721	654	682	751	791	842	6.5
Growth (%)	NA	-9.4	4.4	10.1	5.3	6.5	
Europe	146	139	134	144	158	170	5.2
Growth (%)	NA	-4.8	-3.7	7.3	10.2	7.6	
Asia/Pacific-ROW	150	186	212	240	282	314	14.0
Growth (%)	NA	24.0	13.9	13.0	17.7	11.3	
Total	1,378	1,347	1,415	1,551	1,668	1,790	7.4
Growth (%)	N/A	-2.2	5.0	9.7	7.5	7.3	

Note: Columns may not add to totals shown because of rounding.
NA = Not available
Source: Dataquest (November 1992)

Polysilicon Supply Balanced

The worldwide capacity utilization for polysilicon plants is running at 75 percent. The slow-growth environment in the global silicon wafer industry suggests that there is plenty of capacity to meet future demand. Though regional utilization rates vary from a low of 73 percent in Europe to a high of 88 percent in Japan, Dataquest does not believe that any regional imbalances will occur because the polysilicon market is a global market. Table 1 shows polysilicon plant capacity and Dataquest's estimated 1992 utilization rates.

By Kunio Achiwa and Mark FitzGerald

Table 1
Polysilicon Plant Capacity (Metric Tons/Year)

Region	Company	Nominal Capacity	1992 Production	Capacity Utilization (%)	Type of Process
Total Capacity 1992		11,400	8,455	75.2	
United States	Ethyl Corporation	1,250	600		Fluidized Bed-Silane Base
United States	Hemlock	1,600	1,400		Siemens-Trichloro
United States	Advanced Silicon Mat.	1,200	950		Siemens-Silane
Total U.S. Capacity		4,050	2,950	72.8	
Europe	Hüls	700	400		Siemens-Trichloro
Europe	Wacker	3,000	2,300		Siemens-Trichloro
Total European Capacity		3,700	2,700	73.0	
Japan	Kojundo (Hi-) Silicon	1,080	1,000		Siemens-Trichloro
Japan	Komatsu	100	70		Siemens-Silane
Japan	Osaka Titanium	720	500		Siemens-Trichloro
Japan	Tokuyama Soda	1,200	1,150		Siemens-Trichloro
Total Japanese Capacity		3,250	2,870	88.3	
ROW	China (PRC)	400	375		NA
Total ROW Capacity		400	375	93.8	

NA = Not available
Source: Dataquest (November 1992)

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Dataquest Perspective

Semiconductor Equipment, Manufacturing, and Materials

SEMM-SVC-DP-9214 November 9, 1992

In This Issue...

Market Analysis

Korea: Current Trends in Semiconductor Industry Development

Since its embryonic beginnings in the late 1970s, the Korean semiconductor industry has grown into a key force in the world semiconductor market. It has now reached a stage in its development where youthful vitality and self-confidence provide all the assurance needed that it can accomplish what it sets out to do. Two of the Korean semiconductor industry's objectives are self-sufficiency and independence.

Korea relied heavily on outside help during the formative years of its semiconductor industry. Technical assistance was obtained through licensing agreements and imported technology. Manufacturing capacity was launched with imported semiconductor equipment and materials. End-user imports provided the ICs needed to build electronic equipment.

Today the situation is different. From a technology standpoint, the Korean semiconductor industry has already achieved world-class status. It now wants to shake the remainder of the yoke. Korean objectives are twofold: reduce IC imports by balancing domestic chip consumption and production, and reduce semiconductor equipment and materials imports by building a local equipment and materials infrastructure. Electronics power is a well recognized and bona fide goal for all of the world's industrial nations. To achieve it, to develop its own semiconductor industry, Korea is intent on fully integrating its electronic equipment and semiconductor sectors.

This article examines three aspects of today's Korean semiconductor industry: semiconductor consumption and production, semiconductor equipment, and semiconductor materials. For global equipment and materials companies that do business in Korea, understanding the prevailing mood on the Korean peninsula is especially important.

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Semiconductor Equipment, Manufacturing, and Materials

Korean Semiconductor Consumption and Production

Figure 1 shows 1991 Korean semiconductor consumption and production. Of the $2.3 billion Korean demand for semiconductors, 80 percent was satisfied by imported chips and only 20 percent was produced domestically. In contrast, 82 percent of Korean chip production was exported. In other words, the Koreans import most of the chips they need and export most of the chips they produce. Interestingly, the dollar value of chip consumption and production in 1991 was nearly the same.

Why the imbalance? Figure 2 shows consumption and production by device category. With memory ICs accounting for 72 percent of production, the remaining 28 percent of chips produced simply cannot satisfy Korea's need for ICs in other device categories, particularly in the high value-added MOS micro and MOS logic areas.

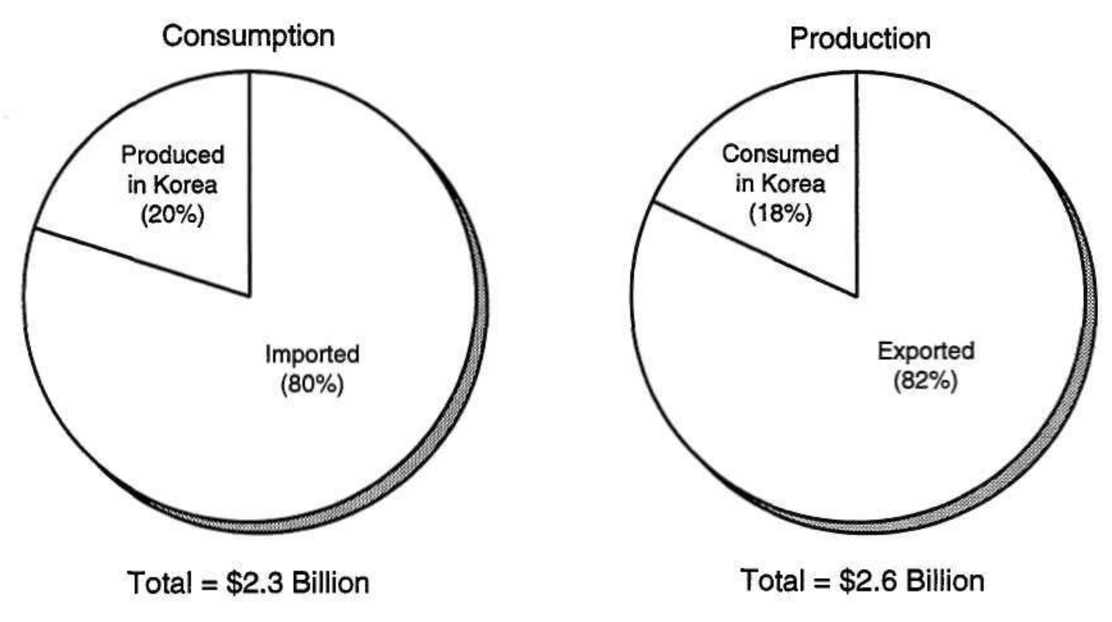
The Koreans expect to correct this imbalance and more Korean IC production in nonmemory device categories may be anticipated. But, since recent capacity additions in Korea have been aimed at DRAMs, additional capacity in other device categories will have to be brought online before production can be ramped up. This means that Korea should continue to be a good market for semiconductor equipment and materials and that equipment and materials companies should now be formulating strategies for continued competition in this market.

Asia/Pacific and Korean Semiconductor Capital Spending

In 1988, semiconductor capital spending in the Asia/Pacific region accounted for about 10 percent of the worldwide total and exceeded spending in Europe for the first time. This year, spending in Asia/Pacific will account for about 20 percent of all worldwide semiconductor capital investment. Korea is the largest spender in the region, with about half the capital investment. It is likely that in 1992, Asia/Pacific, including Korea, will be the world's only growth area for wafer fab equipment. Japan will be down 24 percent, Europe down 12 percent, and North America down 8 percent.

What has been the result of Korean investment? First, new fab lines have been built in Korea and new silicon capacity has been brought online. It is estimated that from 1989 to 1992, Korea's

Figure 1
1991 Korean Semiconductor Consumption and Production for Imports and Exports



Source: Dataquest (November 1992)

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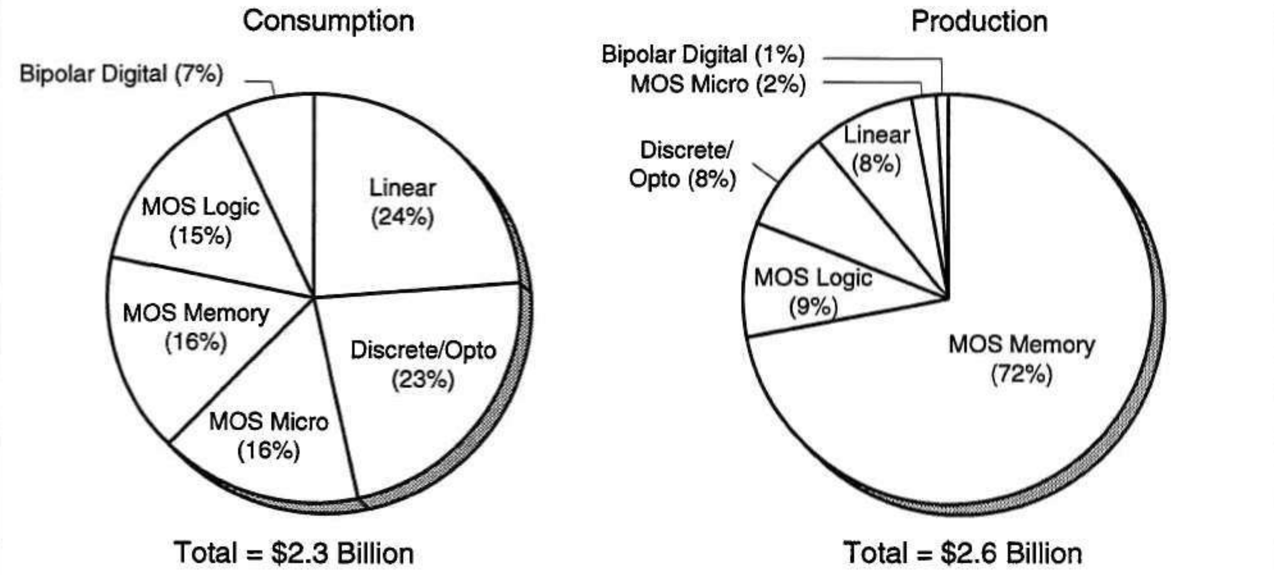
Figure 2
1991 Korean Semiconductor Consumption and Production



Note: Segments may not add to 100 percent because of rounding.

Source: Dataquest (November 1992)

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silicon production capacity per four-week period grew from 1.5 million square inches to more than 10 million square inches. As already noted, most of this added capacity has been for DRAM production.

Second, the added capacity has led to increased IC production. Korean semiconductor revenue has grown from almost zero in 1982 to about $3.0 billion today (see Table 1). In DRAMs in particular, growth has been meteoric. As shown in the table, Korean DRAM manufacturers will hold a 25 percent share of the world's DRAM market by the end of 1992. If the Japanese DRAM market is excluded (it is essentially closed to Korean DRAM suppliers), the Korean's share of the world DRAM market is 37 percent. To underscore this, Samsung is now the world's leading supplier of 16Mb DRAMs. It will be among the top 10 worldwide suppliers of SRAMs in 1992. In the U.S. market in 1992, two other Korean companies, Goldstar and Hyundai, will have 4Mb DRAM sales that will rank them Nos. 5 and 6, respectively.

Third, the recently added Korean production capacity is state-of-the-art. To illustrate the point, consider the following: i-line steppers are state-of-the-art tools, the ownership of which is indicative of the advanced processing capability of a fab line. In 1988, there were few or no i-line steppers shipped into Asia/Pacific, but in 1991

Table 1
Korean Semiconductor Suppliers, Yesterday and Today

	1982	1987	1992 (est.)
Revenue (Millions of Dollars)	58	515	3,000
Worldwide Market Share (Percent)	0.4	1.3	4.1
DRAM Market Share (Percent)	NA	6.6	25.0

NA = Not available
Source: Dataquest (November 1992)

i-line systems accounted for more than two-thirds of all steppers shipped into the region (see Figure 3). Most of these went to Korea.

The speed with which Korea has become a world contender in advanced semiconductor processing technology reflects the large amount of capital spending there. In DRAM processing, this is proving to be a problem for Japanese manufacturers, and it is one reason that capital spending in Japan has plummeted in 1992.

Semiconductor Equipment Market in Korea

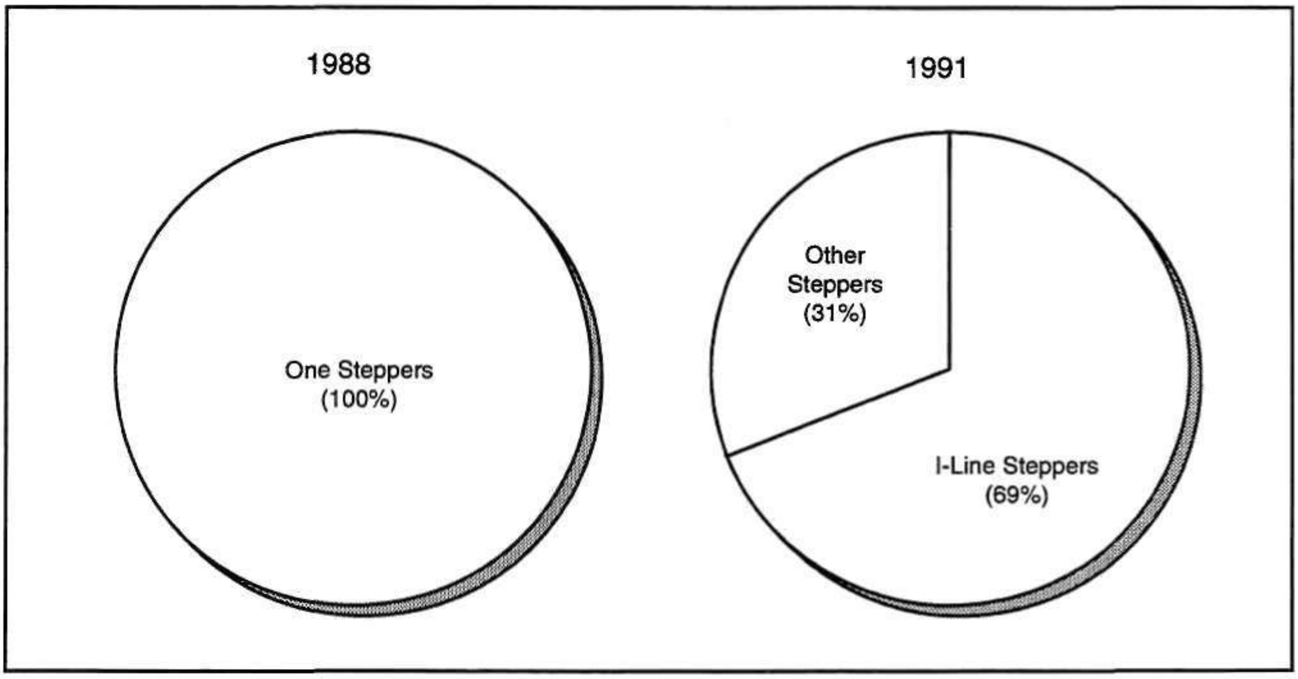
Dataquest forecasts a 1992 domestic semiconductor equipment market of $900 million; 87 percent will be imported equipment (see Figure 4). The remaining 13 percent, a scant $117 million, will be supplied by local companies. This, however, is up from the 6 percent provided by local suppliers in 1990.

Who supplies equipment to the Koreans? According to the Korean Semiconductor Industry Association (KSIA), 49 percent of the equipment is from Japan, 40 percent is from the United States, and 11 percent is from Europe. U.S. equipment companies dominated the equipment market in Korea at one time, but over the years they have lost market share to Japanese companies continuously. Figure 5 shows Dataquest's estimate of the total Asia/Pacific wafer fab equipment market. Prior to 1986, U.S. companies had a 75 percent share, but by 1991, this figure had slipped to 37 percent. In contrast, the Japanese gained share—from 25 to 53 percent—in the same period. KSIA and Dataquest data for Asia/Pacific tell the same story: U.S. equipment companies are losing in one of the fastest growing regions for semiconductor capital spending.

Development of a Korean Equipment Industry

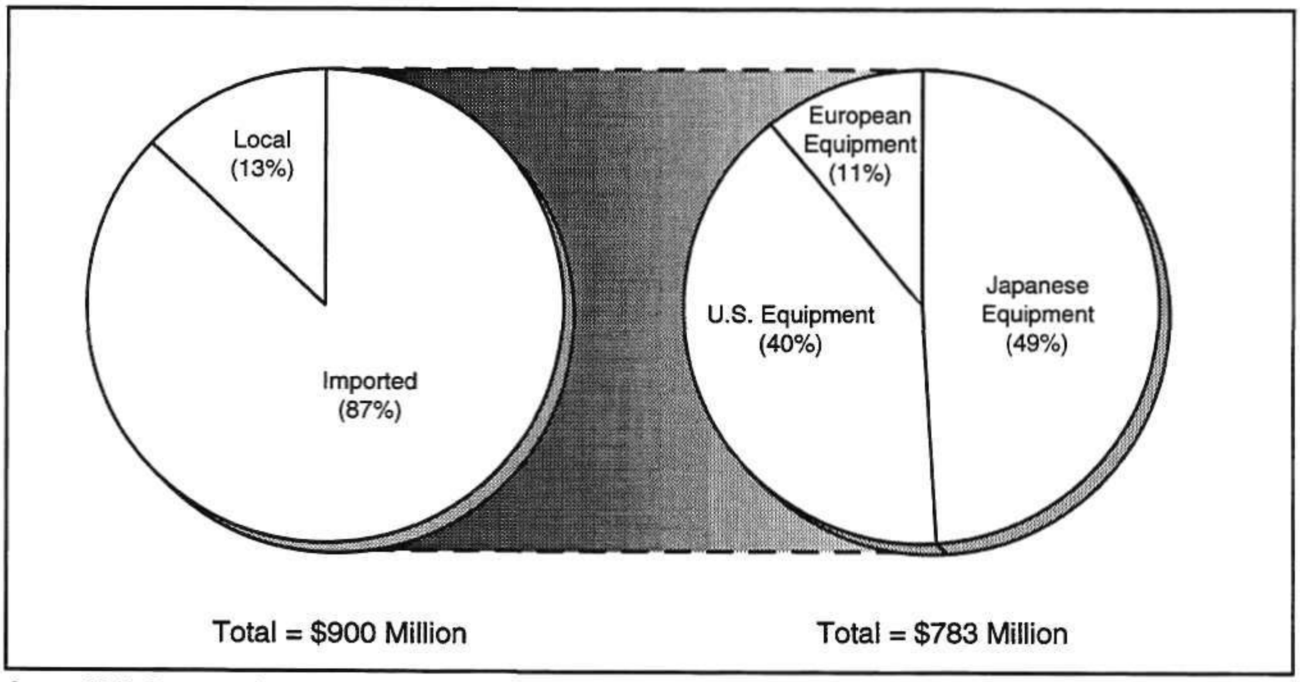
For the Koreans, the issue at hand is to build an infrastructure that provides national self-sufficiency in semiconductor manufacturing equipment. Korea has few equipment manufacturing companies at present. The 13 percent local manufacturing segment comprises companies such as Varian Korea (implanters and sputtering systems), Symtek (I.C. test handlers), P.S.K. Tech (plasma strippers), and Edwards-SungWon (vacuum pumps). All are joint ventures between a Korean company and a U.S., Japanese, or European partner.

Figure 3
I-Line Explosion in Asia/Pacific Region (Percentage of Shipments into Asia/Pacific)



Source: Dataquest (November 1992) G2001820

Figure 4
1992 Estimated Korean Semiconductor Equipment Market



Source: KSIA, Dataquest (November 1992)

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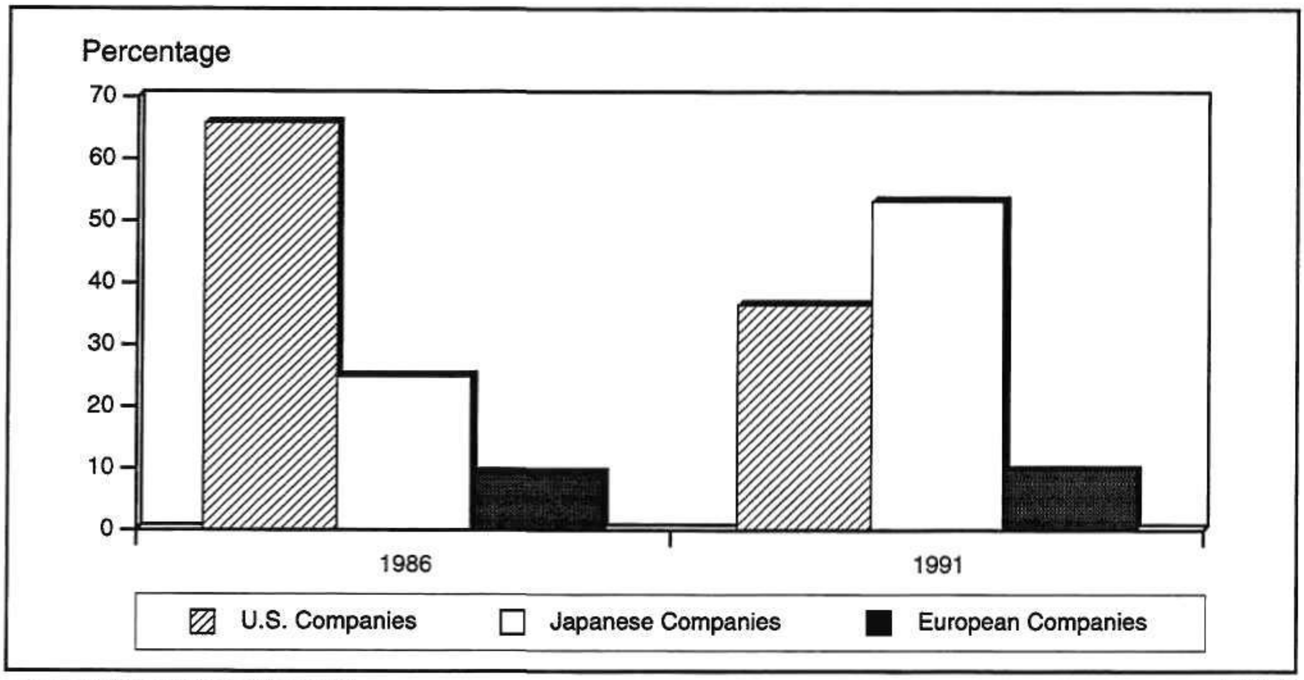
Figure 5
Percentage Share of Asia/Pacific Market Wafer Fab Equipment Companies, 1986 versus 1991



Source: Dataquest (November 1992)

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The Koreans have cited several disadvantages of working directly with foreign suppliers—communications problems and high costs are two—and they believe that the way to begin building their own infrastructure is through joint ventures. A Korean semiconductor manufacturer would much prefer to communicate with a foreign supplier through the supplier's Korean partner.

For the foreign partner, some advantages of local manufacturing joint ventures include increased sales, the use of Korean standard parts, improved feedback from customers, and reduced cost of manufacturing. The foreign and local partners can jointly develop other sales territories outside Korea, for example, China or other Pacific Rim countries. In this regard, South Korea and China have recently established diplomatic relations, suggesting that Korea is interested in developing the vast China market. Access to such growth markets could be a motivation for entering into a joint venture with a Korean equipment company. Of course, this approach to the Asian market must be weighed against other alternatives, for example, direct investment in a country.

In any case, it is apparent that the Koreans are quite serious about developing a local equipment industry. The Korean government has, in fact, set some pretty ambitious goals in this area. One, for example, is to be a net exporter of equipment by the end of the decade. Another is to achieve the use of 50 percent Korea-made parts in locally manufactured equipment. To help promote foreign joint ventures, the Korean government has proposed incentives for foreign investment that include a five-year tax benefit and site preparation benefits.

An equipment company bent on advancing its business in Korea would be well advised to investigate joint manufacturing ventures there. Although an often cited risk of foreign joint ventures is the potential loss of technology and markets—certainly there have been past examples of this sort of thing—there are successful joint ventures where mutual trust and a common vision exists and where both partners are in a win-win situation. Furthermore, if a non-Korean equipment company does not evaluate the feasibility of a joint venture with a Korean partner and its competitors do, the result may be loss of potential Korean business.

The lack of an equipment infrastructure in Korea was a continuous leitmotif at the first Annual Korea Industry Strategy Symposium held September 2 and 3 in Seoul. These discussions plus recent Korean government involvement in semiconductor equipment issues and the formation of the KSIA clearly signal the path that Korea wants to take. Although the growth of a Korean equipment manufacturing industry could be a problem for foreign equipment manufacturers, Dataquest believes that this turn of events also represents an opportunity.

Semiconductor Materials Market in Korea

Korea imports most of its semiconductor materials, although it is a little better off in materials than in the equipment area. KSIA estimates that the 1992 semiconductor materials market in Korea will be $680 million. Of this, 66 percent will be provided by imported materials and 34 percent ($229 million) by local manufacture. Considering that the local manufacture of materials was almost nonexistent in 1984, this represents good progress over the eight-year period. Nevertheless, it is important to remember that semiconductor-related imports into Korea are those that require a high level of manufacturing technology. For example, most of the demand for silicon wafers and photoresist—both high-technology materials—is satisfied by imports (local silicon manufacturers are providing smaller-diameter wafers). KSIA estimates that silicon demand in Korea 1992 will be $180 million and that, of the amount consumed, only about 22 percent will be of local manufacture. Similarly, the Korean photoresist market in 1992 is estimated at $46 million, but only 10 percent of these materials will be provided by local sources.

Who are some of the local manufacturers of materials? Siltron, Posco Hüls, and Dong Yang Electronic Metals provide silicon wafers (Posco Hüls will soon begin production of 200mm wafers). Hoechst Korea and Dongjin Chemical supply photoresist. Dupont Korea and Samsung's captive shop offer photomasks. Local materials manufacturing is derived from Korean materials companies, technology licensing agreements, joint ventures, and 100 percent direct foreign investment (for example, Hoechst and Dupont). Local manufacturers fill most of the demand for items such as bonding wire, photomasks, and lead frames.

Although materials manufacturing in Korea is a bit ahead of equipment manufacturing, it is in the development stage. One may expect the Korean materials industry to progress faster than the equipment manufacturing industry as Korean semiconductor companies seek to ensure a steady supply of the advanced materials that they will need to continue their extraordinary progress in chip production. Development potential in the Korean materials segment parallels the equipment segment and may provide an opportunity for global materials companies that currently export to Korea.

Dataquest Perspective

The Korean semiconductor industry is at the crossroads. Working under the pressure of ambitious government and industry goals, it has achieved levels of technical development and of sales revenue that have surprised industry observers everywhere. Having attained self-sufficiency in DRAM manufacturing, Korea is now headed in the same direction with respect to the manufacture of semiconductor equipment. Dataquest believes that future alliances between foreign equipment companies and Korean companies will increase opportunities for both parties and will shorten the technology ramp-up period, thus providing a continuing series of surprises for doubting industry watchers.

By Joseph Grenier and J. H. Son

Semiconductor Materials

Competition Heats Up in the Japanese Photoresist Market

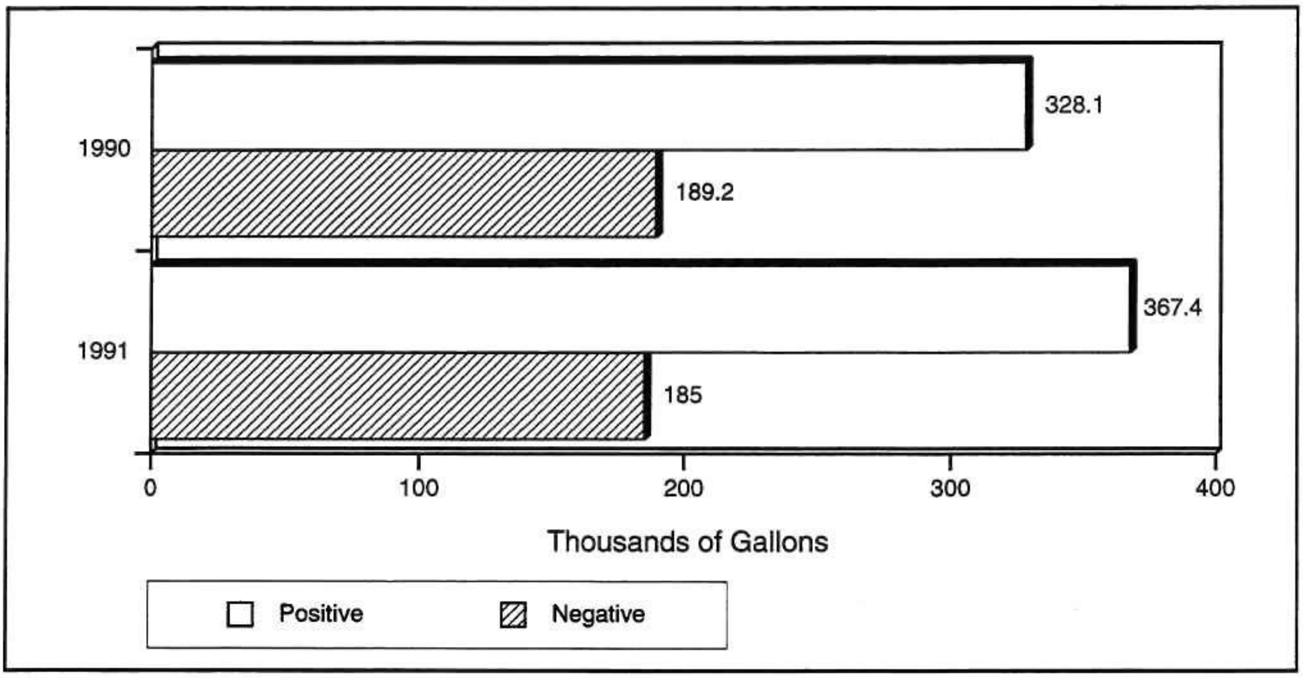
In 1991, Japan remained the largest regional market for photoresist with sales of ¥20.6 billion ($152.8 million), or 552,400 gallons. Consumption of photoresist in semiconductor applications grew 6.8 percent year-to-year on a volume basis.

Growth in the Japanese market occurred exclusively in positive-type resists (see Figure 1). Consumption of positive resist totaled 367,400 gallons (see Table 1), an increase of 12 percent. The market for negative type resists totaled 185,000 gallons (see Table 2), a decrease of 2.2 percent.

TOK's Patent

Tokyo Ohka (TOK) held onto its share of the positive resist market, which totaled 61 percent in 1991. The company is getting more aggressive

Figure 1
Japanese Resist Consumption, Semiconductor Applications



Source: Dataquest (November 1992)
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Table 1
Japanese Positive Photoresist Consumption in 1991, Semiconductor Applications

	Gallons	¥M	Share (%)
Tokyo Ohka	224,000	11,200	61.0
Japan Synthetic Rubber	53,000	2,700	14.4
Fuji-Hunt	23,900	1,140	6.5
Sumitomo Kagaku	20,000	1,160	5.4
Mitsubishi Kasei	14,000	742	3.8
Shipley	12,000	588	3.3
Nagase	8,000	376	2.2
Nippon Zeon	7,000	350	1.9
Hoechst	5,500	308	1.5
Total	367,400	18,564	100.0

Source: Dataquest (November 1992)

Table 2
Japanese Negative Photoresist Consumption in 1991, Semiconductor Applications

	Gallons	¥M	Share (%)
Tokyo Ohka	115,000	1,180	62.2
Japan Synthetic Rubber	44,000	574	23.8
Nagase	11,000	134	5.9
Fuji-Hunt	9,000	115	4.9
Nippon Zeon	6,000	60	3.2
Total	185,000	2,063	100.0

Source: Dataquest (November 1992)

in defending its market share. It appears that TOK is now implementing a legal strategy to protect its sizable g-line market.

In March 1992, a patent concerning a positive resist compound was issued to TOK. The patent covers positive g-line photoresist compounds using 2,3,4,4-Tetrasomy Ester and featuring high sensitivity, excellent heat resistance, and low contaminates when used as a solvent. Warnings concerning the potential violation of this patent have been issued to device makers and resist vendors.

Although TOK's real intention of obtaining the broad-based patent is unclear, other resist vendors and device makers view the company's aggressive stance on the enforcement of the patent as high-handed behavior. If TOK forces competitors to discontinue production of resists violating this patent, it runs the risk of alienating device makers that are using these competitive products.

Since TOK already dominates the Japanese positive resist market, it is unlikely that its strategy will help it to win a larger market share. Device makers would view this as unhealthy, from a competitive point of view.

Dataquest believes that a more likely strategy is that TOK will attempt to use the patent as leverage against intellectual property claims by other companies or as a powerful bargaining chip for cross-licensing negotiations. However, the greatest value of the patent may be the deterrent effect such a broad-based patent would have on price competition.

Increasing Competition

TOK's strategy may reflect the intensifying competition in the Japanese resist market. Several large companies just entering the resist business gained market share in 1991, including Sumitomo Kagaku and Nippon Zeon. Sumitomo Kagaku increased its market share because of a strong product offering in advanced g-line and i-line resists and further penetration of NEC. Sumitomo also benefited from being a primary manufacturer of the raw materials used to make resists, which provides it with a lower cost position than TOK.

Mitsubishi Kasei saw its market share erode slightly. Its volume shipments are still small and were negatively impacted by the delay in the introduction of its i-line resist. Even sales to its parent company, Mitsubishi Electric, stalled in 1991.

Large LCD Opportunity

The demand for resist in thin film transistor (TFT) LCD applications totaled 43,700 gallons (see Table 3). Volume shipments are still small relative to semiconductor resist applications, but are expected to grow quickly over the next five years. TOK also dominates this market, but other companies including Shipley, Hoechst, and Fuji-Hunt are investing in LCD resist technology.

Dataquest estimates that 20cc of resist is required for each mask step; there are five to seven mask steps on average for TFT LCDs. Considering the low yields achieved on TFT panel lines, we expect resist volumes to grow rapidly over the next five years.

Table 3
Japanese Photoresist Consumption in 1991, TFT Panel Applications

	Gallons	Share (%)
Tokyo Ohka	28,800	65.9
Shipley	5,400	12.4
Hoechst	6,000	13.7
Fuji Hunt	3,500	8.0
Total	43,700	100.0

Source: Dataquest (November 1992)

Dataquest Perspective

The recent acquisition of Shipley by Rohm and Haas leaves TOK as the last resist vendor with company revenue less than $500 million. New competitors such as Sumitomo Kagaku and JSR are eroding TOK's share of the Japanese resist market and increasing pricing pressures. The patent issues being raised by TOK this year most likely indicate that TOK will pursue an aggressive defense of its substantial market share in Japan through legal channels.

By Kunio Achiwa and Mark FitzGerald

What LCD Manufacturing Equipment Makers Should Know, but Are Afraid to Ask About: Their Future

Semiconductors and liquid crystal displays (LCDs) share a number of common elements, including their market structure. In fact, the present expansion of the LCD market resembles the start-up of the semiconductor market 14 years ago. A widely held belief is that the Japanese LCD market will reach ¥1 trillion (about $7.43 billion) in 1995 and ¥2 trillion (about $14.85 billion) by 2000.

The semiconductor market has accompanied the rapid growth of the semiconductor equipment market. In the nascent stage, semiconductor makers made major capital spending at a level comparable to the current value of semiconductor production. Although the investment/production ratio has declined with the maturing of the industry, its level is still an impressive 20 percent. Nevertheless, the similarity in growth patterns between the semiconductor and LCD markets does not necessarily suggest the rosy future for the LCD manufacturing equipment industry enjoyed by the semiconductor equipment industry. There is a crucial difference between the two equipment industries.

This article examines the credibility of the alleged claim for a ¥1 trillion market in 1995 by comparing the growth patterns of the LCD market with the development history of the semiconductor industry. We also will try to answer the question of whether the LCD equipment market will follow the path of the semiconductor equipment market.

LCD Industry

The Japanese LCD market neared ¥200 billion ($1.49 billion) in 1990. A compound annual growth rate (CAGR) of about 40 percent in the subsequent five years is forecast, reaching ¥1 trillion in 1995. Although the growth pace will slow to 15 percent afterward, the market will reach ¥2 trillion in 2000 (see Figure 1). Undoubtedly, a number of the advantages offered by LCDs—thinness, light weight, low voltage, and low power consumption—promise that LCDs will become a mainstay of flat-panel displays with significant growth potential when combined with technological advancements in color graphics, higher resolution, and larger display.

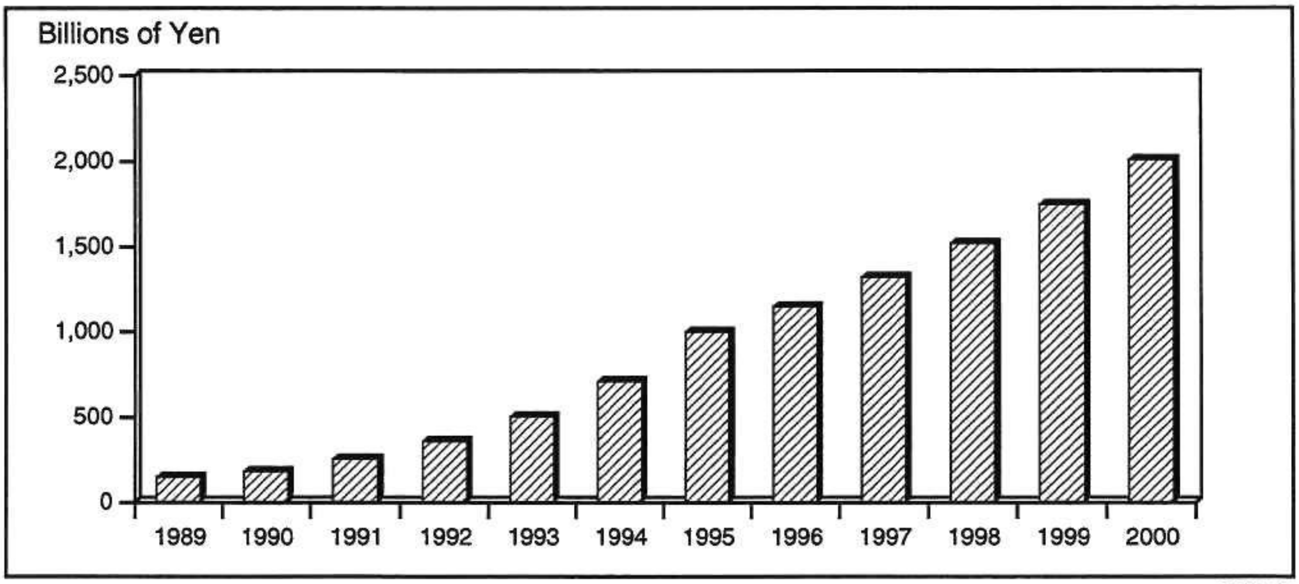
High expectations for the LCD industry are intensifying as the semiconductor industry nears the maturing stage and LCDs become regarded as another semiconductor industry. This is mainly because the growth pattern of the LCD industry resembles that of the burgeoning semiconductor industry 14 years ago. Because there are various similarities between LCDs and semiconductors, it is useful to review the semiconductor's history when forecasting for the LCD industry. Similarities between the two industries are as follows:

- Both are high-tech industries characterized by high risk and high return
- Many competitors are involved in both markets (see Table 1)
- Manufacturing processes are similar (see Table 2)
- Both require massive investment (see Table 3)
- PCs are a major application for both industries

Is there credibility to the LCD production forecast of ¥1 trillion in 1995 and ¥2 trillion in 2000? Although forecast demand for PCs and wall-hanging TVs—major applications of LCD panels—would seem to support the projections more accurately, our forecast relies on the similarity of the LCD and semiconductor industries.

The semiconductor industry emerged in 1975. For the purpose of comparison with LCDs, semiconductor production is indexed as a multiple of the 1975 production for every five years after 1975 (see Figure 2). The active matrix-based LCD market started full-scale growth in 1989, and again, subsequent production is indexed as

Figure 1
Japanese LCD Production



Source: MITI, NRI, Dataquest (November 1992)

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Table 1
Participants in the Semiconductor and LCD Markets

	NEC	Toshiba	Hitachi	Fujitsu	Mitsubishi	Matsushita	Sanyo
Semiconductor	Y	Y	Y	Y	Y	Y	Y
LCD	Y	Y	Y	N	Y	Y	Y
	Sharp	**Sony**	**Oki**	**Seiko Epson**	**Stanley**	**Kyocera**	**Citizen**
Semiconductor	Y	Y	Y	N	N	N	N
LCD	Y	Y	Y	Y	Y	Y	Y
	Casio	**Hoshiden**	**Alps**	**Optorex**	**Seiko Instrument**	**Rohm**	
Semiconductor	N	N	Y	N	Y	Y	
LCD	Y	Y	Y	Y	Y	Y	

Y = Participant
N = Not a participant
Source: Dataquest (November 1992)

Table 2
Comparison of Manufacturing Processes: TFT LCD and LSI

	TFT LCD	LSI
Mask Layers	5 to 7	15 to 20
Line Geometry (Microns)	3 to 5	0.8
Integration (Millions)	1 to 1.5	4
Size	300 to 700 cm^2/panel	0.8 cm^2/chip

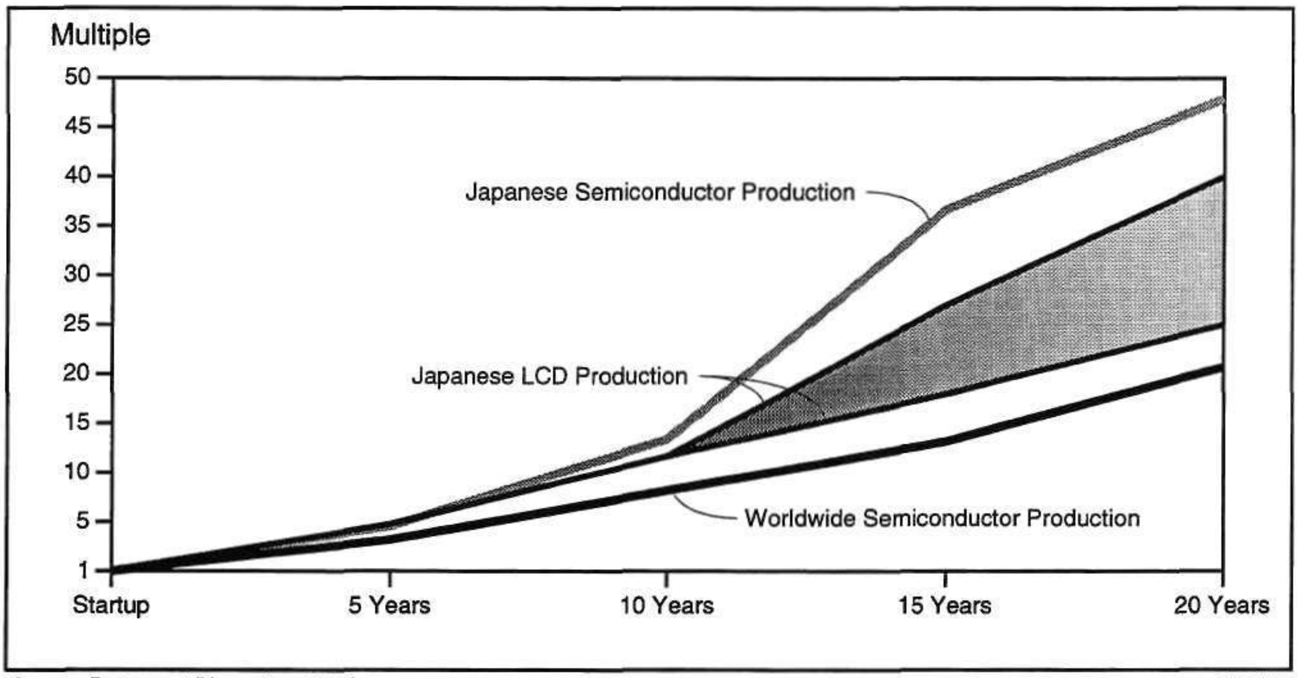
Source: Sharp, Dataquest (November 1992)

Table 3
Comparison of Fab Lines

	TFT LCD	DRAM
Production Capacity	15,000 panel	20,000 wafer
Substrate/Wafer Size	300 x 400 mm^2	6 inch
Output	2 panels/substrate	133 units/wafer
Yield (Percentage)	60	85
Fab Cost (¥B)	15	40

Source: Dataquest (November 1992)

Figure 2
Production Expansion of LCDs and Semiconductors



Source: Dataquest (November 1992) G2001725

mentioned previously. As Figure 2 shows, the startup time of the two markets is 14 years away, but the growth pattern of the Japanese LCD production closely resembles that of the semiconductor market, suggesting credibility of the ¥1 trillion and ¥2 trillion markets in 1995 and 2000, respectively. If the current pace of market growth continues, LCD production is expected to reach ¥4 trillion ($29.70 billion) in 2010 at the worldwide semiconductor production growth rate and ¥6 trillion ($44.55 billion) at the Japanese semiconductor production growth rate.

LCD Capital Spending Trends

Most electronics makers will announce poor operating results for the first half of the fiscal year ending September 1992, as well as downward adjustment of future performance. The business environment surrounding the LCD industry is becoming increasingly murky. Factors causing the poor performance of the electronics industry include delayed recovery of the computer market, cutbacks in capital investment by the securities and banking industries, and sluggish demand for consumer electronic equipment, audio/visual equipment in particular. As a result, electronics makers are paring their capital investment. Toshiba, for example, announced a ¥30 billion ($222.75 million) reduction of semiconductor investment in FY1992, on top of a previous ¥20 billion ($148.50 million) cutback. This is the first time that such a major cutback in capital spending has been launched in the industry during the current term, which suggests not only the magnitude of recession being encountered, but also creates uncertainties about future LCD investment. Because the LCD industry largely consists of semiconductor companies, semiconductor recession is hitting the LCD business and capital spending hard. Principal causes for the present semiconductor recession are as follows:

- Sluggish demand for DRAMs, consumer analog ICs, and single-chip microcomputers
- Eroded financial position because of nearing maturity of warrants
- Difficulty in equity financing because of the recent stock market slump

In addition, slowdown in LCD-related investment is a direct result of the stagnated PC industry—which is the largest consumer of LCDs—and improvement in LCD yield that will ensure sufficient supply capacity and thus eliminate a pressing need for new fab lines. As a result, LCD makers such as Sharp and Display

Technology—a joint venture of Toshiba and IBM—postponed construction of new LCD production lines. Nevertheless, current LCD production capacity is far from meeting future demand. Dataquest believes that initial investment will continue in the coming few years, and that the current slowdown is temporary because of the repercussions of the slackened semiconductor market.

LCD Equipment Industry

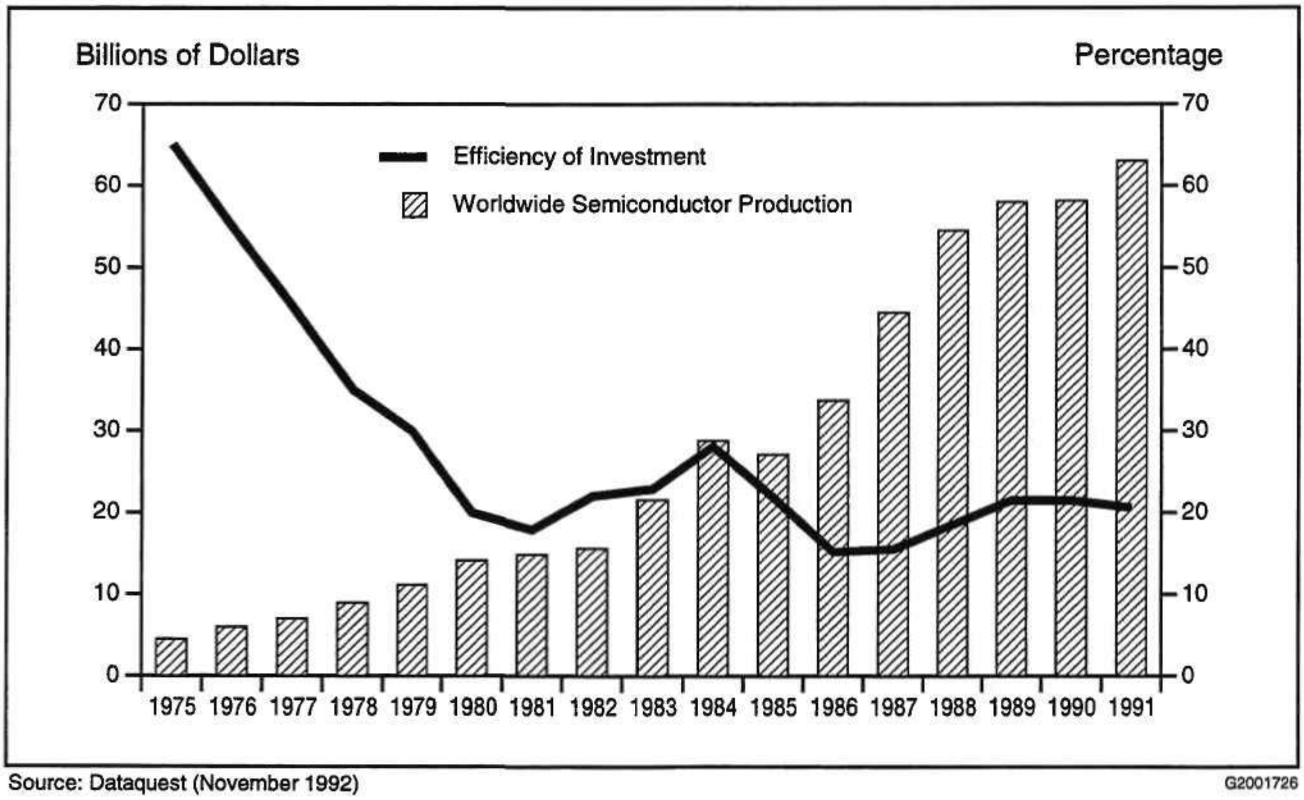
LCD production lines basically consist of the same processes as semiconductor production such as lithography and film deposition, except that LCDs use glass substrate in place of silicon wafer. Also, both processes are extremely sensitive to dust particles. It is not surprising that semiconductor equipment makers flocked to the LCD business.

When forecasting the future of the LCD industry from the viewpoint of a correlation between production and capital spending, it should be remembered that any industry is required to make initial investment almost equivalent to the value of production at the start-up phase, which declines gradually to settle at a certain level when actual demand and supply capacity are balanced.

The investment/production ratio indicates efficiency of investment. The semiconductor industry's efficiency of investment in the initial year was 65.1 percent. It declined to 54.9 percent in the second year, then to 45.1, 35.0, 29.9, and 20.0 percent. Thereafter, it averaged 20.7 percent between 1982 and 1991, with some deviations because of the business cycle (see Figure 3).

On the other hand, the LCD industry's efficiency of investment is estimated to be 54.6, 69.9, 69.4, and 43.6 percent from 1989 through 1992, respectively. Assuming that it will generally follow the declining trend of the semiconductor industry, say 35 and 30 percent in 1993 and 1994, respectively, then remain stable at 20 percent from 1995 (see Figure 4), the LCD equipment industry could expect to have a bright future.

Figure 3
Worldwide Semiconductor Production and Efficiency of Investment



Source: Dataquest (November 1992)
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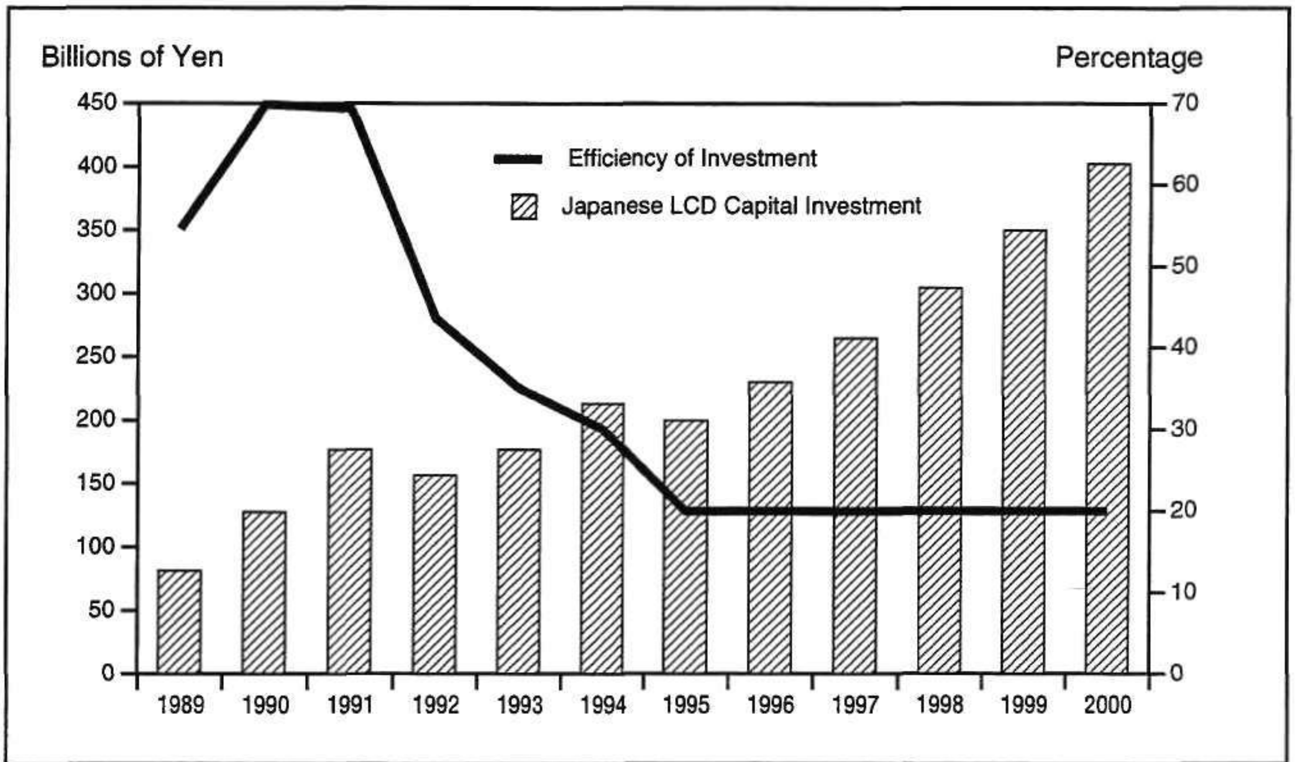
Figure 4
Japanese LCD Capital Investment and Its Efficiency (Optimistic Forecast)



Source: Dataquest (November 1992) G2001727

Dataquest Perspective

However, this simulation based on experience in the semiconductor industry does not consider a critical difference between LCDs and semiconductors, a difference that dims the apparent bright future of the LCD equipment industry. What lacks in the LCD industry is "generation shift."

The semiconductor industry has been spawning a new generation of products with miniaturized circuit patterns every three years, which spurred a suitable semiconductor equipment market that grew side-by-side with products. In contrast, LCDs are expected to provide high resolution that can be satisfied visually at a certain level, but not require a higher level of miniaturization emulating the submicron geometries of leading-edge devices. Thus, there is little impetus for development of new generations of LCDs.

Next, consider the potential LCD demand for a larger panel size. So far, the LCD industry has been slow in standardizing substrates, whose sizes differ from one maker to another. Accordingly, LCD equipment makers are expected to supply equipment with flexible designs to accommodate the different sizes; they already supply large chamber systems for higher throughput. In particular, dry systems such as CVD and sputter are designed to process four panels in one batch, so that the increase in panel size can be accommodated by reducing the number of panels in each batch. This basically eliminates a strong need for increase in equipment size. Although technological advancement will certainly continue in a number of areas—for example, TFT's yield, improved brightness, and response time—the LCD equipment market will not undergo repeated technological shifts from generation to generation, a critical difference from the semiconductor equipment market. A lack of generation shift means less opportunity for an equipment market expansion.

Nobody disputes the similarities between LCDs and semiconductor devices, and the growth potential of the LCD industry. At the same time, it should be reiterated that the LCD equipment industry is intrinsically different from the semiconductor equipment industry. The semiconductor industry has consistently made, at least until now, capital investment equivalent to about 20 percent of its production, a figure that served as the lifeblood of the equipment market. On the other hand, the LCD equipment industry seemingly is doomed to face a setback of capital spending once production lines to satisfy panel demand are completed and come online.

The LCD equipment industry has experienced a healthy growth of initial investment, which will continue for a while, but not forever. It is becoming an increasingly risky business for semiconductor equipment makers to enter, for growth potential of the LCD industry is deceptive; it will not provide much fruit to the LCD equipment industry and will leave only a tantalizing taste of success.

By Kunio Achiwa

Inquiry Summary

Dataquest's Semiconductor Equipment, Manufacturing, and Materials inquiry summaries are designed to inform our clients of commonly asked questions and Dataquest's respective answers. No confidential information provided by our clients is included in this material.

Microprocessors Drive Fabrication Technology

Q. How are microprocessors acting as process technology drivers?

A. Microprocessors may not be driving new processes in terms of minimum feature size as DRAMs do, but they are serving as a vehicle for the development of multilevel metallization process flows. Table 1 shows the process technology and selected parameters for several current and future microprocessors. The different processors can be characterized as being highly integrated; they tend to incorporate the CPU, FPU, data and instruction cache memory, cache control logic, memory management unit, bus control logic, and other functions integrated on the chip. Many new microprocessors are also shifting to 64-bit internal bus architecture. Clearly, the incorporation of memory, control, and test logic onto the same chip as the integer and floating point execution units creates a large demand for additional interconnect layers to route the increased number of signals, and to maintain a manageable die size. This trend is expected to continue as processors become even more highly integrated, with multiple processors integrated onto a single chip, with associated complex logic, higher levels of test support, error detection and correction, and other functions.

Because complex microprocessors and application-specific standard products derived from the processor cores comprise an increasing portion of total semiconductor production, advanced multilevel metal processes will constitute a larger fraction of the worldwide production capacity. This carries some strong implications for the wafer fab equipment industry. For a three-layer metal process, the number of process steps from the beginning of the process to the point at which the first metal layer is deposited is about equal to the number of process steps from that point to the end of the process flow. In other words, the three-layer metal process is the point at which the multilayer metallization process steps become equal to all of the front-end process steps. The mix of wafer fabrication equipment will therefore tend to be more heavily weighted toward process tools used in the multilevel metal process module—sputter deposition systems, metal CVD systems for contact and via plugs, dielectric CVD and PECVD systems for the intermetal dielectric (IMD) deposition, dry-etch systems for contact and via etching, and process tools for planarization of the IMD and the tungsten contact and via plugs.

Figure 1 illustrates the trend toward heavier use of multilevel metallization process equipment, by showing the total worldwide wafer fab equipment spending segmented by equipment type on a percentage basis. The purchases of CVD/PVD equipment and dry etch/dry strip equipment have risen as a percentage of total spending since about 1988, while the purchases of lithography/track equipment have fallen. This shift in equipment spending has been caused by greater use of multilevel metallization processes, and by the evolution from batch to single-wafer processing equipment, particularly for intermetal dielectric processes. Dataquest expects this trend to continue as multilevel metal processes find greater use in production, and the number of interconnect layers continues to grow.

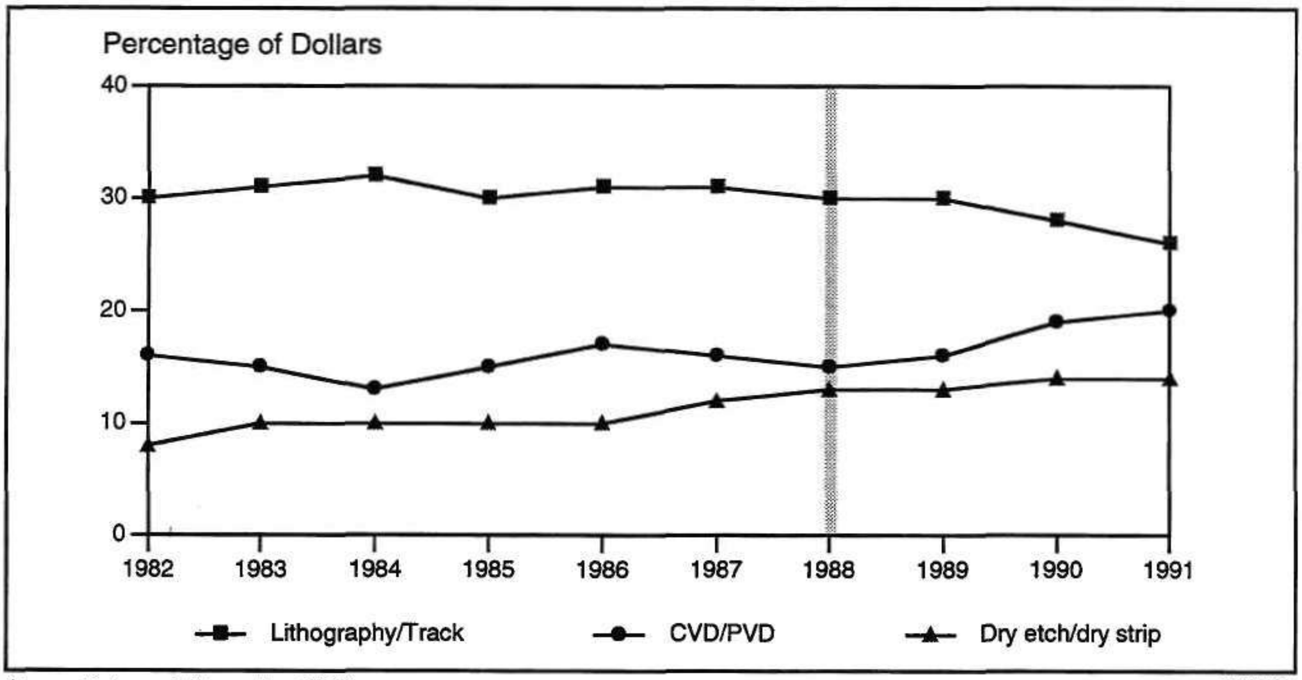
By Charles Boucher

Table 1
Process Technologies for Current Microprocessor Products

Manufacturer	Microprocessor Architecture	Minimum Line Geometry	Number of Metal Interconnect Layers	Die Size (sq. mm)	Number of Transistors
Intel	486	0.80	3	82	1.2 million
AMD	486	0.70	3	NA	1.2 million
Intel	Pentium	0.80	3	264	3.1 million
IBM/Motorola	Power PC 601	0.60	4*	103	2.8 million
Motorola	68060	0.50	3	149	2.8 million
TI	SuperSPARC	0.80	3	255	3.1 million
DEC	Alpha	0.75	3	233	1.7 million

NA = Not available
*Uses a metal local interconnect layer in addition to four full interconnect layers.
Source: Dataquest (November 1992)

Figure 1
Major Equipment Segments As a Percentage of Total Wafer Equipment Spending



Source: Dataquest (November 1992)

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Dataquest Perspective

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Semiconductor Equipment, Manufacturing, and Materials

SEMM-SVC-DP-9213 October 5, 1992

In This Issue...

Market Analysis

Semiconductor Manufacturing

Problems at Japanese Computer Companies Point to Deeper Cuts in Semiconductor Capital Spending

Computer systems are the largest end-use application for semiconductors in Japan. Therefore, it is no coincidence that the four largest semiconductor vendors in Japan—Fujitsu, Hitachi, NEC, and Toshiba—also dominate the Japanese computer systems business.

In the current business downturn, computer systems sales fell more than 10 percent in the first half of calendar 1992, according to the Japan Electronic Industry Development Association. Because the system groups at the four largest Japanese computer companies purchase a large share of the output of their captive semiconductor operations, it is reasonable to conclude that the semiconductor divisions at these companies are suffering in the current downturn in large part because of the weak demand for computer systems.

The problems at the Fujitsu, Hitachi, NEC, and Toshiba computer systems divisions may extend well beyond the current downturn. It is unlikely that these companies have either the correct cost structure or the necessary product offerings to effectively compete in a global computer market in which prices are collapsing and end users are quickly moving to distributed computing solutions.

The turmoil in the systems business will certainly impact Fujitsu, Hitachi, NEC, and Toshiba semiconductor operations because captive device demand is such a large part of each company's device output.

Big Share in Weak Japanese Market

The financial problems afflicting the Japanese economy suggest that most Japanese businesses will continue to cut capital spending on computer systems. Businesses especially hard hit by the downturn are banks and securities firms.

In the past, these two segments were the largest buyers of computer systems in Japan. But now, capital is tight at banks because of bad loans and the need to meet the BIS capital adequacy requirement that goes into effect in spring 1993. In the face of a sluggish stock market and steep quarterly losses, spending on computer systems has evaporated at securities firms.

The tight capital spending environment in Japan points to weaker sales of computer equipment, especially the large business systems. Dataquest expects this climate to persist for several years.

Because Fujitsu, Hitachi, NEC, and Toshiba systems revenue is concentrated in Japan (see Table 1), Dataquest expects each to report weak sales and steep losses in their systems business for fiscal 1993 (ending March 1993). The squeeze on sales and profits is likely to persist into fiscal year 1994 (ending March 1994), as we continue to forecast a weak recovery for the Japanese financial sector.

Toshiba has the smallest exposure to the Japanese market, with 47.4 percent of its 1991 system sales in Japan. The other three companies have considerably more exposure: sales in Japan account for 83.5 percent of Fujitsu's total computer system sales, 71.2 percent for Hitachi, and 74.7 percent for NEC.

Table 1
1991 Computer System Sales

	Worldwide	Percentage, by Region			
	Revenue ($M)	Japan	United States	Europe	Asia-Pacific/ROW
Fujitsu	4,735.5	83.5	0.4	15.3	0.8
Hitachi	2,368.1	71.2	22.6	6.2	0.0
NEC	6,257.7	74.7	7.4	4.6	13.3
Toshiba	1,848.3	47.4	19.0	27.0	6.6

Source: Dataquest (October 1992)

Tough Product Mix

In addition to a weak economic environment, Fujitsu, Hitachi, NEC, and Toshiba have invested heavily in computer segments, which Dataquest expects to have low growth or be very competitive. Fujitsu, Hitachi, and NEC have a large percentage of their computer systems business in the mainframe and midrange market, which Dataquest is forecasting to decline. NEC and Toshiba also have a large percentage of their systems business in the PC market, which is undergoing severe pricing pressures. It is unlikely that these two companies have the cost structure in place to compete in this environment.

Fujitsu

Fujitsu is the world's third largest computer maker. Its computer sales are concentrated in the large mainframe and midrange markets (see Table 2). Sales in these segments have been particularly hard hit because of cuts in capital spending by Japanese businesses. As a result, Fujitsu is now preparing to revise downwardly both yearly and interim profit forecasts for the current fiscal year.

Dataquest believes that Fujitsu faces bigger challenges in its computer business over the long term. It must cope with the restructuring of the computer industry and the move to distributed computing utilizing PCs, workstations, and networks. Fujitsu has benefited from the slow pace at which Japanese businesses have adopted new information systems. But the current economic downturn is expected to speed up the move to distributed computing in Japan, forcing Fujitsu to move more quickly to adapt to this new product environment.

Dataquest believes that fallout from the problems in the systems business is a major reason that Fujitsu has turned cautious about its semiconductor business. We estimate that 29 percent of its semiconductor group's production in 1991 was used by internal operations (see Table 3). Among these internal operations, the computer systems group accounted for the lion's share of the captive semiconductor usage.

Table 2
1991 Computer system Sales, by Percentage

	Fujitsu	Hitachi	NEC	Toshiba
Supercomputers	5.1	1.9	1.9	NA
Mainframes	46.1	84.4	23.5	6.4
Midrange	37.0	6.3	23.5	18.5
Workstation	3.7	4.7	3.1	2.0
Personal Computer	8.1	2.6	48.0	73.1
Total Revenue ($M)	4,735.5	2,368.1	6,257.6	1,848.4

NA = Not applicable
Note: Percentages may not add to 100 percent because of rounding.
Source: Dataquest (October 1992)

Table 3
1991 Semiconductor Sales (Revenue in Millions of Dollars)

	Worldwide Revenue ($M)	Percentage Captive	Percentage DRAM	Percentage Japan
Fujitsu	2,705	29.0	18.6	73.0
Hitachi	3,765	20.0	17.6	68.2
NEC	4,774	26.0	15.6	72.9
Toshiba	4,202	15.0	22.8	58.0

Source: Dataquest (October 1992)

Fujitsu has announced a 33 percent capital spending cut in its semiconductor division. Dataquest believes that additional cuts are likely to be announced in October 1992. The cuts in semiconductor capital spending are expected to mark a much slower period of growth in Fujitsu's semiconductor operations because its main customer, its own computer systems group, will require less product.

Hitachi

Hitachi's computer systems business is primarily focused on the mainframe market, accounting for 84 percent of all computer system sales. None of the other four companies we are reviewing has a higher concentration of sales in mainframes. Its worldwide mainframe sales are second only to IBM. As Table 1 shows, Hitachi's computer sales are concentrated in Japan (71.2 percent) and to a lesser extent in the United States (22.6 percent).

The importance of Hitachi's mainframe business is magnified after recognizing that 40 percent of the entire company's profits in the past several years was earned by the mainframe business. So, as one might well expect, the current downturn in Japanese computer system sales is causing the red ink to flow at Hitachi.

As with Fujitsu, Hitachi faces challenges in realigning its computer product line. And, as with Fujitsu, the company's focus on mainframes will have a deleterious impact on its semiconductor operations.

Captive consumption of semiconductors at Hitachi in 1991 accounted for 20 percent of its IC sales (see Table 3). So the downturn in Hitachi's systems business, which includes computers and computer storage, will certainly mean changes for the semiconductor business.

Hitachi announced a 23 percent cut in semiconductor capital spending at the beginning of the current fiscal year. The entire electronic equipment market in Japan has deteriorated further since that initial announcement, so we believe that additional cuts will be made in October 1992.

In addition, Hitachi plans to reduce memory products as a percentage of total semiconductor output. A sharp drop in 1991 DRAM prices caused the company's profits to fall below initial and midterm expectations, prompting it to reduce its dependence on memory products. DRAM products accounted for 17.6 percent of Hitachi's semiconductor production last year.

Hitachi will increase production of logic devices and semiconductors designed for use in mobile communications equipment, which it plans to start designing and manufacturing in the United States. The company is also developing its own proprietary 32-bit RISC chip for embedded applications based on Hewlett-Packard's Precision Architecture RISC microprocessor.

NEC

NEC is facing problems similar to those of Fujitsu and Hitachi in its mainframe business. Sales and profits are off and revenue is expected to decline over time. But mainframes and midrange computers each account for only 23.5 percent of NEC's computer system sales (see Table 2).

A much larger problem for NEC is the competitive pressures building in the PC market. PCs account for 48 percent of NEC's computer system sales, by far the largest computer systems segment for the company. NEC sold 1.4 million PCs in 1992, 1.2 million in the domestic market, and 200,000 overseas. The company still holds 45 percent of Japan's PC market, but this share is likely to decline because Japanese desktop users want lower prices and more powerful machines than those offered by NEC. We believe that the PC business profit contribution—the underpinning for overall computer business profits—will decline sharply.

Captive semiconductor consumption accounts for 26 percent of NEC's semiconductor division's sales (see Table 3), so we expect a downturn in computer systems to cause weaker sales in NEC's semiconductor operations. In response, NEC cut semiconductor capital spending by 28 percent in fiscal year 1993.

Toshiba

Toshiba's PC sales account for 73.1 percent of its computer systems sales (see Table 2). It differs from the other three computer makers in that it does not have a large mainframe/midrange business.

At first glance, Toshiba's concentration in the PC market appears as a strength. Furthermore, the company has strong overseas sales; about 53 percent of its systems revenue is earned outside of Japan (see Table 1). But its large overseas market exposure is proving to be more of a liability because of fierce pricing pressure in the U.S. and Asian PC markets. As PC makers such as AST, Compaq, and even IBM cut prices, Toshiba's market share is expected to erode.

Toshiba has cut semiconductor capital spending, as have the other major Japanese computer manufacturers. At the beginning of its fiscal year, Toshiba announced a ¥20 billion cut in semiconductor spending. The company plans to now cut an additional ¥30 billion. The midyear cut is the first time the company ever lowered spending halfway through the fiscal year. The unprecedented nature of the cut reflects the severity of the current downturn.

Dataquest Perspective

Dataquest expected semiconductor capital spending in Japan to grow only 3.3 percent over the next five years. A large part of the deceleration in spending can be attributed to the problems facing the Japanese computer industry, which is the largest end user of semiconductors in Japan.

There are no easy solutions for Japanese computer manufacturers. For many years these companies chased IBM in the mainframe business. But just as IBM is recreating itself, so must these companies realign their product offerings and lower their cost position if they are to compete in the global computer market.

The restructuring of the Japanese computer industry will take time. This secular shift is one of the primary drivers behind the slower growth forecast by Dataquest for semiconductor capital spending in Japan.

By Mark FitzGerald

Semiconductor Materials

CVD Diamond: Will It Be a Package-Design Engineer's Best Friend?

Founded in 1984, Crystallume Inc. of Menlo Park, California, is one of 12 companies known to be involved in CVD diamond, a nascent technology touted as a potential low-cost substrate material for electronic packages, specifically multichip modules (MCMs). Other known suppliers of diamond materials and substrates are as follows:

- Diamonex
- General Electric
- IBM-Watson R&D
- Indemitsu Petrochemical
- Kennametal Corporation
- Mitsubishi Metal
- Nachi Fujikoshi
- Norton Company
- Raytheon Corporation
- Sumitomo Electric
- Toshiba Tungaloy

Crystallume has used plasma-activated CVD to create a polycrystalline diamond composite material. Crystallume's plasma CVD process typically includes using microwave to convert methane while maintaining 700°C to 900°C temperatures. As reported by Crystallume, the process has shown penetration of the deposition process to thicknesses from 0.1mm to 4.0mm. Crystallume has developed diamond composite material below 600°C, even to 350°C, and can still maintain fairly good quality in its material. The quality and growth rate of the diamond composite material is reduced as the temperature is lowered.

Crystallume is working with Hughes to develop a chemical vapor infiltration process. During this process, a plasma is formed by 2.45-GHz microwave excitation over a mass of diamond particles. The gases flow through the process to prevent porosity problems. There still is between 80 and 85 percent consolidation with 10 to 15 percent porosity in this process, but Crystallume believes that this porous state can be filled with other materials. Diamond composites would provide the following advantages as an MCM substrate:

- Superior heat-spreading capacity
- IC life-cycle enhancement
- Improved IC performance
- High electrical resistivity
- Good TCE match with silicon
- Reduced module size and weight

The challenges to CVD diamond substrates are cost and limited availability to product technology, fabrication technology, and application technology. Production scaleup is expensive and market acceptance is expected to be slow. According to estimates made by International Research Development (IRD) and reported by Crystallume, CVD diamond is expected to have a compound annual growth rate of 61 percent from 1990 to 2000. Table 1 shows other IRD estimates.

CVD diamond applications include the following:

- Laser diodes/diode arrays
- Fiber-optic coupled diodes
- High-speed power GaAs communications devices
- Hybrids
- Heat pipes
- Less than 300-MHz clock rate performance devices
- 3-D packages
- MCM substrates

CVD diamond substrates for packaging costs fall between that for beryllium oxide (BeO) and natural diamond, or about $10,000 per cm^2. This is expected to decline to $1,000 per cm^2 by 1994. Table 2 offers a comparison of thermal properties of CVD diamond with other substrate materials used in electronic packages.

Ceramics

Ceramic compositions or substrates are the result of combining refractory materials such as nitrides, oxides, and silicides of aluminum, silicon, and beryllium, as well as magnesia and zirconia. These raw materials are synthesized and refined, formed, and fired in a controlled but complex process. Ceramic substrates have been used in the packaging of electronics for the following valuable characteristics:

- Hermetic protection
- Environmental stability

Table 1
CVD Diamond Market Statistics (Millions of Dollars)

	1990	2000	CAGR (%)
Market Shipment Growth	37	4,315	-
R&D	150	150	-
Electronic Package Applications	20	525	39
Total Application Markets	187	4,465	37

Source: International Research Development

Table 2
Thermal Properties of Base Substrates, CVD Diamond versus Other Substrates

	CVD Diamond	BeO	AlN	Al_2O_3	SiC	PWB	Si	Mullite
Thermal Conductivity (watt/mass flow rate at 100°C)	1,300	200	150	18	70-260	0.003/0°C	1.5/0°C	NA
Thermal Diffusivity (cm^2/sec.)	7.4	0.67	0.65	0.05	NA	NA	NA	NA
TCE	2.0	6.0	3.6	4.6-6.2	3.7-3.8	NA	3.3	4.2
Dielectric Constant	5.2-5.7	6.7	8.5-8.8	8.9-9.5	42.0	5.0	11.7	5.5-6.8
Electrical Resistivity (Ohm-cm)	10^{12}-10^{14}	10^{14}	10^{13}	10^{11}- 10^{14}	-	-	-	-
Dielectric Strength (V/million)	8,750	850	1,275	850	NA	NA	NA	NA

NA = Not available
Source: Crystallume Inc.

- Provides a protective barrier
- High mechanical stability
- Thermal shock and cycling
- Rigid stable platform
- No geometry limitation
- Good insulation properties
- High yield during assembly

As noted by P. Garrou and I. Turlik in *Thin Film Multichip Modules*, ceramic processing can be categorized in several ways, including thick versus thin film and low- versus high-temperature cofire. Ceramic substrates can be used as a mechanical support with power, ground, and signal layers or as a cofired ceramic structure containing power and ground distribution planes. The following sections discuss the most common ceramic substrates considered for high-performance MCM designs.

Aluminum Oxide

Aluminum oxide (Al_2O_3), often referred to as alumina, is an inorganic compound from the element aluminum. The oxide alumina is found naturally as ruby, sapphire, corundum, and emery. Alumina is the most commonly used ceramic substrate material in electronic packaging, from hybrids through complex MCM designs. Aluminum oxide requires high firing temperatures and comes in several grades of purity from 92 to 96 percent. Because of its high design implementation in aerospace, electronics, and metrology tools, it is the most cost-effective substrate available.

Aluminum Nitride

Aluminum nitride (AlN) is an inorganic compound from aluminum. It is a relatively new substrate material used in electronic packaging applications. It costs 10 to 15 times more than alumina. Aluminum nitride has been used for heat sinks and in hybrids, in selected IC packages, and more recently in MCM designs requiring high thermal conductivity. Although AlN is an attractive material because of its thermal properties, technical barriers during synthesis of the powder have delayed its entrance as a competitive ceramic substrate material. The purity of the powder can be critical to the properties of the finished product.

The electrical and mechanical comparisons of different types of AlN vary according to the when, where, why, and how of manufacturers and their processes. The quality and thermal conductivity of translucent AlN is higher than that of the darker AlN. The cost also increases incrementally as the level of purity rises. The darker quality of AlN indicates a higher level of contaminants.

Although the thermal characteristics of AlN and BeO are very close, the overall attributes of silicon more closely match those of AlN, making AlN a substrate for silicon components preferred by many substrate suppliers and MCM design engineers.

Mullite

Mullite ceramic is a compound of alumina (Al_2O_3) and silicon dioxide (SiO_2). Mullite is a new substrate whose thermal characteristics are similar to AlN. According to Kyocera, multilayer mullite packages under development are fabricated using cofire technology with tungsten or molybdenum metallization.

Silicon Carbide

Silicon carbide (SiC) is an inorganic compound from the base element silicon. It has a thermal expansion coefficient of 3.7 ($10^{-6} \times {}^{\circ}K^{-1}$), close to that of silicon 2.5, making it an excellent substrate for MCM designs, as well as for applications requiring embedded heat sinks. As noted in IBM's *Microelectronics Packaging Handbook*, SiC incorporated in MCM designs has a thermal resistance of 5°C/W in air-cooled systems and 1.5°C/W in water-cooled systems. Silicon carbide is often used as a structural material in high-temperature applications such as internal combustion machines.

Low-Temperature Glass Ceramics

The low-dielectric, low-firing-temperature glass ceramic substrate materials are crystallizable glasses, glass-filled/glass-bonded composites, and crystalline phase ceramics. Glass ceramic substrates typically are formed using ceramic technology. The glass ceramic substrate is a mixture of alumina powders and glass powders.

Beryllium Oxide (BeO)

Beryllium oxide, referred to as beryllia, is an inorganic compound of the base element beryllium. Although expensive in comparison to alumina, beryllia has been used because of its superior thermal conductivity characteristics in hybrid, microwave, scanning, and energy-gathering mirrors in military applications, and for MCM designs that require high heat dissipation characteristics. Beryllia-substrate-based applications can operate in temperatures from -453°F to 500°F. Crystallume has signed an agreement with Brush Wellman for development of diamond-coated BeO.

Silicon

Silicon used as a hybrid or MCM substrate is often referred to as silicon on silicon. Used by IBM over the last two decades in conjunction with flip-chip attachment, its obvious advantages as a substrate include the following:

- Coefficient of thermal expansion matching silicon die
- Thermal conductivity higher than alumina
- Known lithography and multilevel metallization process

Three-dimensional memory stacking technology such as that developed by companies such as Irvine Sensors, Texas Instruments, and Micro-Module Systems incorporates silicon-on-silicon technology in the solid-state memory array module design. A disadvantage is that it does not have the mechanical stability offered by ceramics.

Laminate Substrates

The most common substrate material for the MCM-L category will be printed wiring boards comprising various types of laminates including the standard FR-4 substrate materials. The more advanced materials being incorporated into the MCM-L category are glass epoxy substrates FR-405 and FR-406 with respective glass transition temperature (T_gs) of 155°C and 177°C. Rogers Corporation is licensing its RO2800 fluoropolymer material as an MCM substrate.

The MCM-L category represents a low-cost module with performance improvements over single-chip designs. The more cost-efficient laminate MCM designs will serve the 50- to 60-MHz systems. Compared to the MCM ceramic and thin film categories, MCM-L designs are limited in thermal conductance, power dissipation, speed beyond 60 MHz, and density. Although 100-MHz MCM-L designs are achievable, indications are that beyond 60 MHz, the MCM-L design declines in cost efficiencies in comparison to the higher-speed MCM-C and MCM-D module designs. Design applications for the MCM-L category are expected to be predominant in the consumer market in pocket computers, and to be incorporated in memory modules and COB designs with low I/O and lower speed demands. Comparison of individually packaged chips with the MCM-L designs indicates that costs should be comparative if the module yields are good.

Dataquest Perspective

The choice of substrate material for the MCM design represents the first level in the MCM fabrication process. The substrate serves as a carrier for the chips as well as a means of interconnecting the chips. Most MCM technologies make a rigid mechanical connection between the die and the substrate. In addition, the electrical connection between the die and the substrate is often made by some form of welding. As a result, it becomes difficult to remove the die for repair or replacement. Thus, the major issues of MCM test and repair come into play. Dataquest maintains that the reparability issue continues to be a major factor limiting the growth of some but not all MCM manufacturers. Module manufacturers should test chips and substrates so well that module repair is seldom required, or develop die and lead attachment techniques that lend themselves to easy removal.

In summary, substrate selection for MCM designs will determine the overall performance of the entire MCM within the system. The role of the substrate is to provide the interconnect base for the die, meet the thermal properties of the die, as well as provide a pathway for heat dissipation, and be mechanically strong enough to endure environmental factors such as handling, thermal cycling, and thermal shock.

Future issues of Semiconductor Worldwide Products, Markets, and Technologies *Dataquest Perspective* will delve into the choice of substrates by MCM vendors, their design capability, and their R&D expenditure in developing MCM capability.

By Mary Ann Olsson

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Technology Analysis

Intermetal Dielectric Technology: The Quest for Market Superiority

As more products are manufactured using multilevel metal processes, the need for equipment capable of addressing the needs for metal deposition, contact, and via plug, and intermetal dielectric (IMD) deposition and planarization are increasing rapidly. Dataquest predicts that the market for equipment utilized for multilayer metal processes will outperform the overall wafer fab equipment market through the remainder of this decade. Driving this growth will be adoption of three- and four-level metal processes for next-generation microprocessors, increasing numbers of three- and four-layer metal ASIC designs, and the migration of the DRAM to a two-level metal process with the 16Mb generation.

This article will focus on IMD deposition and planarization technologies that are competing for this market, with particular emphasis on processes that will be required as design rules shrink below the 0.5-micron level. There is no clear winner yet, and proponents of each technology are putting much effort into technology development, codevelopment work with key fab partners, and aggressive marketing in an attempt to become the mainstream technology in the burgeoning submicron IMD deposition and planarization marketplace.

Dielectric Deposition Technology

The Past: PECVD Silane Oxide

The choice of a particular IMD deposition technique is one of the more complicated issues in a modern wafer fab. It is widely accepted that the device yield is largely dependent on defects introduced during the multilevel metal portion of the process flow. A viable deposition process would ideally include the following partial list of attributes:

- Low deposition temperature
- Excellent gap fill capability
- Low film stress
- Low dielectric constant
- Low moisture absorption
- Ability to be etched with standard techniques
- High deposition rate
- Low particulate defect level
- High wafer throughput

Table 1 lists IMD deposition technologies and the top companies that supply equipment utilizing those processes. The material of choice has, of course, been silicon dioxide. At line geometries greater than 1.2 microns, silane-based PECVD oxides are widely used, because of the low deposition temperature, high deposition rate, low particle levels, and well controlled film properties. The relatively poor conformality of silane-based oxide films precludes their use as a gap-filling material as the metal line spaces fall below 1.2 microns. However, the films find continued application as a capping layer following planarization, where conformality is no longer an issue.

The Present: PECVD TEOS Oxide and Spin-On-Glass

The materials in widest use today at the submicron level are tetraethylorthosilicate (TEOS)-based PECVD oxides, which offer superior film conformality compared to silane-based oxides but are more difficult and expensive to deposit because of the cost of the liquid TEOS

Table 1
Intermetal Dielectric Deposition Technologies

Silane-Based PECVD Oxide	TEOS-Based PECVD Oxide	APCVD Ozone-TEOS Oxide	ECR CVD Oxide
Applied Materials	Applied Materials	Watkins-Johnson	Sumitomo Metals
Novellus	Novellus	Alcan (Canon)	Anelva
E.T. Electrotech		Applied Materials	Lam/Sumitomo

Source: Dataquest (October 1992)

source and the need for a specialized TEOS delivery system. Applied Materials developed one of the earliest versions of a PECVD TEOS deposition system, which ran on the Precision 5000 platform, with which it established and continues to hold a dominant market share position. Dataquest estimates that Applied Materials holds about 90 percent of the PECVD TEOS oxide market. Novellus Systems offers a TEOS process for its Concept One dielectric deposition system, but failed to establish significant market share because of early technical problems associated with the TEOS delivery system. Dataquest believes that the problems have been resolved, and predicts that Novellus will aggressively position the Concept One TEOS system against the Precision 5000, emphasizing the low cost of ownership that served the Concept One silane system so well.

Dataquest forecasts that the market for PECVD dielectric deposition equipment will grow at a compound annual growth rate of 11.8 percent from 1991-1996 (see Table 2). Note that the PECVD segment in Table 2 includes interlayer dielectric (ILD) applications as well as IMD applications. The use of two-level metal processes for the 16Mb DRAMs and for super-shrink 4Mb DRAMs will stimulate increased shipments of PECVD TEOS oxide equipment for IMD applications in the next two years, as well as the migration to three layers of metal for the 486 microprocessor, increasing to an expected four layers of metal for the P5 microprocessor.

Some IC fabs deposit thick films of PECVD TEOS oxide, relying on the excellent conformality to fill the spaces between metal lines without forming a void. The most common IMD process in submicron production today, however, deposits a thin PECVD TEOS oxide film, then applies spin-on-glass (SOG) as a gap fill and planarizing material. Following plasma etch-back planarization, a capping layer of either TEOS or PECVD silane oxide is deposited. Dataquest believes that this will continue to be the dominant technology down to about 0.5-micron line geometries. Below the 0.5-micron limit, the use of SOG as a gap fill material poses potential problems, such as the formation of voids at the bottom of high aspect ratio gaps, and high film stress and cracking because of excessive film shrinkage upon curing. Another complication is the lack of global planarization of the SOG process, which could pose a problem for the advanced lithography requirements below 0.5 microns and concomitant depth of focus constraints. Such limitations are particularly serious for metal systems with three or more layers.

The Future: APCVD Ozone TEOS and ECR CVD

As IC manufacturers eye the impending arrival of subhalf-micron processing, a flurry of development activity has been undertaken to establish an acceptable process technology to meet the needs of that generation. One candidate studied extensively is the APCVD ozone-TEOS oxide deposition process, which uses a liquid TEOS source and an ozone/oxygen mixture as the oxidizing agent. The reaction is carried out at atmospheric pressure to provide higher deposition rates, and the films possess unusually good gap-filling capability. Watkins-Johnson and Alcan Technology (marketed and sold by Quester Technology in the United

Table 2
Worldwide Dielectric CVD Equipment Forecast, by Equipment Type (Millions of Dollars)

	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
Worldwide CVD Market	747	680	755	900	1,045	1,190	9.7
APCVD	92	83.6	89	120	130	150	10.3
PECVD	282	263	317	370	435	492	11.8
Horizontal Tube LPCVD	44	20	15	12	10	10	-25.6
Vertical Tube LPCVD	192	174	177	208	257	296	9.1
ECR CVD	7	7	8	10	12	16	17.0

Source: Dataquest (October 1992)

States) are each marketing a continuous process APCVD ozone-TEOS system. Applied Materials offers a similar process, dubbed subatmospheric CVD (SACVD), running on the Precision 5000 platform.

The continuous process systems have already attained strong market acceptance for BPSG film deposition, but are still in the evaluation phase for IMD applications. The primary drawback at this point is the relatively high tensile stress in the films, which can lead to cracking and metallization failures. Another issue is the sensitivity to the type of surface being deposited on for high-ozone-content films, which are necessary to maximize the gap fill properties. Dataquest believes that these problems will ultimately be resolved, and the process will establish a reasonable degree of market acceptance, because of the void-free gap-filling capability and the very high wafer throughputs that can be achieved. APCVD films will require some form of planarization step, but still offer the benefits of process simplification by filling the minimum metal spaces with a single deposition step. Consequently, Dataquest foresees healthy growth in the APCVD oxide deposition equipment market. The APCVD market forecast in Table 2 includes silane and ozone-TEOS ILD applications, in addition to the ozone-TEOS IMD segment.

A final film deposition technique under development is electron cyclotron resonance (ECR) CVD. This process generates a dense plasma at low pressures using microwave excitation, and utilizes an RF bias on the wafer to add a controlled degree of ion bombardment as the film is deposited. The deposition in essence fills the gap from the bottom up, like filling a glass with water, and as a result, can fill seemingly impossible spaces seamlessly. The market size for ECR CVD systems is quite small, only $7.3 million in 1991. ECR CVD systems are offered by Sumitomo Metals, Anelva, and Plasma Technology (a slightly modified version of the Sumitomo system is marketed in the United States by Lam Research). Sematech is working with a Lam Research ECR system in an effort to develop an IMD process for the 0.35-micron process generation, but several problems remain. ECR plasmas are notoriously nonuniform at eight-inch wafer sizes, and promise to be difficult to scale further. The deposition rates tend to be somewhat low, which will compromise wafer throughput, and the process still needs to demonstrate acceptable consistency and defect levels. Dataquest subsequently forecasts a relatively small market size for ECR systems through 1996.

Planarization Technology

To provide a complete IMD process solution, the film or films used to fill the spaces between the metal lines need to be planarized. The degree of planarization required depends on how many layers of metal will ultimately be used in the process, the line geometries of the various metal layers, and the depth of focus budget of the lithography system. In general, even if a high degree of planarization is not required, the topography must be smoothly varying with no re-entrant angles at any steps. As more layers of metal are added and the line geometries continue to shrink, a greater degree of planarization is required. The ultimate planarization process would deliver true global planarity, resulting in a perfectly flat dielectric surface on which to pattern the next metal layer.

Etch-Back Planarization

Etch-back planarization involves the use of a sacrificial planarizing material to enhance the planarity of the deposited dielectric film. The earliest incarnation spun photoresist onto the wafer following deposition of a thick PECVD oxide film. The wafer was then etched in an oxide etcher with a process that etched the oxide and photoresist at the same rate. The resist smooths the topography of the oxide over the metal, and the smoothed profile of the resist is transferred into the oxide layer during the etch back, resulting in a smoothed oxide film. This process is still used by many companies, although the oxide is now TEOS-based instead of silane-based. Photoresist planarization has fallen out of favor in many fabs, however, because of difficulty in maintaining low particle levels and problems in filling the gap between metal lines with TEOS oxide as the spaces continue to narrow.

As mentioned earlier, the most popular process for 1.0- through 0.5-micron process technologies has been the use of SOG as both a gap-filling material and a sacrificial planarization film. Typically, the wafer is coated with one or more SOG films, and cured at temperatures of 400-450°C. The SOG is then etched in a plasma oxide etch system until it is completely removed from on top of the metal lines, but is allowed to remain in the gaps.

Equipment suppliers that have served the market driven by this type of process are manufacturers of dry etch equipment. Applied Materials, Lam Research, Tokyo Electron, and Tegal all provide oxide etch tools and support planarization etch processes. Dataquest believes that entrenchment of SOG/etch-back planarization technology, combined with development of new SOG materials with reduced shrinkage and hence lower film stress, will permit this process scheme to be used in sub-0.5-micron applications where global planarity requirements are not stringent. A potential upside for SOG exists if it can address the needs of the 0.25-micron process technology. The dielectric constant of silicon dioxide may be too high to meet the electrical requirements at that level. SOG compounds can have substantially lower dielectric constants, increasing their attractiveness.

Chemical-Mechanical Polishing

A relatively new arrival on the planarization scene, and one that is generating tremendous interest and excitement, is chemical-mechanical polishing (CMP). CMP is a process that has been in use for many years for the polishing of silicon wafers to a mirror finish. Within the last few years, it has been adapted to polish oxide films to planarize them, and has also been used to polish tungsten films to planarize contact and via plugs. The process consists of contacting the wafer with a rotating porous pad and saturating the pad with a polishing slurry. For oxide planarization, commercial slurry mixtures consisting of a suspension of silica particles in an aqueous KOH solution are used. The oxide can be removed at a controlled and uniform rate, resulting in a smooth, planar surface. The resulting surface, if the process is controlled properly, can be almost perfectly smooth, possessing true global planarity.

The process is being used in production by several IC manufacturers. IBM, which pioneered the use of CMP for planarization in the mid-1980s, uses the process for IMD planarization and tungsten plug planarization in its 4Mb and 16Mb production process flow. Dataquest believes that Intel is utilizing CMP in its 0.8-micron, three-layer metal process used for the 486 microprocessor, and that AMD is integrating the CMP process into a 0.7-micron, three-layer metal process.

CMP is not yet a panacea, however. Several problems make the process difficult to use in a manufacturing environment, such as pattern sensitivity of the oxide removal rate, lack of a means of endpoint detection, and the tendency of the oxide removal rate to drift downward over time. The current implementation of the process demands heavy engineering support and a large amount of test time to calibrate the film removal rate, causing the cost of ownership to be somewhat high. Dataquest believes that, in the near term, CMP will be used where it confers a technological advantage, in three-or-more-layer metal processes with tight metal pitch, and in production of high-margin products where some loss in manufacturing efficiency can be traded for the development of a strategic technology that will be critical later. Dataquest does not believe that CMP will make significant inroads into DRAM production processes, with the exception of IBM, until the 64Mb generation.

Table 3 lists the four companies wrestling to establish control in the CMP marketplace. Westech Systems owns the lion's share of the installed base, aided in part by its collaboration with Sematech and IBM. The experience base accumulated by Westech should prove valuable in helping its customers solve problems and improve the manufacturability of the process. Cybeq Systems offers a system that addresses the throughput issue by allowing six wafers to be polished simultaneously, compared with two wafers per batch for the Strasbaugh machine and single-wafer processing on the Westech tool. The Westech system utilizes two separate polishing stations, each with single-wafer capability. One station is used for planarization, the other is used for a post-planarization cleaning step. The Strasbaugh machine polishes two wafers on a single polishing pad. Cybeq's CMP tool also features a patented floating head design that results in uniform oxide removal across the wafer, which is a problem on other machines. This is dealt with on the Westech system by dynamically curving the wafer holder during the polishing process to compensate for nonuniform oxide removal.

Dataquest believes that the company that can demonstrate the lowest cost of ownership will ultimately occupy the dominant position in the market for CMP tools. Dataquest believes that the market for CMP tools will ultimately grow substantially. CMP is the only technique that offers true global planarization capability, which will be essential in reconciling the need for

Table 3
Chemical Mechanical Polish Equipment Companies

Company Name	Equipment Model	Equipment Features	1991 CMP Revenue (Millions of Dollars)
Westech Systems	Model 372	2 single wafer polishing pads Active correction for nonuniform film removal	11.6
Cybeq Systems	Model 3900	6 wafers on a single pad Floating head design for uniform film removal	1.6
Strasbaugh	Model 6DS	2 wafers on a single pad Working on active correction for nonuniform film removal	2.5
Speedfam	NA	NA	0
Pressi	NA	NA	0

NA = Not available
Source: Dataquest (October 1992)

several layers of tight pitch interconnect with diminishing depth of focus budgets as feature sizes continue to shrink. In the near term, market growth will be driven by technology buys as more companies commit to developing the process, and companies such as Intel that have both the technological need and the profit margins to pay for the process in its early phase. Dataquest expects the market for CMP equipment to begin to expand rapidly in the 1995-1996 time frame, when 0.35-micron processes begin to run in production facilities.

Dataquest Perspective

The evolution of the integrated circuit, with the emphasis on integration, is exerting pressure on the process technologist to increase the number of metallization layers in the process flow. At the same time, line geometries continue their relentless drive downward to ever smaller dimensions. This places a multitude of demands on the metal and IMD process modules, which already are the yield-limiting region of the process flow in many cases. The multilayer metallization portion of the process will equal the remainder of the process in terms of number of process steps in a three-layer metal flow; it will dominate the process flow beyond three layers of metal. These factors, in Dataquest's opinion, will give rise to a thriving market for IMD deposition tools, planarization equipment, metal CVD equipment, and other systems used in multilevel metal processing.

The suite of processes have been established for the process flows down to the 0.5-micron level, and the dominant unit process techniques will be PECVD TEOS oxide deposition, SOG for gap filling, and planarization with plasma etch-back. Some use of resist etch-back with thick PECVD TEOS oxide films also will occur. Dataquest predicts that the sales of these process tools will continue to grow at a healthy rate as more DRAM processes switch to two-level metal processes, and ASIC and microprocessor fabs continue to increase the number of metal layers to three or more. Dataquest believes opportunities remain for equipment suppliers that can address these process needs with low cost of ownership solutions.

In the longer term, there is not yet a clear successor to the current family of process tools at the sub-0.5-micron level. The process tools that ultimately become the status quo for future fine-line geometry processes will be those tools that best meet the complex and stringent technical requirements in the most economical fashion. Certain fundamental technical needs include the ability to fill narrow, high aspect ratio gaps in a seamless way, high wafer throughput, and acceptable, reproducible film properties with low contamination levels.

Dataquest believes that no single process will dominate the applications base, but the choice of processes will increasingly be tailored to the technical needs and cost basis of a particular fab. APCVD ozone-TEOS films, combined with CMP, appear to be well matched to the most severe technical requirements of processes that will employ more than three layers of metal at fine line geometries. ECR CVD may be a technically viable solution, but must surmount several hurdles in order to be considered a manufacturable process. In two-layer metal systems and three-layer metal processes with relaxed metal pitch on the top layer, extension of the SOG gap fill and planarization processes may be more suitable, provided that SOG vendors can deliver material with the appropriate properties. Dataquest believes that this will be the case. The total available market for these systems will be large, and their complexity and relative importance to the overall process flow means that they will carry hefty price tags. The battle for market supremacy will be fiercely fought, and the victors will be well compensated for their vision and effort.

By Charles Boucher

News and Views

Material Notes

Kawatec Expands Santa Clara Facility

Kawasaki Wafer Technology plans to expand its Santa Clara, California, silicon wafer plant. It hopes to double the polished and epitaxial wafer capacity at the plant by moving ahead with a $30 million investment. After completing the expansion, polished capacity will total 3.4 million square inches (msi) and epi capacity will total 1.0 msi using ASM reactors. The expansion will include the addition of 200mm wafer production. The expansion is expected to be completed by the fourth quarter of 1993.

IBM Pulls Mask-Making In-House

Photoronics Inc. reported that the loss of IBM's mask business will continue to pressure its earnings growth. IBM has pulled most of its mask production in-house. Further adding to margin pressures at Photoronics are the ongoing cost of the expansion occurring at its California facility and the hiring of two senior people in anticipation of the eventual opening of the planned, new, Texas manufacturing facility.

BOC to Handle CVD Chemicals

BOC Group companies including Airco in the United States and Osaka Sanso in Japan will distribute the CVD chemicals made by Olin Hunt Speciality Products. These products include TEOS (tetraethylorthosilicate), TMB (trimethylborate), TMP (trimethylphosphate), phosphorus oxychloride, boron tribromide, and phosphorus tribromide.

Lam Sells Epi Equipment Group

Lam Research has sold its Gemini epitaxial equipment group to Concept Systems Design. Concept will manufacture all new Gemini systems, as well as provide new product installation, service, and warranty to customers. R.E. Dixon will continue to supply spare parts and service for the Gemini products.

Lam Research has planned to exit from the epi market for several years. The Gemini product line did not fit with its strategy of being a focused etch and deposition equipment vendor. In addition, the $20 million investment required to develop the next-generation epi system targeting the high-growth CMOS epi market was prohibitive.

Dataquest estimates that more than 235 Gemini systems are installed worldwide. The large installed base of Gemini systems prevented Lam from dropping the equipment line before a credible alternate vendor was identified. Concept Systems has developed equipment enhancements for the Gemini product line, so the sale is a good fit.

BiCMOS Process Planned for Intel's P5

Intel's P5 chip will be built using BiCMOS process. There is a 10 percent increase in device complexity for the BiCMOS process, but it provides about a 30 to 35 percent performance benefit without a size or power penalty, according to Intel.

Intel's X86 product line has been built using a CMOS process. However, Intel is running out of bandwidth. The fastest microprocessor offered today by Intel is the 486DX2, which runs at 66 MHz. As future generations of microprocessor move to higher speeds in the range of 100 or 150 MHz, a BiCMOS process will provide more room for designers to achieve these speeds.

One of the results of the move to BiCMOS is that Intel is developing in-house expertise in silicon epi film deposition. The BiCMOS process requires epi films beyond the first masking level and consequently this deposition will be done internally.

Hoxan and Daido Sanso to Merge

Hoxan and Daido Sanso will merge on an equal basis, effective April 1, 1993. Hoxan is an industrial gas supplier based in Sapporo City, Japan, and is listed on the first section of the Tokyo Stock Exchange. Daido Sanso is an industrial gas supplier headquartered in Osaka. Annual sales of the two companies, after merging, will exceed ¥150 billion, ranking the new company second only to Nippon Sanso, which boasts the largest sales of about ¥200 billion in the Japanese industrial gas industry.

The industrial gas industry is facing sluggish demand from steel and other base material industries. Demand for specialty gases for electronic applications is also slowing down. In addition, the growing presence of the U.S. and European manufacturers in the Asian markets seems to have prompted the decision by the two companies. The merger is expected to trigger the restructuring of the Japanese industry, which suffers low profitability.

The new company will be named Daido Hoxan and its first president will be Shigeru Mizushima, current president of Hoxan. Hiroshi Aoki, president of Daido Sanso, will be appointed chairman.

Hoxan is diversifying its core business of industrial gas into a variety of fuels such as liquefied petroleum gas (LPG), solar batteries, and industrial and building materials such as welding machinery. The company is based in Hokkaido and has offices in Nagoya and Osaka.

Daido Sanso principally operates in Osaka and the western part of Japan. Because the two companies offer similar product lines, centering on industrial gases, oxygen, and nitrogen in particular, the new company will be able to utilize existing resources effectively without duplication.

In the 1980s, Japanese industrial gas prices collapsed because of fierce competition. The industry is under the supervision of the Ministry of International Trade and Industry, which has imposed various restrictions, for example, the industrial gas makers require the ministry's permission to add production. The formation of a new company is expected to streamline the distribution system and to pare sales and production costs for both companies.

Hoxan is a medium-size industrial gas maker based in Hokkaido Prefecture. With its high-pressure gas and LPG as core businesses, the company is diversifying into other fields, including bathtubs, frozen food, and medical-related products. It has working capital of ¥5,718 million and about 1,100 employees. For the fiscal year ended in March 1992, Hoxan reported revenue of ¥89,412 million and operating profit of ¥2,016 million.

Daido Sanso, established in 1933, is a leading industrial gas supplier specialized in oxygen and nitrogen. Its chief stockholder is Air products & Chemicals, a U.S. corporation that owns roughly 15 percent of Daido. The company is expanding its operation into industrial machinery, including welding machines and cryogenic systems. With working capital of ¥5,466 million, the company employs about 400 persons. For the year ended in March 1992, the company reported operating profit of ¥1,953 million on ¥63,600 million revenue.

By Mark FitzGerald
Kunio Achiwa

Conference Announcement

Dataquest's 18th Annual Semiconductor Industry Conference

Each October, Dataquest brings together the top executives in the electronics industry for a forum on the latest issues facing this industry. This year's conference will focus on today's semiconductor marketing and technology issues, and preview tomorrow's major semiconductor applications that are *Fueling the Engines for Growth.*

Highlights of the conference are as follows:

- Special guest speaker: David Packard, Cofounder and Chairman of the Board of Hewlett-Packard.
- Eleven top industry executives sharing their insightful perspectives, real-world experiences, lessons, and bottom-line analyses.
- Two interactive panel discussions covering ASICs and strategic processor directions. Panels will be moderated by Dataquest and feature key industry leaders.
- Four breakout sessions presented by Dataquest senior analysts. The sessions will focus on manufacturing trends, semiconductor procurement issues, and two emerging applications areas: personal information and communications devices (PICDs), and multimedia.

In addition to the presentations and panel discussions, this year's agenda has been designed to allow social time for conferring with your peers on the critical issues and challenges facing the industry. You'll find the two days interesting, very informative, and, we hope, thoroughly enjoyable.

Seats are limited for this premier semiconductor event. To register for this conference, or to request a complete conference agenda, please call our toll free number, 1 (800) 457-8233, today!

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Monterey Conference Center
Monterey, California
October 5 and 6, 1992
Dataquest Client Rate: $1,095
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Dataquest Perspective

Semiconductor Equipment, Manufacturing, and Materials

SEMM-SVC-DP-9212 September 7, 1992

In This Issue...

Market Analysis

Semiconductor Materials

1991 U.S. Specialty Gas Market—Volumes Up, Revenue Flat

Consumption of electronic specialty gases in the United States increased marginally in 1991 in the face of deteriorating wafer starts. Revenue that totaled $77.9 million (see Table 1) pushed ahead 4.0 percent on a year-to-year basis. Silicon wafer starts measured in millions of square inches sank 4.5 percent over the same period.

Price Erosion

Growth rates for U.S. electronic specialty gases have slowed over the last three years to a 6.0 percent compound annual growth rate (CAGR). Certainly, part of the revenue slowdown is attributable to the deceleration in wafer starts in the United States. But, slower revenue growth is especially curious if, as we believe, semiconductor device makers are migrating to the higher-grade gases, which carry higher average selling prices. Both reports from the gas vendors and the growth of submicron capacity in the United States (see Table 2) suggest that the higher-grade products should be a larger part of the product mix.

Processing trends also suggest that specialty gas volumes should outpace silicon wafer unit growth. Advanced designs now include two and three levels of metal, and the average number of mask steps is approaching 20.

Assuming that the demand for the higher-grade gases is growing and knowing that advanced designs are moving into production, we would expect specialty gas revenue per square inch of silicon to show very strong growth rates because of the higher selling prices and larger volumes. However, gas revenue per square inch of silicon has only grown 3.4 percent CAGR since 1989, suggesting that average selling prices have eroded over this period.

Table 1
U.S. Market Electronic Specialty Gases (Millions of Dollars)

Product Usage	1989	1990	1991	Three-Year CAGR (%)
Silicon Precursor	20.6	21.9	22.3	4.1
Silane	14.4	15.2	15.6	.9
Dichlor	4.5	4.2	3.6	-10.6
Trichlor	1.0	1.6	2.0	43.4
Sil Tet	0.7	0.8	1.1	26.9
Dopants	6.5	7.2	7.3	5.8
Plasma Etchants	14.1	16.0	17.0	9.7
Reactant Gases	11.0	13.4	12.4	6.2
Atmo/Purge	17.2	16.4	19.0	5.0
Total Specialty	69.4	74.9	77.9	6.0
Annual Growth	6.0	7.9	4.0	
Company Market Share	**1989**	**1990**	**1991**	**1991 Share (%)**
Airco	23.4	26.2	28.2	36.2
Air Products	13.5	15.9	16.6	21.3
Liquid Air	1.7	1.6	2.2	2.8
Praxair	11.7	14.0	13.6	17.5
Matheson	10.2	10.2	10.6	13.6
Scott Speciality	2.9	2.9	3.4	4.4
Solkatronics	0.0	1.7	2.2	2.8
Others	6.0	2.3	1.1	1.4
Total	69.4	74.9	77.9	100.0
U.S. Specialty Gas Consumption per Square Inch of Silicon	**1989**	**1990**	**1991**	**Three-Year CAGR (%)**
Specialty Gas Consumption	69.4	74.9	77.9	6.0
Silicon Consumption (MSI)	582	640	611	2.5
Revenue/Square Inch	$0.119	$0.117	$0.127	3.4

Source: Dataquest (September 1992)

Table 2
U.S. Capacity Distribution by Linewidth (Microns)

	Percentage MSI			
	1989	1990	1991	1992
<0.5	0	0	0	0
≥0.5 and <0.8	3	4	5	5
≥0.8 and <1.0	9	10	12	14
≥1.0 and <2.0	41	40	40	40
≥2.0	40	38	36	35
Unknown	7	8	7	7

Source: Dataquest (September 1992)

If in fact this trend is occurring, then there could be some serious problems for vendors as the demand for higher-grade gases grows. Gas purities are moving into the part-per-billion range, and the higher costs incurred with hitting these specifications increasingly are associated with adding expensive analytical equipment and clean packaging environments. It is difficult to see how companies will pay for these investments if prices for high purity electronic specialty gases are falling rapidly.

Regional Trends

Though the U.S. market is viewed as healthy, semiconductor production growth rates over the forecast period will be well below historical levels for several reasons. First, we believe that the rate of fab closures will remain high. Nineteen fab lines in the United States were or are expected to close in 1991 and 1992. The United States has the oldest semiconductor manufacturing infrastructure and many of these facilities are becoming obsolete.

Semiconductor production in the United States is expected to have a 9 percent CAGR through 1996. The main driver will continue to be the PC/workstation market. Companies continue to invest in new fabs for advanced microprocessors. Telecommunication and especially networking will be other prominent themes in the growth of U.S. semiconductor production.

Second, the demand for military devices is forecast to decline because of Pentagon budget cuts that will accelerate through 1996. Already, companies such as Harris Semiconductor, Hughes, and McDonnell Douglas are downsizing their semiconductor operations to adjust to this new environment.

Foreign companies and especially Japanese semiconductor companies are expected to cut their level of investment in U.S. fabs over the forecast period. Therefore, U.S.-based companies will account for most of the growth in device production in the United States. Investment by Digital Equipment Corporation, Intel, IBM, Motorola, Texas Instruments, and Hewlett-Packard will drive device production growth.

For specialty gas vendors, these trends point to a concentration of purchasing power among the top-tier U.S. semiconductor companies. Gas vendors that will grow faster than the overall market will increasingly need to target these top companies. Dataquest also expects service revenue to grow rapidly among the leading device companies in the United States and be an important source of revenue for gas vendors.

Process Drivers

Processing trends in the United States are expected to drive the rapid growth of several materials over the next five years. The following sections describe materials that Dataquest believes will grow faster than the overall specialty gases market.

Tungsten Hexafluoride

Blanket tungsten CVD for plugs and global interconnect applications is rapidly becoming the largest segment of the tungsten thin film market. Tungsten applications previously have been dominated by silane-based tungsten silicide films. Tungsten hexafluoride volumes are poised for growth as several device companies transition from pilot to production using blanket tungsten CVD for polycide gate/local interconnect applications.

But just as the volumes for tungsten hexafluoride are poised to grow rapidly, pricing has declined dramatically. WF6 pricing has fallen below $1 per gram in 1992, which will result in only marginal growth in revenue in 1992 even as volumes push ahead quickly.

TEOS

As devices move to a higher number of metal layers, planarization problems increase. TI's 16Mb DRAM, Intel's P5 microprocessor, Digital's Alpha architecture, Sun Microsystems' SuperSparc architecture, and the IBM/PowerOpen architecture are all based on 0.8- to 0.5-micron processes using triple-metal processes.

TEOS volumes are expected to benefit from this trend to more levels of metallization. Dataquest believes that TEOS' excellent conformal qualities will make it the material of choice as the planarization challenge increases in intermetal dielectric processing. We expect total U.S. volume shipments in 1992 to increase 20 to 30 percent for the next three to five years (see Table 3).

Metal Etchants HCl, Cl2, HBr

The transition to multilevel metal designs is expected to also drive the market for metal etchant gases. Volumes of these materials should outpace the growth of the overall specialty gases market.

Tantalum Pentaoxide

If stacked gate transistor technology is employed for future DRAM generations, then there will certainly be a need for new capacitor dielectric materials. Materials such as CVD tantalum pentaoxide, with a high dielectric constant, may be required.

Table 3
U.S. TEOS Vendors

	1991	
Vendors	Revenue ($M)	Volume (kg)
J.C. Schumacher	2.5	5,560
Olin-Hunt (Apache)	1.1	2,440
Advanced Delivery and Chemical Systems	2.0	4,440
Others*	0.2	440
Total	5.8	12,880
Average Selling Price per Gram		0.45

*Others include: Shinetsu Chemical through Micro-sci (foreign production) Kojundo through Airco (foreign production) Yamanaka through Eagle-Pitcher (foreign production) Pacific/Pac (domestic)
Source: Dataquest (September 1992)

Dichlorosilane (DCS)

The development of a reproducible and reliable dichlorosilane high-temperature process for enhanced step coverage and low fluorine content in thin oxide dielectrics could grow the demand for DCS. However, equipment development in this area lags and could possible miss the market window.

Dataquest Perspective

As device manufacturers move to the submicron level, the demand for high-purity specialty gases is expected to expand. The growth in revenue for specialty gases should stay ahead of the silicon wafer growth rate if pricing for the advanced grades of gases does not erode.

Dataquest's current forecast for U.S. consumption of silicon measured in millions of square inches is 6.2 percent CAGR through 1996. Specialty gas revenue in the United States could easily grow in the 10 percent or more range in a stable pricing environment. Revenue growth will fall closer to the silicon growth rate of 6.2 percent CAGR if pricing cuts are not arrested.

The history of the industrial gases business suggests that vendors are far too eager to use pricing to grab market share. But, there are a few differences in the current climate that may cause companies to respond differently than in the past.

First, the investment hurdle to supply the high grades of electronic specialty gases is rising so quickly that it is unlikely that smaller players can stay the course. It is reasonable to project that only three or four players will remain serious competitors in the U.S. electronic specialty gases market over the long term.

The small size of the market, $77.9 million in 1991, further supports this trend. Gas companies cannot justify the required investment in their electronic specialty gas operations if the total pie is shared among seven or more competitors.

Second, the globalization of the semiconductor industry increasingly is driving device makers to work closely with a handful of vendors positioned to supply them in all the regions in which they have built fabs. Among gas vendors, this trend obviously benefits the five major vendors and their affiliates.

Device makers may become even more selective as the service component of electronic specialty gases increases. It is not unreasonable to argue that semiconductor makers would benefit by paring the number of gas vendors with whom they choose to work on a worldwide basis. If indeed this trend takes hold, then developing a close relationship with the major device makers will be the key to future growth for globally positioned industrial gas companies.

By Mark FitzGerald

Inquiry Summary

Dataquest's Semiconductor Equipment, Manufacturing, and Materials inquiry summaries are designed to inform our clients of commonly asked questions and Dataquest's respective answers. No confidential information provided by our clients is included in this material.

Collimated Sputtering Displaces CVD Metal

Q. What is collimated sputtering and what effect will it have on the CVD metal market?

A. Collimated sputtering is a technique in which a collimator, which is a type of filter, is placed between the sputtering source and the wafer in a conventional sputtering system. The collimator only permits metal atoms to pass that are on a path nearly perpendicular to the wafer, and blocks divergent atoms. The result is that metal deposition can be realized in small, high aspect ratio contacts and vias with excellent step coverage. Experimental studies have successfully deposited metal into contacts with aspect ratios as high as 7:1. However, for practical applications, the technique will probably not be economical beyond the 0.35-micron technology generation, which will utilize via aspect ratios of between 2:1 and 3:1.

Dataquest believes that the dominant applications for collimated sputtering will be the deposition of diffusion barrier materials and adhesion layers for CVD tungsten deposition. The most widely used materials are Ti/TiN or TiW for diffusion barriers, and TiN for the tungsten adhesion layer. Collimated sputtering has several inherent advantages over CVD for these materials: the film is deposited at low temperature, it possesses known properties, and it utilizes a mature equipment technology with a relatively inexpensive modification. The only major drawback is that the net deposition rate is reduced by the collimator, thereby reducing throughput. The collimator also presents a potential source of particles, but existing techniques for particle control should prevent that from becoming a serious problem.

The net result is that the Ti and TiN sputter applications market will grow at a healthy rate, at least through 1996. Table 1 shows the forecast revenue growth in the sputter market segmented by film application. The market for Ti and TiN sputtered films is expected to grow at 17.1 percent and 19.6 percent CAGR, respectively. This growth will be driven by the increased use of Ti/TiN barriers and tungsten for contact/via plugs and interconnect in process flows as a greater fraction of the fab capacity shifts to 0.35- to 0.5-micron technology levels. Dataquest therefore believes that the market for CVD TiN will not begin to develop until the 1995 to 1996 time frame.

By Charles Boucher

Lower Capital Spending to Device Production Ratio

Q. In reviewing Dataquest's recent capital spending forecast and semiconductor production forecast we have noticed that the ratio of capital spending to production in the United States has dropped. Could you please explain your reasoning behind this trend?

A. Tables 2 and 3 present historical and forecast semiconductor capital spending and device production in the United States. We believe that the ratio of capital spending to device production is falling for the following reasons:

- In the short run, the worldwide overcapacity situation means that revenue can grow without additional capacity.
- Over the longer term, Dataquest expects device makers to focus on raising their fab utilization rates. National is a good example. It has gone from 55 percent utilization to more than 70 percent by closing older fabs. Further evidence of this trend is the increased level of fab closures in the United States (19 in the last two years).

Table 1
Worldwide Sputtering Equipment Market Forecast, by Film Application (Millions of Dollars)

Sputtered Film	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
Aluminum Alloys	281	265	290	339	394	452	10.0
TiW	24	20	21	20	20	22	-1.8
TiN	42	45	53	69	85	102	19.6
Titanium	55	57	67	85	102	120	17.1
MoSix	15	12	10	10	11	12	-4.0
WSix	8	8	9	10	11	12	8.2
Other Films	13	11	11	11	12	13	0.1
Total Worldwide	438	416	460	546	637	734	10.9

Source: Dataquest (September 1992)

Table 2
Historical Ratio of U.S. Capital Spending to U.S. Production Merchant and Captive Semiconductor Companies
(Millions of Dollars)

	1985	1986	1987	1988	1989	1990	1991
Device Production	12,654	14,456	16,712	20,171	21,324	22,789	25,103
Capital Spending	2,629	2,082	2,594	3,434	3,875	4,088	3,851
Ratio (%)	20.8	14.4	15.5	17.0	18.2	17.9	15.3

Source: Dataquest (September 1992)

Table 3
Forecast Ratio of U.S. Capital Spending to U.S. Production Merchant and Captive Semiconductor Companies
(Millions of Dollars)

	1992	1993	1994	1995	1996
Device Production	27,695	31,136	34,542	36,063	38,592
Capital Spending	3,559	3,754	4,344	4,883	5,688
Ratio (%)	12.8	12.1	12.6	13.5	14.7

Source: Dataquest (September 1992)

- Dataquest believes that the number of greenfield sites in the United States will decline dramatically from historical levels. Consequently, land purchases and building infrastructures will decline as companies focus more on upgrading or retrofitting existing facilities.
- Military capital spending is expected to decline. Though small, these cuts will pull down the ratio because military capital spending is high relative to the IC revenue generated.
- Though equipment ASPs are increasing quickly, we expect the productivity gains to keep ahead of the ASP curve. The sharp decline in the annual unit shipments of steppers is a prime example.
- The growing trend toward alliances as evidenced by the recent spate of announcements will spread the capital investment over several companies, thereby slowing capital spending.

By Mark FitzGerald

0.5-Micron Technology—What Do They Really Mean?

Q. When will true 0.5-micron technology be used in volume manufacturing, and for what application?

A. It is first necessary to define what is meant by 0.5-micron process technology. Table 4 indicates the minimum feature sizes for each critical layer in a typical 0.5-micron process flow. As Table 4 clearly shows, the minimum feature size is defined by the N-channel MOSFET drawn gate length; this dimension is adopted to describe the overall process technology.

Table 4
Minimum Feature Sizes for Typical 0.5-Micron Process

Layer	Line Dimension (μm)	Space Dimension (μm)
Active	0.5	0.6
Poly	0.5	0.6
N Gate	0.5	-
P Gate	0.6	-
Contact	0.6	-
Metal 1	0.6	0.7
Via	0.6	-
Metal 2	0.6	0.7

Source: Dataquest (September 1992)

New process technology generations usually are developed using DRAM or SRAM products as technology drivers, and these products will first utilize the process technology in a production environment. For a given generation of process technology, the DRAM technology driver will be four times the density of an SRAM product built with the same technology level, because the SRAM memory cell contains four (or even six) transistors, whereas the DRAM cell only contains one. It should be noted, however, that although either vehicle can be used to develop the basic facets of a technology generation, such as lithography capability, etch techniques, thin film deposition methods, and overall defect reduction, a DRAM process flow and an SRAM process flow are in the end very different entities. Many DRAM process enhancements have in fact focused on reducing the size of the storage capacitor to minimize memory cell size. Conversely, SRAM process enhancements have been largely concerned with improving the memory cell stability, and typically utilize three or even four layers of poly at the 4Mb level, involving a host of unique process integration problems.

Process technologies are also becoming increasingly differentiated for different product segments. DRAM processes typically used a single metal layer through the 4Mb generation, and expanded to two metal layers at the 16Mb level, while ASIC products and highly integrated microprocessors are using three layers of metal and are migrating to four-level metal processes. Many specific process issues need to be solved in a multilevel metal process that are distinct from the generic problems associated with patterning and etching smaller features.

SRAM and DRAM families in volume production are 1Mb SRAM and 4Mb DRAM devices. These products are built using 0.7- to 0.8-micron process technology. In development and very early pilot production are 4Mb SRAMs and 16Mb DRAMs. These devices are being developed using 0.55- to 0.6-micron process technology, and Dataquest predicts that both devices will begin low-volume production in late 1993, ramping strongly during 1994 and 1995. We expect design rules to continue to be pushed as improved process capability is established, and 0.5-micron processes will be in volume production in 1994 as shipments of 4Mb SRAMs and 16Mb DRAMs begin to grow rapidly.

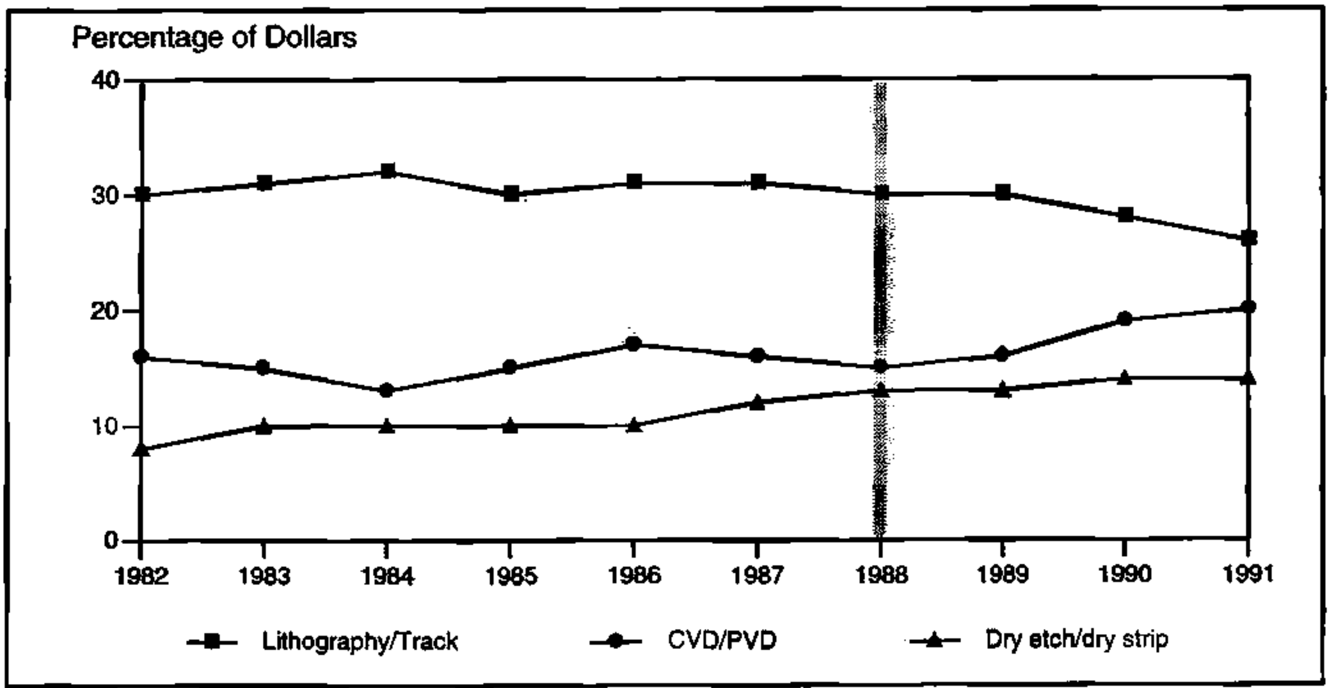
By Charles Boucher

Trends in Spending for Major Wafer Fab Equipment Segments

Q. What has been the historical trend in the percentage share of total wafer fab equipment spending for the major wafer fab equipment segments?

A. Figure 1 illustrates the historical market trends for three major segments of equipment as a percentage of total wafer fab equipment spending. Figure 1 shows a line at the year 1988

Figure 1
Major Equipment Segments As a Percentage of Total Wafer Fab Equipment Spending



Source: Dataquest (September 1992)
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to distinguish what we believe are two different periods of market behavior. Throughout much of the early and mid-1980s, lithography and track equipment have maintained essentially a constant slice of the total equipment spending pie at about 30 percent. The combined categories of CVD and PVD during this same period have varied somewhat on the order of 1 to 2 percentage points per year. The etch/strip categories of equipment have maintained essentially a constant level with some modest increases noted beginning in the mid-1980s.

Clearly, though, in the last three to four years lithography/track equipment spending has declined as a percentage of the total while CVD/PVD equipment has garnered a larger and larger portion of total wafer fab equipment spending. Part of the explanation for this can be directly correlated with the move to multilevel metallization schemes for ASICs, advanced logic, and now, with DRAMs for the 4Mb shrink and the 16Mb products.

A second component of our explanation for this market trend is the consideration of system throughput. Stepper manufacturers have aggressively worked to increase wafer throughput and to improve overall equipment productivity. At the same time, there has been a significant emphasis in the CVD arena to move from batch to single-wafer systems, which has had a net effect of reduced throughput for a given unit of CVD equipment. We believe that these two factors are the major reasons behind the increase in CVD/PVD spending over the last several years.

By Peggy Marie Wood

In Future Issues

Look for the following articles in future issues of *Dataquest Perspective:*

- Stepper and photoresist technology mix in the future
- Interlevel metal dielectric trends

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Dataquest Perspective

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Semiconductor Equipment, Manufacturing, and Materials

SEMM-SVC-DP-9211 August 10, 1992

In This Issue...

This edition of *Dataquest Perspective* covers our midyear forecast. Additional information, including semiconductor consumption and silicon wafer demand, is published in our *Semiconductor Equipment, Manufacturing, and Materials Forecast July 1992* document.

Market Analysis

Semiconductor Manufacturing

Semiconductor Capital Spending Forecast: A Secular Change for the Market

Worldwide semiconductor capital spending is expected to decline 9.5 percent in 1992 (see Table 1) largely because of severe cuts in spending by Japanese companies. Dataquest believes that 1992 will mark the bottom of the spending cycle. However, we are only forecasting moderate growth in spending in 1993. Moreover, the five-year worldwide compound annual growth rate for spending through 1996 is estimated to be 6.9 percent. This rate is at an historic low and is caused in the short term by weak global economic conditions and an overhang in production capacity. Over the longer term, the slower growth scenario is attributable to weak growth in the global economy and uncertainty about the emergence of a high-octane semiconductor application.

Worst-Case Scenario for Japanese Semiconductor Capital Spending Unfolds

Our recent survey of Japanese device makers reveals that capital spending on new plant and equipment will drop 24.0 percent in 1992. Sharp cuts in spending can be attributed to several factors, including a large production capacity overhang caused by the boom in spending in the late 1980s, weak domestic and export markets, and mounting trade friction with Western countries.

The vertically integrated Japanese computer makers will make on average the smallest cuts in semiconductor capital spending in 1992. Even so, we expect companies such as Fujitsu, NEC, and Toshiba to cut spending levels 13 to 30 percent (see Table 2). These companies face a weak domestic economic environment and poor returns on their 4Mb DRAM investment. Dataquest estimates that Japanese 4Mb lines are running at 60 to 65 percent capacity utilization.

Table 1
Worldwide Capital Spending by Region Forecast, Including Merchant and Captive Semiconductor Companies
(Millions of U.S. Dollars)

	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
North America	3,851	3,559	3,754	4,344	4,883	5,688	8.1
Percentage Growth	-5.8	-7.6	5.5	15.7	12.4	16.5	
Japan	5,636	4,312	4,601	5,107	5,551	6,634	3.3
Percentage Growth	3.9	-23.5	6.7	11.0	8.7	19.5	
Europe	1,234	1,087	1,011	1,110	1,359	1,808	7.9
Percentage Growth	-18.4	-11.9	-7.0	9.8	22.5	33.0	
Asia/Pacific	2,274	2,808	2,676	2,914	3,138	4,002	12.0
Percentage Growth	52.1	23.5	-4.7	8.9	7.7	27.5	
Worldwide	12,995	11,765	12,042	13,475	14,932	18,131	6.9
Percentage Growth	3.8	-9.5	2.4	11.9	10.8	21.4	

Source: Dataquest (August 1992)

The slow adoption of the 4Mb DRAM and an anticipated slow ramp up of the 16Mb DRAM has caused the computer makers to turn cautious on capital spending. In addition, Korean DRAM vendors are continuing to win a larger share of the market, thus adding to the competitive pressures in the memory segment.

Weak domestic consumer demand and weak export markets have prompted the large vertically integrated consumer electronic companies to deeply cut their spending on their semiconductor operations. Consumer electronic equipment inventories continue to mount, although companies such as Sony and Matsushita are doing a better job at managing the problem than they were at the beginning of the year. However, shrinking profit margins and quarterly losses suggest that capital spending by consumer electronic companies will not snap back in 1993.

Japanese steel companies such as Kawasaki Steel and NKK, which were late entrants to the semiconductor game, are in a more precarious position. In a scramble to diversify beyond the declining steel industry, the largest steel companies in Japan made large investments in the semiconductor business in the late 1980s.

Dataquest believes that the production capacity brought on by the steel companies is currently running at less than 50 percent capacity utilization. Moreover, Japanese steel companies will face serious problems filling those factories if the weak economic environment persists because steel companies do not have a captive market for their devices.

Many Japanese companies announced delays in 200mm line investment plans late in 1991. Japanese companies have not earned a return on their 4Mb investment, and their strategy to achieve this return is to postpone the next round of investment in 16Mb lines. However, because of the severity of capital spending cuts in 1992, we now expect that some of these delayed lines will not be built at all.

Japanese spending on advanced semiconductor lines in the United States and Europe is also expected to decline. Though Japanese companies have completed most of their "green-field" investment in offshore fabs, many capacity additions to these facilities are not expected to proceed anytime soon.

U.S. Spending Pulled Down by Japanese Companies' Cuts

Capital spending in the United States will decline by 7.6 percent in 1992. The largest falloff will be experienced by Japanese companies spending in the United States, from more than $400 million in 1991 to less than $200 million in 1992. This precipitous drop will be attributed to the completion of some major green-field projects by Japanese companies such as Fujitsu and NEC.

Spending by U.S. companies in the United States will be down slightly in 1992. Investment in new microprocessor lines by Intel, Digital Equipment Corporation, and Hewlett-Packard will prevent capital spending from decreasing steeply. Intel is building a new development line in Oregon and is converting its R&D line in Santa Clara, California to 200mm. There also are rumors that Intel has selected Austin, Texas as a site for a new green-field facility, on which construction will begin either at the end of the year or the beginning of 1993. Both Digital and HP are commercializing their RISC microprocessor technology and are investing in fabs to ramp device production.

Other new fab activity not in the MPU area includes National Semiconductor's expansion in Arlington, Texas and AT&T's new line in Orlando, Florida. IBM is also refurbishing buildings 222 and 223 in East Fishkill, New York.

Europe Expected to Decline through 1993

Capital spending in Europe is forecast to decline 11.9 percent in 1992 and sink another 7 percent in 1993. The bleak outlook for spending is based on steep cuts by European companies and cutbacks by Japanese companies that have recently completed a round of investment in new fabs. The situation would be much worse if it were not for the major projects being undertaken by IBM in France and Intel in Ireland. However, Intel will complete the lion's share of its spending in 1992, leaving only the IBM project as the main driver for spending in 1993. Consequently, we are expecting 1993 to be a down year as well. Dataquest is more optimistic from 1994 and beyond as we expect the European economy to begin benefiting from unification. Even so, the timing on this upturn is still very speculative.

Korean Companies Place Some Big Bets

Dataquest believes that the Asia/Pacific region will be the one bright spot in terms of semiconductor capital spending in 1992. We are forecasting that spending will leap ahead 23.5 percent. The Korean chaebols (conglomerates) will account for the bulk of that spending. Investment in Korean fabs is expected to climb to U.S.$1.8 billion in 1992.

In the short term, with excess worldwide DRAM capacity, the gamble for the Korean companies rests on the strength and timing of the recovery in the U.S. and European economies. If the Western economies have a strong recovery over the next several years, DRAM demand will grow quickly and the Korean companies may exit the recession with more market share than they had prior to the recession. Toshiba pursued a similar strategy in the 1985 recession with the 1Mb DRAM and was very successful. On the other hand, if the Western economies limp out

Table 2
1991 and 1992 Calendar Year Semiconductor Capital Spending Estimates (Merchant), Millions of U.S. Dollars, Top 10 Rankings

		1991 Rank	1991	1992 Rank	1992	Percentage Change
1	Intel	2	948.0	1	1,000.0	5.5
2	Fujitsu	1	1,147.2	2	769.6	-32.9
3	Samsung	8	530.0	3	730.0	37.7
4	NEC	4	752.2	4	654.2	-13.0
5	Toshiba	3	789.3	5	654.2	-17.1
6	Motorola	5	673.0	6	550.0	-18.3
7	Hitachi	7	646.0	7	500.3	-22.6
8	Mitsubishi	6	664.5	8	461.8	-30.5
9	Goldstar	11	410.0	9	380.0	-7.3
10	Sony	9	519.8	10	365.6	-29.7
11	Matsushita	10	462.6	11	344.8	-25.5

Source: Dataquest (August 1992)

of recession and there is only moderate growth in DRAM demand, then these investments are not expected to pay off financially.

There is a more fundamental problem for the chaebols over the longer term. History has shown that the health of a company's semiconductor operations cannot rest on merchant sales of devices alone. For companies involved in the production of commodity devices, a healthy semiconductor operation is increasingly dependent on captive operations using those devices.

Yet, Korean electronic products are losing their competitive edge. Increases in wages are driving up the prices of Korean electronic products, although their quality still lags behind high-end Japanese and U.S. products. On the low end, developing countries such as China and Thailand, with much lower labor costs, are grabbing market share.

Dataquest believes that Asian/Pacific investment will decline 4.7 percent in 1993 as the three large Korean companies complete the current round of investment in 4Mb and 16Mb lines. However, we expect the Asia/Pacific region to remain the fastest-growing region in terms of capital spending. Much of the growth in capital spending will occur outside of Korea, which now dominates the semiconductor industry in the region. As countries such as China and India develop, we believe that semiconductor production capability will be a key strategy in building their industrial infrastructure.

Dataquest Perspective

Capital spending growth rates are expected to decline from the double-digit compound annual growth rates of the late 1980s to single-digit growth over the next five years. The biggest change in spending levels will happen in Japan as companies adjust to a more restricted capital environment. U.S. spending, on the other hand, will benefit from the region's strong position in the microprocessor market, although we do not expect capital spending levels to achieve the growth rates of the past decade. European spending will remain in a downward spiral through 1993, though we expect unification to kick life back into this market toward the middle of the decade. And finally, the Asia/Pacific region is expected to remain the star performer in terms of spending, although we strongly believe that there will be a rotation away from the current countries that dominate the capital spending roster in this region.

By Rebecca Burr
Mark FitzGerald

Updated Device Production Forecast: Systems Key to U.S. Production Growth

Production in North America is expected to have a 9 percent compound annual growth rate (CAGR) through 1996 (see Table 1). The main driver will continue to be the PC/workstation market. Companies are continuing to invest in new fabs for advanced microprocessors. Telecommunication and especially networking are other themes that will be prominent in the growth of U.S. semiconductor production.

Foreign companies and especially Japanese semiconductor companies are expected to cut their level of investment in U.S. fabs over the forecast period. Therefore, U.S.-based companies will account for most of the growth in device production in the United States. Investment by Intel, IBM, Motorola, Texas Instruments, and Hewlett-Packard will drive device production growth.

Fabs Closures

Though the U.S. market is viewed as healthy, production growth rates over the forecast period will be well below historical levels for several reasons. First, we believe that the rate of fab closures will remain high. Nineteen fab lines in the United States were or are expected to close in 1991 and 1992. The United States has the oldest semiconductor manufacturing infrastructure and many of these facilities are becoming obsolete.

Second, the demand for military devices is forecast to decline because of Pentagon budget cuts that will accelerate through 1996. Already, companies such as Harris Semiconductor, Hughes, and McDonnell Douglas are downsizing their semiconductor operations to adjust to this new environment.

Finally, the economic growth rate for the United States is forecast to decelerate for most of the decade. The surge in borrowing over the last 10 years has strapped both consumer and business demand and is causing the economy to

Table 1
Worldwide Semiconductor Production Forecast by Region, Merchant and Captive Semiconductor Company Sales (Millions of U.S. Dollars)

	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
Total North America	25,103	27,695	31,136	34,542	36,063	38,592	9.0
Growth (%)	10.2	10.3	12.4	10.9	4.4	7.0	
Total (%)	39.8	41.9	41.1	40.3	39.5	39.3	
Merchant	22,460	25,170	28,704	32,142	33,663	36,192	10.0
Captive	2,643	2,525	2,432	2,400	2,400	2,400	-1.9
Total Japan	29,411	29,161	33,734	36,193	38,319	40,621	6.7
Growth (%)	11.5	-0.9	15.7	7.3	5.9	6.0	
Total (%)	46.7	44.2	44.5	42.2	42.0	41.4	
Merchant	29,121	28,946	33,500	35,943	38,069	40,371	6.8
Captive	290	215	234	250	250	250	-2.9
Total Europe	6,086	6,294	7,018	8,631	9,324	10,292	11.1
Growth (%)	-10.2	3.4	11.5	23.0	8.0	10.4	
Total (%)	9.7	9.5	9.3	10.1	10.2	10.5	
Merchant	5,677	5,915	6,613	8,180	8,812	9,784	11.5
Captive	409	379	405	451	512	508	4.4
Total Asia/Pacific-ROW	2,435	2,895	3,851	6,362	7,578	8,644	28.8
Growth (%)	10.2	18.9	33.1	65.2	19.1	14.1	
Total (%)		3.9	4.4	5.1	7.4	8.3	8.8
Merchant	2,435	2,895	3,851	6,362	7,578	8,644	28.8
Captive	NA	NA	NA	NA	NA	NA	
Worldwide	63,036	66,044	75,739	85,728	91,284	98,149	9.3
Merchant	59,694	62,925	72,668	82,627	88,122	94,991	9.7
Growth (%)	9.4	5.4	15.5	13.7	6.7	7.8	
Captive	3,342	3,119	3,071	3,101	3,162	3,158	-1.1
Growth (%)	-7.4	-6.7	-1.5	1.0	2.0	-0.1	

NA = Not applicable
Source: Dataquest (August 1992)

grow at a slower rate. A wild card in our economic analysis is the upside potential of the South American market.

Japan Searches for a New Strategy

Dataquest expects semiconductor production in Japan to decelerate during the next five years. Semiconductor factory revenue spurted 14.9 percent CAGR from 1986 to 1991. We believe that growth will slow to 6.7 percent CAGR during the next five years.

Trade Problems

We expect trade friction caused by mounting trade deficits to aggravate the already weak export picture for semiconductor production. Because Japan is a net exporter of devices, the mounting trade deficits with the United States and especially Europe are reigniting the call for protectionist measures. It is possible that this problem will haunt the Japanese semiconductor industry well past 1992 and cause slower growth in production once the general economy improves.

What Follows DRAMS?

There is some risk that the downturn in production is the beginning of a structural change in the Japanese semiconductor industry. Early in the last decade, Japanese companies made a conscious decision to pursue the commodity memory market, a strategy that proved very successful because of the PC boom and U.S. companies' abdication of the memory market.

Currently, 45 percent of Japan's semiconductor capacity is dedicated to MOS memory. However, the Achilles heel of this strategy is becoming apparent. Squeezed from below by low-cost Asian memory producers and from above by the increasingly fragmented application-specific nature of the MOS microcomponents and MOS logic makers in the United States, Japanese device companies are scrambling for a strategy. Complicating their dilemma is the slower adoption of the advanced memory products in end-use applications. These problems threaten the long-term growth of Japanese production and consequently we have lowered our five-year forecast for semiconductor production.

Cut in European Production

Dataquest has cut back its European semiconductor production forecast. Our current five-year CAGR is 11.1 percent verses our previous forecast of 13.3 percent in November 1991.

Last year proved to be a pivotal juncture for the European semiconductor industry. Many economies in the region slowed or went into recession, dragging the semiconductor industry down. The hairline cracks in EC 1992 opened up, exposing some of the major problems facing a unified European market. Also, the true costs, both in political and economic terms, of raising living standards in Eastern Europe became apparent, and it is now evident that these costs will crowd out investment in other areas of the economy. As a result, we have cut our forecast for semiconductor production.

Foreign Investment Slows

The prospects of a unified Europe in 1992 appear now to provide little incentive for many foreign device makers. Companies such as Mitsubishi, Toshiba, and Samsung that had planned fab investment in Europe are delaying or canceling their plans. Other companies with facilities in Europe are delaying expansion plans: TI's expansion at Avezzano, Italy is on hold; NEC will hold off expanding in Europe until its Roseville, California fab is completed; and Fujitsu has pushed out plans for its second phase at its fab in England.

Foreign device makers emphasize that the main problem with locating operations in Europe is the high cost of doing business. In the current climate, in which many device companies are unprofitable and spending budgets have been slashed, the cost of manufacturing in Europe is outweighing the political inducements. Dataquest expects this to remain a major hurdle for the European market over the forecast time horizon.

Domestic European Companies Pull Back

Furthermore, our lower forecast for semiconductor production reflects the poor performance of domestic European companies, which account for the lion's share of production in Europe. European companies continue to lag in the development of semiconductor manufacturing and process technology. Consequently, they are finding it increasingly difficult to make the spiraling investments required to develop and stay in the manufacturing game.

The three largest European companies all have cut spending and/or closed fabs in the last year. Siemens has closed three lines and cut spending, Philips has slashed capital spending and closed several lines, and SGS-Thomson's semiconductor operation is being propped up by the French government, which is quickly losing its patience with the company.

In addition, other non-European companies have closed lines, further dampening the growth in production. Siliconix shut one line in Wales and LSI Logic also closed a line England.

Asia\Pacific-Rest of World Device Production Will Boom

Semiconductor production in Asia/Pacific is expected to pick up in 1992, benefiting from the stronger demand in the United States for semiconductors. We are estimating that Asia/Pacific production will grow 18.9 percent in 1992 and accelerate through 1994. Our five-year CAGR for production in the region is 28.8 percent.

The economies of the countries in the Asia/Pacific region are the fastest growing in the world. We believe that a vibrant semiconductor industry will be the key factor in building many of these countries' industrial infrastructures.

Capital investment in fabs in the region continues at a breakneck pace. The lion's share of the current capital spending on new fabs is taking place in Korea. This spending trend will benefit device production over the next several years as these facilities ramp-up.

Over the long term, the real star performer in terms of growth in device production will be the group of countries which fall under the rubric rest of world (ROW). Countries that will benefit from this growth are Hong Kong, Singapore, China, and newly industrializing Pacific Rim nations such as Thailand and Malaysia. Much of the growth in the ROW category will be fueled by investment and technology transfers from Japanese and to a lesser extent U.S.-based companies.

Dataquest Perspective

The Asia/Pacific region remains the most vibrant in terms of growth rates for IC production. However, we do expect some rotation away from the current leaders within the region to those countries that are just beginning to build their industrial infrastructure. The ultimate growth opportunities will be China and India because of the sheer size of the markets. But political turmoil, fragile legal systems, and underdeveloped infrastructures make the timing of these opportunities difficult to gage.

By Mark FitzGerald

Semiconductor Equipment

Wafer Fab Equipment Forecast: 1992 Market Decline Followed by Modest Growth

The go-for-broke capital spending spree of the late 1980s has left excess capacity hanging like a dark cloud over the semiconductor industry. A 2 percent decline in wafer fab equipment spending in 1990, followed by only 3 percent growth in 1991, clearly reflected the beginning of a capital spending slowdown. This year, however, many semiconductor manufacturers have slammed on the brakes and cut capital investment to such an extent that on a worldwide basis we anticipate a 10 percent decline in wafer fab equipment demand.

Dataquest evaluates its five-year forecast for wafer fabrication equipment demand about every six months. The midyear forecast outlook presented here does not substantially differ from that published at the end of 1991, at which time we anticipated an 8 percent decline in 1992 wafer fab equipment demand. As compared with our November 1991 forecast, we have moderated our expectations for growth in 1993 and 1994 downward by several percentage points. This modification is in response to our decidedly conservative position on the industry, which we believe will continue to suffer from the problems of excess submicron capacity and weak global macroeconomic conditions.

Assumptions behind Our Forecast

In our November 1991 forecast for wafer fabrication equipment, we presented four assumptions that constituted the foundation of our five-year equipment forecast. Those assumptions are reviewed in the following paragraphs.

Macroeconomic Assumptions

Our assumptions today regarding global macroeconomic conditions remain consistent with our view six months ago. The global economy is clearly weaker in 1992 than it was in 1991. The Japanese and German economies are decelerating, the U.K. economy continues to have difficulties shaking off its recession, and the U.S. economy has entered a period of very weak recovery. Both the Japanese and European economies are expected to pick up in 1993, but we believe that, as in the U.S. economy, these recoveries will be modest. We expect all major regions of the world to return to healthy GNP growth in the 1994 through 1996 time frame.

Shifts in the Semiconductor Device Product Mix

Dataquest is forecasting that the combined MOS micro and MOS logic categories in the device revenue product mix will continue to increase as a percentage of the total market. MOS micro, the fastest-growing segment of the worldwide IC market, is being driven increasingly by system-on-a-chip ultralarge-scale integration (ULSI) trends and the adoption of application-specific standard product chip set solutions for many end-use markets. The high value-added, design-intensive nature of certain MOS micro segments, such as microprocessors and microperipherals, translates to higher average selling prices (ASPs) and lower unit volumes relative to the DRAM market. We do note that recent competitive market forces in the microprocessor arena are driving prices down. However, microprocessors have yet to achieve the status of commodity pricing that characterizes the DRAM marketplace.

Programmable logic devices, a subset of MOS logic, are similar to microcomponents in that they also represent high value-added, low-volume manufacturing, which requires proportionately less wafer fab equipment than DRAMs. Shifts in the semiconductor device product mix toward MOS micro and MOS logic segments characterized by high value-added, low-volume manufacturing will contribute to lower fabrication equipment unit demand and thus deceleration in the long-term growth rate for the wafer fab equipment market.

Escalating Cost of Process Development and Advanced Manufacturing

We believe that our premise still holds true that the rising cost of advanced technology is driving a number of semiconductor companies to pursue joint-development and/or manufacturing pacts as a strategy to control both the costs and risks associated with advanced technology development. We believe that such joint-development and manufacturing strategies and shared foundry facilities between semiconductor manufacturers will contribute to a smaller number of megafabs being built in the future.

Increased Wafer Fab Equipment Productivity

We maintain our position that wafer fab equipment will continue to get more expensive, reflecting the increasingly sophisticated technical requirements of advanced submicron manufacturing. In response to demands from semiconductor manufacturers for increased equipment productivity to offset higher equipment prices, wafer fab equipment companies will continue to aggressively compete on equipment cost of ownership. Increased equipment productivity will contribute to overall lower equipment unit demand. For example, the newer models of steppers have significantly improved wafer throughput as compared with tools available several years ago. Stepper manufacturers today offer leading-edge machines with throughput on the order of 60 wafers per hour, with some tools achieving 80-plus wafer-per-hour processing capability. This improvement in productivity has a direct impact of stepper unit demand and is a key consideration in our forecast for steppers over the next five years.

For the reasons cited, revenue growth in the wafer fab equipment market primarily will reflect escalating ASPs of advanced equipment technology. For a number of wafer fab equipment categories, unit demand in 1996 is expected to be essentially flat relative to shipment levels in 1991.

Wafer Fab Equipment Markets

Table 1 presents Dataquest's five-year historical estimates and forecast for wafer fabrication equipment by segment. As the semiconductor industry continues to push into the submicron era, process complexity and fabrication technology requirements continue to increase dramatically. Lithography, deposition, and etch/clean equipment continue to be the technology drivers that fuel the wafer fabrication equipment industry's growth.

Dataquest anticipates i-line technology to dominate the stepper product mix for new system shipments between 1991 and 1996. I-line will be the stepper technology of choice as advanced microprocessor and ASIC designs push below 0.8-micron geometries. Advanced resolution techniques, such as phase shift masks and newly announced illumination modification techniques, push i-line resolution to the 0.35-micron regime with improved depth of focus. Although such techniques are suited only for highly repetitive device patterns such as memory products, conventional i-line lens systems are available that provide sub-0.5-micron lithographic capability regardless of the device pattern being printed. We expect excimer/deep-UV systems to continue to gradually increase as a percentage of new stepper shipments over the forecast period as device manufacturers pursue research and development programs for 64Mb and 256Mb DRAM processing.

Table 1
Worldwide Wafer Fab Equipment Market Forecast, 1991-1996
(Millions of U.S. Dollars)

	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
World Fab Equipment Market	6,040	5,431	6,036	7,145	8,218	9,354	9.1
Lithography							
Contact/Proximity	21	17	16	15	14	13	-9.0
Projection	68	55	57	62	67	75	1.9
Steppers	1,029	925	1,035	1,200	1,380	1,580	9.0
Maskmaking Lithography	46	51	63	76	91	101	17.1
Direct-Write Lithography	55	59	69	86	97	109	14.5
X-Ray	4	10	20	38	53	70	75.5
Total	1,224	1,117	1,260	1,477	1,702	1,948	9.7
Automatic Photoresist Processing Equipment	369	330	363	430	490	569	9.1
Etch and Clean							
Wet Process	405	355	390	465	530	600	8.2
Dry Strip	119	105	115	135	155	180	8.6
Dry Etch	705	640	710	850	990	1,125	9.8
Ion Milling	17	14	16	17	19	20	3.7
Total	1,246	1,114	1,231	1,467	1,694	1,925	9.1
Deposition							
Chemical Vapor Deposition	747	680	755	900	1,045	1,190	9.7
Physical Vapor Deposition	474	450	495	585	680	780	10.5
Silicon Epitaxy	89	60	53	68	60	63	-6.6
Metalorganic CVD	51	45	50	60	67	70	6.4
Molecular Beam Epitaxy	59	52	57	63	67	71	3.8
Total	1,420	1,287	1,410	1,676	1,919	2,174	8.9
Diffusion	335	288	325	380	445	510	8.8
Rapid Thermal Processing	42	40	48	58	74	85	15.3
Ion Implantation							
Medium Current	108	92	106	126	146	161	8.4
High Current	218	189	216	265	303	332	8.8
High Voltage	18	22	35	43	48	56	26.0
Total	343	303	357	434	497	549	9.9
Process Control							
CD (Optical and SEM)	154	135	146	172	198	229	8.3
Wafer Inspection	90	82	91	106	124	140	9.3
Other Process Control	398	365	400	475	540	600	8.6
Total	641	582	637	753	862	969	8.6
Factory Automation	227	200	220	255	290	345	8.7
Other Equipment	193	170	185	215	245	280	7.7
Total World Fab Equipment	6,040	5,431	6,036	7,145	8,218	9,354	9.1
Percent Change	3	-10	11	18	15	14	

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (August 1992)

The adoption of double-level metal technology for the 16Mb DRAM generation, together with the rapid move toward triple- and even four-level metal for MOS microprocessor and ASIC devices will continue to push the CVD, PVD, and dry etch thin films market to outperform the overall wafer fab equipment market. The dry etch equipment market will experience healthy growth because of the triple factors of increased dry etch process steps, complex new plasma source technologies, and rapid ASP increase because of the need for tighter process control at sub-0.5 micron geometries.

In addition to the well-established low temperature, plasma-enhanced CVD reactor market, the thermal CVD market (including metal CVD and thermally driven atmospheric and low-pressure CVD) will experience healthy growth over the next five years because of the continuing need for planarized device topology. New organic CVD precursor sources will lead to precisely tailored metal and dielectric CVD films that exactly satisfy specific device topology requirements. Concurrently, new advances in PVD technology such as advanced barrier metallization, laser reflow, and planarization of sputtered aluminum will lend impetus to growth in the PVD market. Sputter equipment continues to offer excellent step coverage capability at a very attractive cost of ownership.

Dataquest Perspective

Opportunities in Asia/Pacific

One significant trend we expect for the wafer fab equipment industry over the next five years will be the growth in the semiconductor manufacturing base in Asia/Pacific. Dataquest's capital spending estimates for 1991 show that Asia/Pacific represented about 12 percent of total worldwide capital spending. We are forecasting that in 1996 this region of the world will represent 22 percent of semiconductor capital investment and will gain its share of the capital spending pie at the expense of all other regions. This significant increase in capital spending activity in Asia/Pacific will translate to a substantially larger portion of worldwide wafer fab equipment expenditure in the future.

Asia/Pacific represents a significant market opportunity for wafer fabrication equipment companies because the barriers to entry for doing business in this regional market are fairly low. The cost structure for establishing local operations and providing service and support personnel is lower than in other regions of the world. U.S. and European companies benefit from close historical ties to the countries of Asia/Pacific, and English is widely spoken throughout the region.

Japanese wafer fab equipment companies have already aggressively targeted the Asia/Pacific region, and in 1991 they garnered an increase in regional market share of more than 10 percentage points. Several factors are behind their successful market penetration, including the relative proximity of Japanese companies to fabs in Asia/Pacific, their advanced technology product offerings focused on high-volume manufacturing, and the significant emphasis that Japanese vendors place on customer support. These factors have allowed Japanese equipment companies to expand their presence from a mere 10 percent share of the Asia/Pacific market in 1982 to more than 50 percent share last year.

Although some larger companies, such as Applied Materials, Lam, and Varian, have already established a direct presence in Asia/Pacific, many smaller wafer fab equipment companies use representatives and distributors to sell and support their products. We believe that more and more wafer fab equipment companies will need to have a local presence in order to stay close to their customers and effectively compete in this high-growth regional market.

By Peggy Marie Wood

The Regional Economic Outlook for Our Forecast

North America

The North American economy is moving into a an extended period of slow growth following the heated expansion of the 1980s. We believe that the recovery will be subpar when compared with previous recoveries. U.S. Gross Domestic Product (GDP) is not expected to grow much higher than 2.6 percent between 1992 and 1996.

The main factor preventing more robust growth is the forecasted weak rebound in real income. The problems with income are attributable to lingering consumer and business debt overhang, weak productivity growth, high levels of business failures, weak demographic demand for housing, and the lack of fiscal stimulus. With unit consumer spending having a less than normal recovery, the rebound in industrial production is also certain to fall short of normal historic cyclical proportions.

Though internal demand will be moderate, we believe that the export picture will continue to improve. Latin America is expected to become a key driver for the U.S. high-technology sector. Exports to these countries have almost doubled over the last two years. If the North American Free Trade Agreement is passed later this year, Mexico could easily exceed Japan as the second-largest customer of the United States by 1994.

The continued growth of exports is contingent on companies' abilities to invest in new plants and equipment. The U.S. Federal Reserve's easing monetary policies are helping. We believe that the Fed can maintain an accommodating policy through the first half of 1993. There will likely be a moderate firming of interest rates in the second half of 1993 as the economy picks up speed.

However, the federal budget deficit, which is expected to widen to about 6 percent of gross domestic product, threatens to crowd out private investment. The budget deficit continues to deteriorate and the U.S. Government's claim on the savings of the country continue to rise. We are assuming that Washington will take measures to arrest the growth of the deficit over the next several years, though such an assumption has proved overly optimistic to date.

Japan

The Japanese economy is undergoing a fundamental shift. Very strong growth in the money supply during the second half of the 1980s fueled an unprecedented capital spending binge. Capital spending for all industries as a percent of gross national product (GNP) peaked in 1989 at 23.5 percent, which is unparalleled when compared with any other period in post-World War II history.

Dataquest believes that the rate of GDP growth will decelerate over the next five years and drop to 2 percent in 1992. We are forecasting a moderate rate of growth in GDP over the next five years, rising to 4 percent by 1995. However, these growth rates will be well below the 5 to 6 percent range of GDP growth experienced in the latter half of the 1980s.

Perhaps, the biggest problem facing Japanese electronic manufacturers is the unwinding of the Japanese financial machine that funded the years of growth. Asset deflation has hit the Japanese banking sector hard. The bank's capital base has declined because of the fall in stock prices. At the same time, declining land prices are eroding the collateral for outstanding loans. As a result, banks have turned cautious on lending. It is a cycle that could take a long time to work out.

Though the financial problems add a great deal of downside uncertainty to our forecast, other indicators point to a stronger outcome. Inflation is well under control and will allow real disposable income to expand. Consequently, the Japanese consumer will remain a strong link in the economy.

Also, the recovery in the United States and the continued expansion of the Pacific Rim countries is a good sign for Japanese exports. We expect large trade and current account surpluses to continue in Japan. This trend is a doubled-edged sword. In the short term, exports for Japanese industry will deaden the impact of decreasing industrial production. However, the growing surpluses over the long term will add to trade friction problems.

The current environment is difficult for the Japanese economy. It is very likely that the banks have not faced up to all their problems and therefore the financial uncertainties are very high. Capital spending, which has been the main economic engine for the economy, will certainly not snap back. But external surpluses and domestic consumption should enable Japanese GNP to continue growing at moderate levels.

Europe

The European economy, driven largely by Germany, will see weak growth in 1992. We expect GDP in Germany to grow only 1.1 percent in 1992. Despite negative growth last year, growth in the United Kingdom will be 5.5 percent, while growth in France will be 2.1 percent.

Germany, the main engine for the European economy, continues to struggle with problems associated with unification. Inflation is stuck in the 4.5 percent range, forcing the Bundesbank to hold the line on interest rates. Because the other European currencies are tied to the deutsche mark, interest rates throughout Europe remain stubbornly high. We do not believe that rates will begin edging downward until 1993.

Wages in eastern Germany will converge to western Germany's standards by 1995. Consequently, we expect that the ability of German companies to compete will deteriorate because productivity gains will not keep up with cost increases.

In the United Kingdom, evidence of a post-election recovery is still very thin. Inflation is subsiding. We do not believe that inflation will be much of a problem for the foreseeable future. Even with the gains on inflation, interest rates remain high. We do expect a significant move lower next year, assuming that German short rates are by then falling. The main problem for the United Kingdom is the deteriorating trade figures, fueled by the increase in domestic demand as the economy emerges from recession.

France avoided recession in 1991 and is moderately improving in 1992. The moderate recovery expected among its European trading partners and a strengthening competitive position vis-a-vis these partners will improve the export picture. But an upturn in domestic demand will most likely be slower coming because the pace of job creation is weak. A fiscal stimulus is unlikely because the government continues to target a lower budget deficit.

Over the long term, we are forecasting moderate growth for Western European countries. The Central and Northern countries are expected to grow in the 2 to 3 percent range. Portugal and Spain, which are less developed than most of their Western European neighbors, are forecast to grow slightly faster, in the 3 to 4 percent range. We believe that Eastern Europe will not have much of an impact on Western European GDP growth until the second half of the 1990s.

Asia/Pacific

Most economists continue to forecast the fastest growth in the world for the Asia/Pacific region. We believe that annual GDP growth rates over the next five years will range from 5 percent to 8 percent for Hong Kong, Indonesia, Malaysia, Singapore, South Korea, Taiwan, and Thailand. Moreover, underdeveloped countries such as the People's Republic of China, India, and Vietnam will increasingly boost the economic activity of the Pacific basin as the decade wears on.

In 1991, many of the Pacific basin countries suffered from slow worldwide growth because the health of their economies is tied so closely to exports. Countries such as Korea and Singapore, which are heavily dependent on sales to the West, experienced a deceleration in GDP growth because of the slow U.S. and European economies.

But Taiwan's economy was more resilient. It benefited from strong exports to trading partners in Southeast Asia and China, which were not affected by the recession in the West. We believe that the intraregional trade theme is a trend that will increasingly impact not only Taiwan's economy but also the economies of other industrializing countries in the region.

The only dark cloud on the horizon is the threat of a slower rate of investment by Japanese companies because of the financial problems at home. If the Japanese banking system were to stumble, then the flow of investment to the Pacific basin would certainly suffer. But this downside has a low probability.

By Mark FitzGerald

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Dataquest Perspective

Semiconductor Equipment, Manufacturing, and Materials

SEMM-SVC-DP-9210 August 3, 1992

In This Issue...

In this issue of Dataquest Perspective, we continue our special coverage and discussion of the general trends in the wafer fab equipment market and those specific issues that characterize the market for the major segments of wafer fabrication equipment.

Market Analysis

Semiconductor Equipment

Wet Processing Sales Stall in 1991: 1991 Wet Process Equipment Market in Review

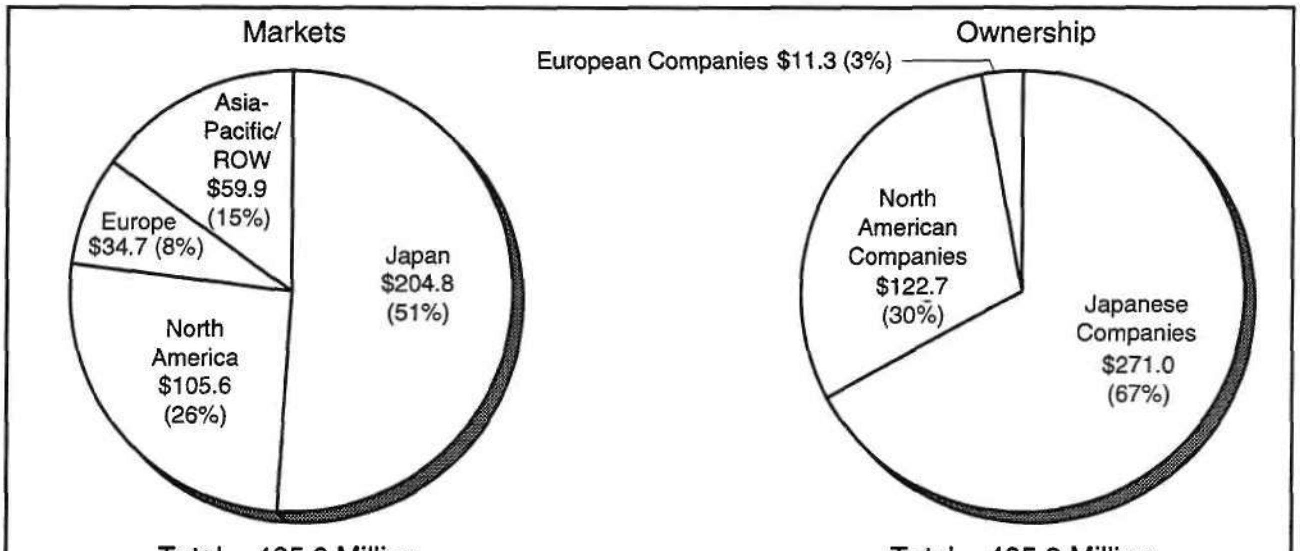
The worldwide wet process equipment market was $405 million in 1991, essentially flat with respect to its level the prior year. This section presents the significant highlights of the 1991 wet process equipment market with a focus on new technology trends and company activities.

Regional Markets and Ownership

Figure 1 shows the worldwide 1991 wet process equipment market segmented by region and ownership. Japan, with 51 percent ($205 million), continued to represent the largest wet process equipment market, though spending in Japan for wet process equipment last year declined sharply by 17 percent from its 1990 level of $246 million. The Japan wet process equipment market was active in the first half of 1991 because of a large backlog of orders from the prior year coupled with long lead times, on the order of six to eight months. However, a drastic reduction in shipments of wet process systems in the second half of the year led to the precipitous decline in wet process equipment sales in Japan for the year as a whole.

The North American market for wet process grew a record 41 percent from $75 million in 1990 to almost $106 million in 1991. The tremendous growth in North American sales is largely attributable to increased spending on integrated wet systems. U.S. device makers are beginning to aggressively adopt the more expensive automated wet systems though automated systems still lag the degree of penetration achieved in Japan.

Figure 1
1991 Wet Process Equipment, Regional Markets and Ownership



Source: Dataquest (August 1992)

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Company Rankings

Table 1 presents the worldwide company rankings for the wet process equipment market. Company revenue for wet process equipment is further segmented into the categories of integrated wet systems, manual wet benches, rinser/dryers, acid processors, and megasonic cleaners.

1991 Market Highlights

Carrierless Wet Stations

One significant trend in the wet processing equipment arena has been development of carrierless wet stations. A carrierless system removes the wafers from the cassette prior to processing. In 1991, 200mm carrierless wet stations for 16Mb DRAM applications were introduced by many equipment manufacturers: Dainippon Screen, Dan Science, Fuji Electric, Kuwano, Shimada, SubMicron Systems, and Sugai. One feature offered by all the carrierless systems is the elimination of chemical carryover and wafer contamination associated with the carrier. This makes these wet stations the most advanced cleaning systems available to satisfy the strict specifications that must be achieved in 16Mb DRAM processing.

The 200mm carrierless system has the same footprint as the corresponding 150mm wet station system with carriers, and thus achieves a very compact size even while processing the larger-diameter wafers. Another advantage of the carrierless systems is a significant reduction of chemical consumption. Table 2 summarizes several of the key features of 200mm carrierless wet stations compared with conventional 200mm systems. The price of carrierless wet stations in Japan ranges from ¥100 million to ¥200 million ($770,000 to $1.5 million). In addition to the companies identified, Sankyo Engineering is developing a carrierless system.

Tokyo Electron Enters the Wet Process Market

Historically, Tokyo Electron's (TEL) activity in the wet process market has been confined to the marketing of Semitool's acid processors and Sugai's wet stations. Strong growth in the wet processing equipment market (24.8 percent CAGR between 1987 and 1991), however, encouraged TEL to terminate its marketing agreement with Sugai and to build its own manufacturing facility. Wet processing equipment product offerings further establish TEL as one of the few players in the industry to provide one-stop shopping with a broad and diverse product mix of wafer fabrication equipment.

In addition to its desire to explore new market opportunities, there are several other key reasons

Table 1
1991 Worldwide Wet Process Equipment Company Ranking (Millions of Dollars)

Companies	Revenue	Share (%)	Integrated Wet Stations	Manual Wet Benches	Rinsers/ Dryers	Acid Processors	Megasonic Cleaners
Dainippon Screen	66.5	16.4	40.9	0	0	11.5	14.1
Kaijo	33.1	8.2	29.9	0	0.9	0	2.3
Sankyo Engineering	32.7	8.1	27.4	2.6	2.7	0	0
Sugai	32.6	8.0	31.4	1.2	0	0	0
FSI International	21.8	5.4	0	0	3.7	16.8	1.3
Santa Clara Plastics	20.2	5.0	19.5	0.7	0	0	0
Dan Science	19.8	4.9	14.9	4.4	0.5	0	0
Shimada	18.6	4.6	13.4	0	0	0	5.2
Maruwa	15.0	3.7	8.1	6.9	0	0	0
Verteq	14.9	3.7	1.7	0	6.0	0	7.2
Semitool	12.1	3.0	0	0	9.4	2.7	0
Submicron Systems Inc.	12.0	3.0	12.0	0	0	0	0
Enya	11.6	2.9	10.7	0.9	0	0	0
ETE	10.9	2.7	10.4	0.5	0	0	0
Universal Plastics	9.1	2.2	5.5	3.6	0	0	0
S&K Products	8.2	2.0	0	0	7.2	0	1.0
Pocorny	7.8	1.9	6.6	1.2	0	0	0
Toho Kasei	7.1	1.8	5.2	1.2	0.7	0	0
Kuwano Electric	7.1	1.8	7.1	0	0	0	0
Semifab	6.5	1.6	3.0	3.5	0	0	0
Tokyo Electron	5.6	1.4	5.6	0	0	0	0
Musashi	5.5	1.4	4.1	0.7	0	0.7	0
CFM Technology	5.3	1.3	5.3	0	0	0	0
SCI Manufacturing	4.8	1.2	4.8	0	0	0	0
Sapi Equipments	3.5	0.9	2.0	1.5	0	0	0
Advantage Production	3.4	0.8	0	0	0	3.4	0
Fuji Electric	2.1	0.5	2.1	0	0	0	0
Others	7.2	1.8	3.3	0.9	0.2	2.8	0
Total	405.0	100.0	274.9	29.8	31.3	37.9	31.1
Percentage of Total	100		68	7	8	9	8

Note: No revenue associated with spares and service included
Source: Dataquest (August 1992)

for TEL entering the wet process equipment. Dataquest believes that TEL may have sensed a technological limitation in Sugai's wet station capabilities for production of 16Mb and more advanced DRAMs. In addition, TEL has the second-largest share in the world vertical thermal reactor (VTR) market, and it is key that the company develop its own prediffusion clean system to be used in-line with its VTR products. The impact of TEL's decision to terminate its relationship with Sugai is already becoming apparent. With the loss of its major distributor, Sugai slipped from second place in the 1990 worldwide wet process equipment market to fourth position in 1991.

FSI Enters the Japan Market

FSI International, a major supplier of wet processing equipment, recently entered the Japanese market through an alliance with Mitsui Corporation. The new entity formed from this alliance is named m·FSI. Under this arrangement, Mitsui's subsidiary, Chlorine Engineering, becomes one

Table 2
Relative Comparison of Key Features for Conventional and Carrierless 200mm Wet Stations

	Conventional 200mm System	Carrierless 200mm System
Wafers per Batch	50	50
Footprint	1.00	0.70
Chemical Tank Capacity	1.00	0.53
QDR* Tank Capacity	1.00	0.68
Transportation Time between Baths	1.00	0.45

*QDR = Quick Dumper Rinse
Source: Dataquest (August 1992)

Table 3
New Planned Manufacturing Facilities for Wet Process Equipment Suppliers

Companies	New Plant Location	Completion Date	Land (sq. m)	Floor Space (sq. m)
Dainippon Screen	Shiga	Q4/92	26,200	19,900
Dan Science	Tokyo	Q3/92	3,518	4,196
Sankyo Engineering	Oita	Q2/91	8,440	2,877
Shimada	Shizuoka	Q3/92	7,410	NA
Tokyo Electron	Saga	Q3/92	104,482	13,100

NA = Not available
Source: Dataquest (August 1992)

division of m·FSI and will continue to market ozone ashers for photoresist stripping applications. The joint venture also plans to manufacture and distribute FSI's surface conditioning products in Japan.

FSI is a leading manufacturer of hydrofluoric (HF) acid vapor phase cleaning systems. These systems are particularly effective in preventing organic as well as inorganic contaminants and particles from depositing on an activated silicon surface. The main application for vapor phase cleaning is the removal of native oxide. FSI's entry to the Japanese market, the major DRAM production base, is a key strategic move for the company because the removal of native oxide becomes critical as the oxide film becomes thinner in advanced DRAM fabrication. Dataquest believes that future vapor phase systems will be clustered with CVD equipment. However, current equipment is designed to carry out the rinsing/drying process under an atmosphere of nitrogen gas.

Megasonic Cleaner Market Experiences High Growth

As design rules enter into a submicron level, the allowance for the depth of focus has reduced, thus increasing the need for removing particles on both sides of silicon wafers by mechanical means. This has driven the megasonic cleaner market, especially scrubber systems, to grow at an accelerated pace the last five years from a $4 million level in 1987 to $31 million in 1991, reflecting compound annual growth exceeding 60 percent.

Expansion of Equipment Suppliers

Rapid growth of the wet process equipment market coupled with increasing system complexity has caused the production capability of wet process equipment suppliers to fall short of demand. Dataquest believes that many suppliers had to give up orders during 1989 and 1990 because of capacity shortages in their own facilities. As shown in Table 3, several manufacturers have rushed to build new facilities in order to attain sufficient capacity to meet the demands of semiconductor manufacturers.

Dataquest Perspective

Although today's current carrierless wet processing systems are suited for the 0.5-micron process for 16Mb DRAM production, 64Mb DRAM production with line geometries of

0.3 microns will require the control of 0.03-micron particles. The control and cleaning of 0.3-micron particles is further complicated by the fact that the number of particles increases by geometrical progression inversely proportional to the particle size. Furthermore, the smaller the particle size, the stronger the particle's adherence to the wafer surface, thus making it more difficult to remove. Contact holes of 0.3-micron size have a high aspect ratio and thus will also require a more sophisticated cleaning process. As gate oxide and capacitor dielectric films become thinner (below 10nm), native oxide films will need to be removed completely. Because a limited number of existing wet process manufacturers provide such advanced cleaning technologies, Dataquest expects the wet processing equipment industry to rapidly migrate toward clearer product differentiation.

By *Kunio Achiwa*
Mark FitzGerald

New Players, New Products in Advanced Defect Inspection: 1991 Wafer Inspection Equipment Market in Review

The wafer inspection equipment market was $90 million in 1991, essentially flat when compared with its 1990 level of $91 million. The two segments of the wafer inspection equipment market—microscope-based stations and automated defect inspection tools—experienced only moderately different market dynamics last year. Microscope-based station revenue grew a modest 4 percent to reach $33 million, while the market for advanced defect inspection stations declined 4 percent from its 1990 level to total about $56 million last year.

Regional Markets and Ownership

Figure 1 presents the worldwide 1991 wafer inspection equipment market segmented by region and ownership. As in other major categories of front-end wafer fab equipment, Japan dominated the market, accounting for 46 percent of worldwide demand. It is interesting to note, however, that semiconductor manufacturers in North America and Europe spent proportionately more on wafer inspection equipment as a percentage than is reflected by their total wafer fab equipment expenditure. For example, North America accounted for only 25 percent of the worldwide wafer fab equipment market but represented 30 percent of the wafer inspection equipment market. Similarly, the wafer fab equipment market in Europe represented only 11 percent of the world market, but semiconductor manufacturers in this region purchased 17 percent of the worldwide demand for wafer inspection equipment. One reason behind this seeming anomaly in spending patterns is that advanced defect inspection systems (which have a significantly higher average selling price than microscope stations) in both North America and Europe represent a substantially larger portion of the wafer inspection equipment product mix.

In 1991, we observed a significant gain in regional company share for one group of suppliers. Japanese companies accounted for 42 percent of the worldwide market last year, compared with only 25 percent in 1990. The increase in Japanese company share was mirrored by a decrease of similar magnitude for North America. European company share in 1991 was 13 percent, relatively constant as compared with the prior year. The gain in Japanese share mirrored by a drop in North American company share can be explained in large part by examining what happened in the advanced defect inspection arena. Hitachi, a new supplier of advanced defect inspection tools, entered the market with its new WI-870 system and shipped a number of units its first year. At the same time, North American suppliers of advanced defect inspection equipment—Insystems and KLA Instruments—were still experiencing the effects of overall sluggish market demand. These two companies spent much of their efforts in 1991 developing new tool technology or ramping up their manufacturing capability for new equipment product offerings.

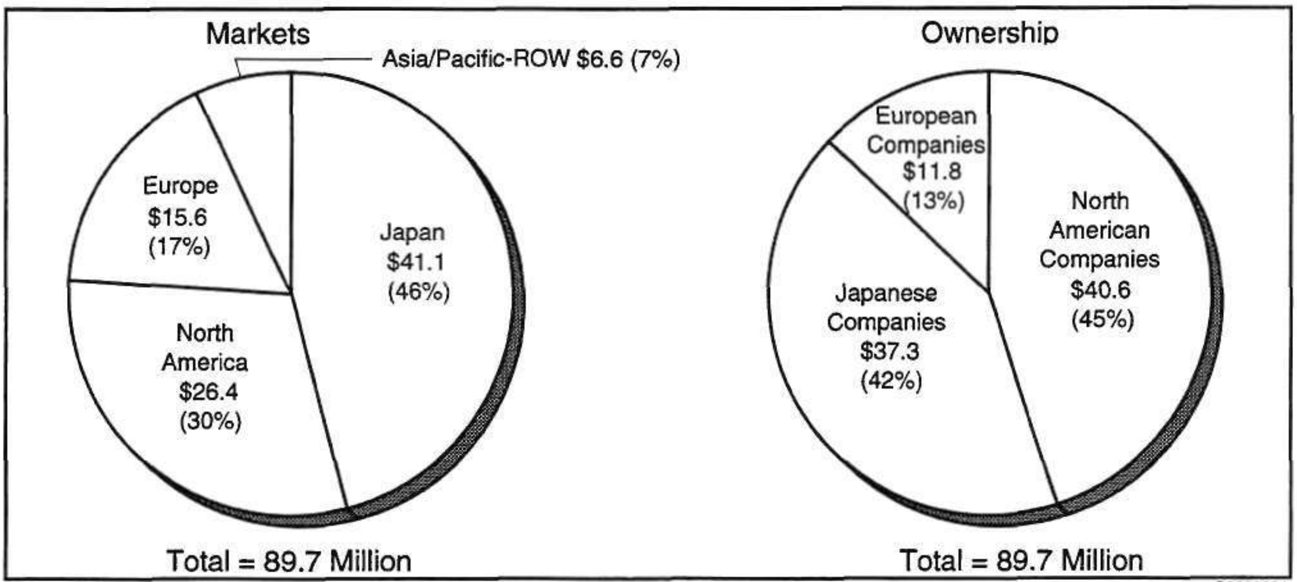
Company Rankings

Table 1 presents the worldwide company rankings for the wafer inspection equipment market in 1991, together with the market segment activities.

KLA Instruments

KLA Instruments continued to maintain its No. 1 position in the wafer inspection equipment market last year through sales of advanced defect inspection systems totaling $26.4 million. The company's share of the market, however, has been steadily declining the last several years. In 1989, KLA commanded 49 percent share of the worldwide market, but by last year that position had eroded to only 29.4 percent share.

Figure 1
1991 Wafer Equipment Inspection, Regional Markets and Ownership



Source: Dataquest (August 1992)

Table 1
1991 Worldwide Wafer Inspection Equipment Company Rankings (Millions of Dollars)

Company	Revenue	% Share	Advanced Defect Inspection	Microscope-Based Stations
KLA Instruments	26.4	29.4	X	
Nikon	13.1	14.6		X
Insystems	13.0	14.5	X	
Hitachi	11.6	12.9	X	
Nidek	7.1	7.9		X
Nano-Master*	5.4	6.0	X	
Leica	4.9	5.5		X
Canon	4.4	4.9		X
Others	3.8	4.2		X
Total	89.7	100.0	56.4	33.3

*Formerly known as Micro-Controle
Note: No revenue associated with service and spares included
Source: Dataquest (August 1992)

One major reason behind this erosion in market share has been the depressed market for advanced defect inspection systems. The drop in demand in advanced defect inspection systems began in the latter half of 1990 at the same time that the aggressive capital spending boom of the late 1980s began to fade. In October 1990, KLA introduced a new family of advanced defect inspection equipment, the 2100 series. Last year represented the first year of shipments for KLA's first product in the family, the 2110 advanced defect inspection system. This system offers 0.25-micron defect sensitivity and substantially improved throughput compared with the company's previous 20xx product line of inspection tools.

In June 1992, KLA introduced its newest product offerings in the 2100 family, the 2111 and the 2130 systems. The 2111 system specifications include a fivefold improvement in speed and a 20 percent increase in sensitivity relative to its predecessor, the 2110. The 2111, like the 2110, has been optimized for inspection of highly repetitive device patterns, such as memories. The 2130 system, also shown at SEMICON/West in June, has been designed as a high-speed inspection system to handle all device pattern types, both repetitive and random. Dataquest understands that a number of 2111 systems have already been shipped and that the 2130 has obtained customer acceptance.

In conjunction with these new advanced defect inspection product offerings, KLA also developed a new image and data analysis workstation, the 2550. The 2550's flexible, open architecture supports multiple KLA and non-KLA inspection tools, as well as optical and SEM defect review stations.

Nikon

Nikon's wafer inspection equipment revenue in 1991 was $13.1 million, which placed the company second in the worldwide ranking. It achieved this position by being the market leader in microscope-based wafer inspection stations. Nikon offers a variety of systems for wafer inspection through its Optistation family of products.

Insystems

Insystems ranked third in the wafer inspection equipment market with system revenue of $13 million. Insystems has suffered financial problems over the past several years as it has attempted to compete head-to-head with KLA in the advanced defect inspection equipment arena. Although Insystems has leading-edge technology, it has been burdened by having only a single product offering. In contrast, KLA has been better able to balance the effect of the industrywide slowdown by dispersing the impact on its business activities over a much wider mix of products.

The year 1991 was decidedly difficult for Insystems, as its cash flow position continued to deteriorate. Finally, in May 1992, it was announced that Optical Specialties Inc. (OSI) would acquire the assets of Insystems. The joint operation of the two companies will be consolidated under the OSI name. Dataquest understands that as part of the agreement all Insystems employees, products, and technology will be transferred to OSI. OSI, like Insystems, provides process control equipment to the semiconductor industry. (For additional information, please see "OSI and Insystems Consolidate Operations," in the SEMMS *Dataquest Perspective* dated June 1, 1992.)

Insystems' latest family of products was announced at SEMICON/West in June 1992. The new IQ inspection systems represent the company's third generation of patterned wafer inspection equipment. The IQ inspection system family currently consists of two products, the IQ-155 and IQ-165. The IQ-155 offers high-speed inspection at 0.25-micron defect sensitivity, while sensitivity for the IQ-165 is specified at 0.1 microns. Both products can provide full wafer defect detection capability in less than five minutes. Several more product offerings in the IQ family are planned over the next 12 to 18 months. Dataquest understands that several IQ systems are in the field and that additional shipments are scheduled prior to the end of September.

Hitachi

Hitachi, a new entrant to the advanced defect inspection equipment market, achieved an impressive market position of nearly 13 percent share its first year with almost $12 million in system revenue. Its new automated defect detection tool, the WI-870, has 0.5-micron defect sensitivity and relies on a light intensity comparison technique to detect the presence of defects. Dataquest believes that a significant number of the company's first-year system shipments went to internal Hitachi semiconductor operations. Although Hitachi achieved impressive sales in its first year of system shipments, its long-term competitive position in this market will depend on its ability to penetrate accounts beyond Hitachi's semiconductor operations and Hitachi's semiconductor partners.

Dataquest Perspective

Advanced defect inspection systems continue to dominate the market and technology issues associated with wafer inspection equipment. Although growth in this segment of the market has been relatively stagnant the last two years, recent activities clearly indicate that companies have been busy. A new competitor entering the arena, the acquisition of an established player, and a host of new product offerings may well herald significant changes in company share and drive new market opportunities in the near future.

By Peggy Marie Wood and Kunio Achiwa

How Does Your Company's Growth Compare with Industry Growth?

In this article we take a look at some general wafer fab equipment industry growth trends in order to indicate two key ideas. The first idea is that there is an increasing concentration of power in the wafer fab equipment industry, and the second is that it is important for a company to outperform the industry growth trend.

Concentration of Power

Table 1 shows the ranking of wafer fab equipment sales for the top 50 wafer fab equipment companies, 1991 compared with 1986. For instance, in 1986, the No. 1 company, Perkin-Elmer, had sales of $213 million, while in 1991 No. 1 company Nikon had sales of $557 million. Sales for companies in the top 20 have grown substantially more over the five-year period than have sales for the rest of the companies beyond the 20th position (actual companies in the top 20 for 1986 and 1991 can be different). In other words, the big are getting bigger and the small are staying small. Table 2 quantifies this latter statement. Figure 1 shows the concentration of power.

The top 10 companies accounted for $1,085 million in wafer fab equipment sales in 1986, or 40 percent of the entire worldwide wafer fab equipment market. By 1991, the top 10 share had grown to $2,859 million, or 47 percent of the world market. In 1991, the sales of the top 10 companies accounted for almost half of the total world market for wafer fab equipment.

Companies Nos. 11 through 30 accounted for 22 percent of the world market in 1991, the same percentage share they held in 1986, except that the Nos. 11 through 20 group grew at a faster rate than did the Nos. 21 through 30 group. Together, the top 30 companies accounted for 69 percent of the market in 1991, compared with 62 percent in 1986. Conversely, all other companies—and there are more than 150 in our database—accounted for only 31 percent of the market in 1991, compared with 38 percent in 1986.

The compound annual growth rate (CAGR) for the worldwide wafer fab equipment market from 1986 to 1991 was 17 percent. Looking at the different groups of companies, note that only the top 10 and the group Nos. 11 through 20 had growth rates that exceeded the industry's 17 percent. The All Other Companies group had only a 13 percent CAGR, quite a bit less than the industry average growth rate. Clearly, this large group of companies is falling behind.

The top 30 companies account for more than two-thirds of the world market for fab equipment. If the growth rates cited here are maintained, the top 10 or 20 companies will continue to gain share of the world market, while the rest of the companies as a group will lose share. That is, once again, the big are getting bigger and the small are staying small or getting smaller. If your company is not in the top 20 or

Table 1
Company Rankings, Sales of Wafer Fab Equipment (Millions of Dollars)

1991		1986	
Nikon	557	Perkin-Elmer	213
Applied Materials	493	Nikon	137
Tokyo Electron Ltd.	397	Canon	130
Hitachi	328	Applied Materials	124
Canon	292	Varian*	119
Varian*	275	GCA	89
Silicon Valley Group	180	ASM International	82
Anelva	155	General Signal	77
Kokusai Electric	138	Ulvac	65
Dainippon Screen	138	TEL/Thermco	60

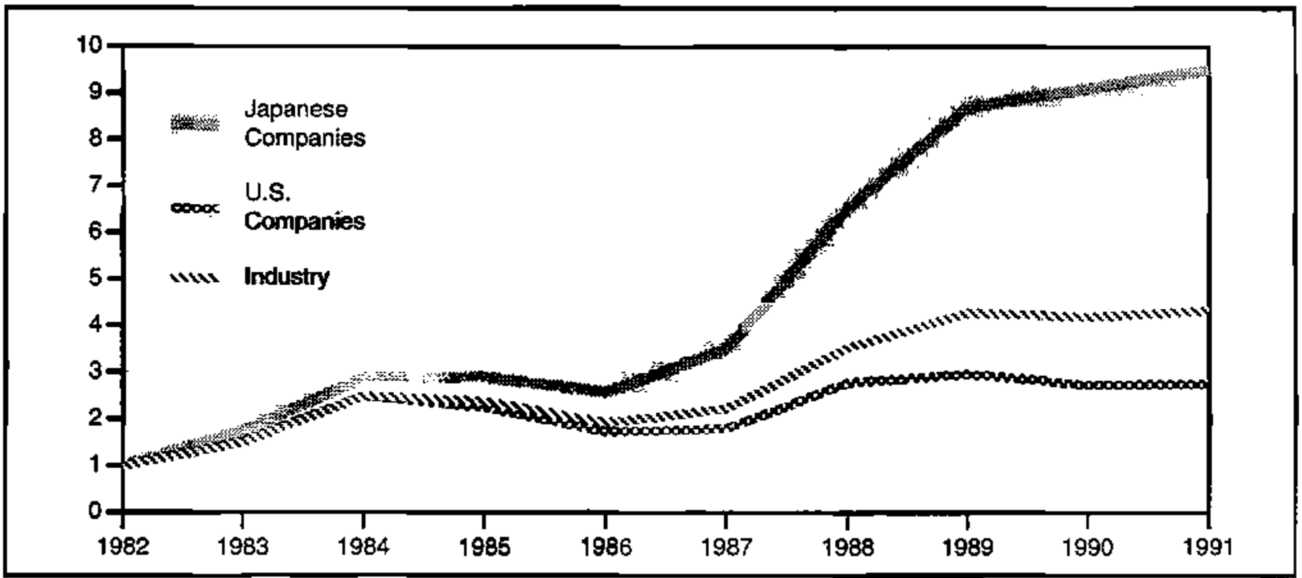
*Includes TEL/Varian and Varian/TEL sales
Source: Dataquest (August 1992)

Table 2
Concentration of Power, Wafer Fab Equipment Companies

	1986		1991		CAGR (%)
	($)	(%)	($)	(%)	1986-1991
Companies 1-10	1,085	40	2,859	47	21
Companies 11-20	374	14	890	15	19
Companies 21-30	218	8	416	7	14
Total Top 30 Companies	1,677	62	4,165	69	20
All Other Companies	1,036	38	1,875	31	13
Total Wafer Fab Equipment Market	2,713	100	6,040	100	17

Source: Dataquest (August 1992)

Figure 1
Concentration of Power, Wafer Fab Equipment Companies



Source: Dataquest (August 1992)
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so, then your company is competing in a continually shrinking piece of the market pie.

The top 10 wafer fab equipment companies provide almost 50 percent of the world fab equipment market. On the other hand, the top 10 semiconductor companies, ranked by amount of capital spending, buy about 50 percent of the world's production of wafer fab equipment. There is truly a concentration of both equipment manufacturing power and equipment buying power.

Top 10 Wafer Fab Equipment Companies

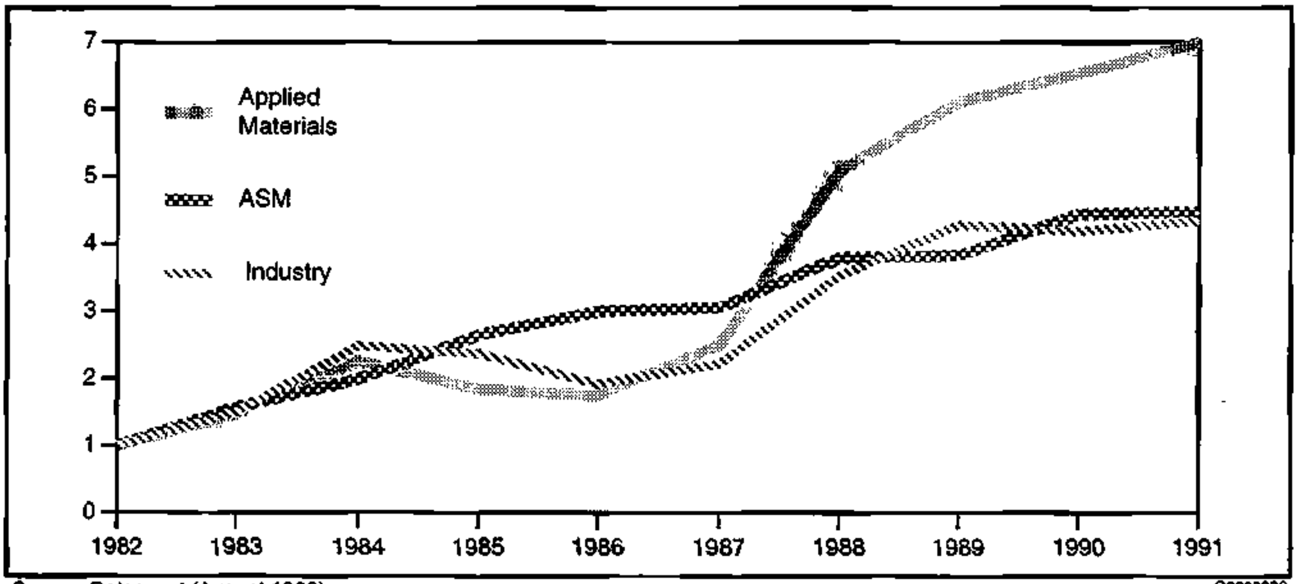
Table 1 showed the company rankings for wafer fab equipment sales in 1986, compared with 1991. Note that in 1986 five companies (the companies in bold) did not make it to the top 10 in 1991. Also, note that 7 of the top 10 companies in 1991 are Japanese companies. We will return to this table in a moment.

Wafer Fab Equipment Sales Growth

Figure 2 shows worldwide wafer fab equipment sales, or industry sales, over the period of 1982 to 1991. The data have been normalized to 1982 so that we can compare individual company growths to the industry. For instance, industry sales of $1,414 million in 1982 grew to $6,040 million in 1991, a growth factor of 4.3.

We also show the sales growth curve for Applied Materials and ASM International. Applied Materials has outperformed the industry growth. It was No. 4 in the 1986 top 10, but it moved to the No. 2 position by 1991 because of its above-average sales growth. ASM International, on the other hand, has performed about

Figure 2
Wafer Fab Equipment Industry and Company Sales (Sales Growth Normalized to 1982)



Source: Dataquest (August 1992)
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the same as the industry over the period. In 1986 ASM was No. 7 in the top 10, but by 1991 it was absent.

An interpretation of the foregoing is this: If a company performs only as well as the industry, like ASM International, or worse than the industry, like others that were in the top 10 in 1986 but absent in the 1991 top 10, it will fall behind the leaders. A company must outperform the industry to stay in the lead pack. The need to outperform the industry applies equally in both up and down markets.

When a company outperforms the industry, it is increasing its market share. Increasing market share comes from new products, technology, and processes, and these result from investment in research and development. The wafer fab equipment industry has a very high rate of R&D investment, perhaps the highest of any high-tech industry in the world. Thus, staying in the lead requires huge investment in R&D, and below-average sales performance is not compatible with this need. If your company is not investing—or cannot invest—to outperform the industry, others will and they will win the market share game and survive.

Figure 3 compares the wafer fab equipment sales of U.S. and Japanese equipment companies with the same industry growth curve. Clearly, Japanese equipment companies have outperformed U.S. companies over the period. As mentioned earlier, this is why seven Japanese companies are in the 1991 top 10.

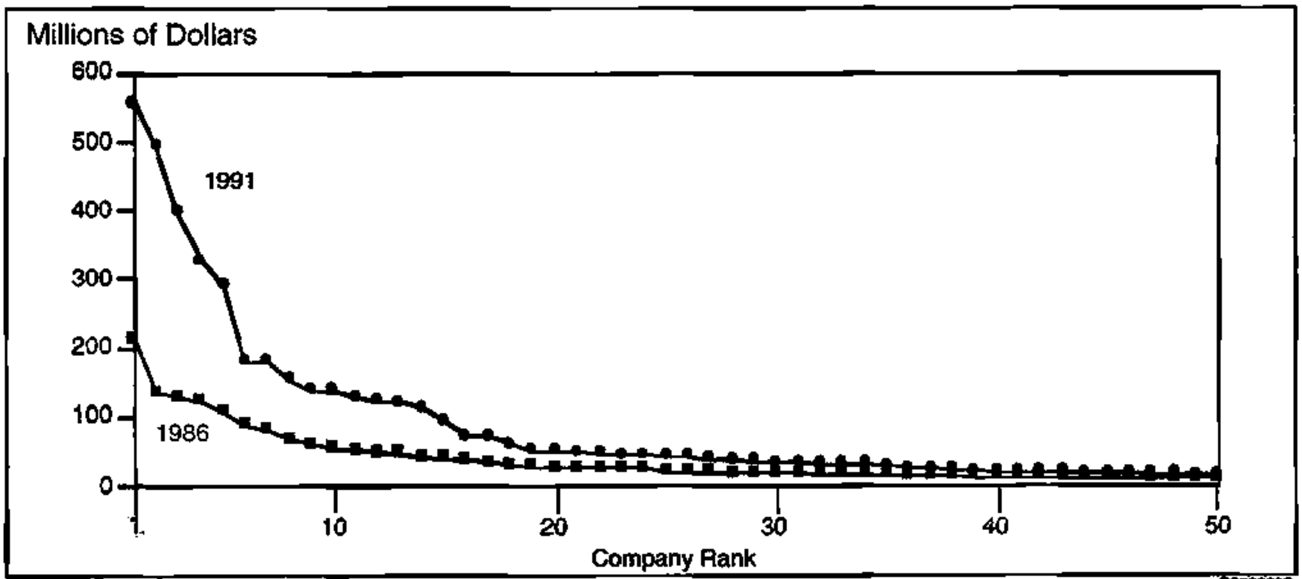
We said that a company must outperform the industry to stay in the lead pack, yet we can see that U.S. companies as a group are underperforming the industry. With this kind of performance it will be very difficult for U.S. companies as a group to regain their leadership. Whether for a group, like U.S. companies, or for any individual company, underperformance leads to market share loss. Underperformance also leads to R&D underinvestment, and eventually to further loss of market share. Thus, underperformance leads to a downward spiral that is very hard to halt.

Actually, we have been witnessing the loss of market share by U.S. equipment companies as a group for many years now. Although individual U.S. companies are outperforming the industry, most are not.

Dataquest Perspective

Many companies have individual growth curves that follow the familiar s-shaped curve of product life cycles. The company's growth starts out a little slow, goes through a fast acceleration phase, and then tapers off. We have seen this kind of growth numerous times among wafer fab equipment companies. Dataquest has observed that there seems to be a revenue

Figure 3
Wafer Fab Equipment Industry and Company Sales (Sales Growth Normalized to 1982, Japanese and U.S. Companies)



Source: Dataquest (August 1992)

G2000935

"wall" somewhere near the $25 million-sales level for equipment companies. They seem to grow very nicely to about this level, and then lose steam. This phenomenon of stalling out is the reason for the concentration of power that is shown in Figure 1.

If a company can maintain its momentum to get propelled beyond the $25 million level, then it has a better chance of continuing its growth to reach higher levels of sales. One way to get to the "critical mass" necessary for sales growth is to merge with another company. In 1991, we saw several instances of two small companies merging, as well as large companies acquiring small companies.

We said that high levels of R&D are needed to ensure leadership. Merger and acquisition activity can help finance this R&D, as small individual companies cannot afford the R&D bill alone.

Finally, we leave you with some questions: How does your company's growth compare with the industry growth trend? How does your competitor's growth compare with your company's growth and the industry trend? Being able to answer these questions may give you better insight into both your own company and your competitor's company.

By Joseph Grenier

Inquiry Summary

Dataquest's Semiconductor Equipment, Manufacturing, and Materials inquiry summaries are designed to inform our clients of commonly asked questions and Dataquest's respective answers. No confidential information provided by our clients is included in this material.

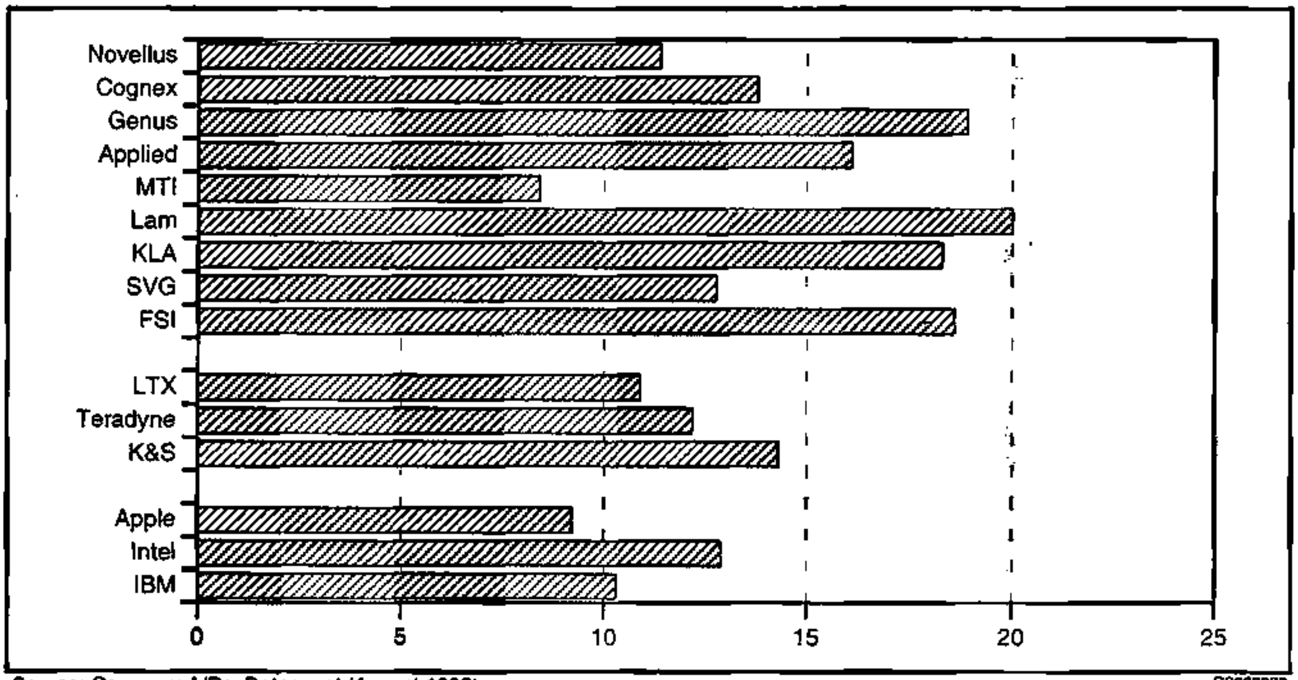
R&D Spending Levels for U.S. Wafer Fab Equipment Companies Are Very High

Q. What is the level of R&D spending for wafer fab equipment companies?

A. Figure 1 shows fiscal year 1991 R&D spending as a percentage of sales for 15 public U.S. companies. The first nine companies in the chart are wafer fab equipment companies, or front-end suppliers (Cognex is included in this category), and three companies provide back-end equipment (LTX, Teradyne, and Kulicke and Soffa). Three other large U.S. companies involved in the electronics industry are included for comparison (Apple, Intel, and IBM).

Companies in the wafer fab equipment industry have research and development investment rates among the highest of any high-tech industry, if not the highest. Several companies shown have R&D rates in the 15 to 20 percent range, and all but one company shown have rates greater than 10 percent.

Figure 1
FY1991 R&D Expense (Percentage of Sales)



Source: Company A/Rs, Dataquest (August 1992) G2000938

Back-end companies have rates somewhat lower than do front-end companies, but the rates are still in the 10 to 15 percent range. For comparison, in 1991, Apple's R&D rate was only 9.2 percent; Intel, such a stellar performer, had a rate of 12.9 percent; and IBM had a rate of 10.3 percent.

Clearly, staying on the leading edge in the wafer fab equipment industry is a costly proposition. As mentioned elsewhere in this issue, a company not making a high rate of R&D investment will fall behind its competition.

What about comparison with non-U.S. companies, which is really needed for a more meaningful analysis of R&D spending?

ASM International, a European company, had an 8.8 percent rate in 1991. R&D spending for Japanese equipment companies is generally not readily available in public reports. For instance, Tokyo Electron Ltd.'s annual report does not separately break out R&D expenditure. For other companies that do (Canon, Nikon), the R&D spending reported is the aggregate for the whole company and may not be representative of its equipment operations.

Nevertheless, we will continue to pursue the acquisition of non-U.S. company data.

By Joseph Grenier

For More Information . . .

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Dataquest Perspective

Semiconductor Equipment, Manufacturing, and Materials

SEMM-SVC-DP-9209 June 15, 1992

In This Issue...

In this issue of Dataquest Perspective, we continue our special coverage and discussion of the general trends in the wafer fab equipment market and those specific issues that characterize the market for the major segments of wafer fabrication equipment.

Market Analysis

Semiconductor Equipment

CD Market Growth Bolstered by SEM Preference: 1991 Optical CD and CD SEM Equipment Markets in Review

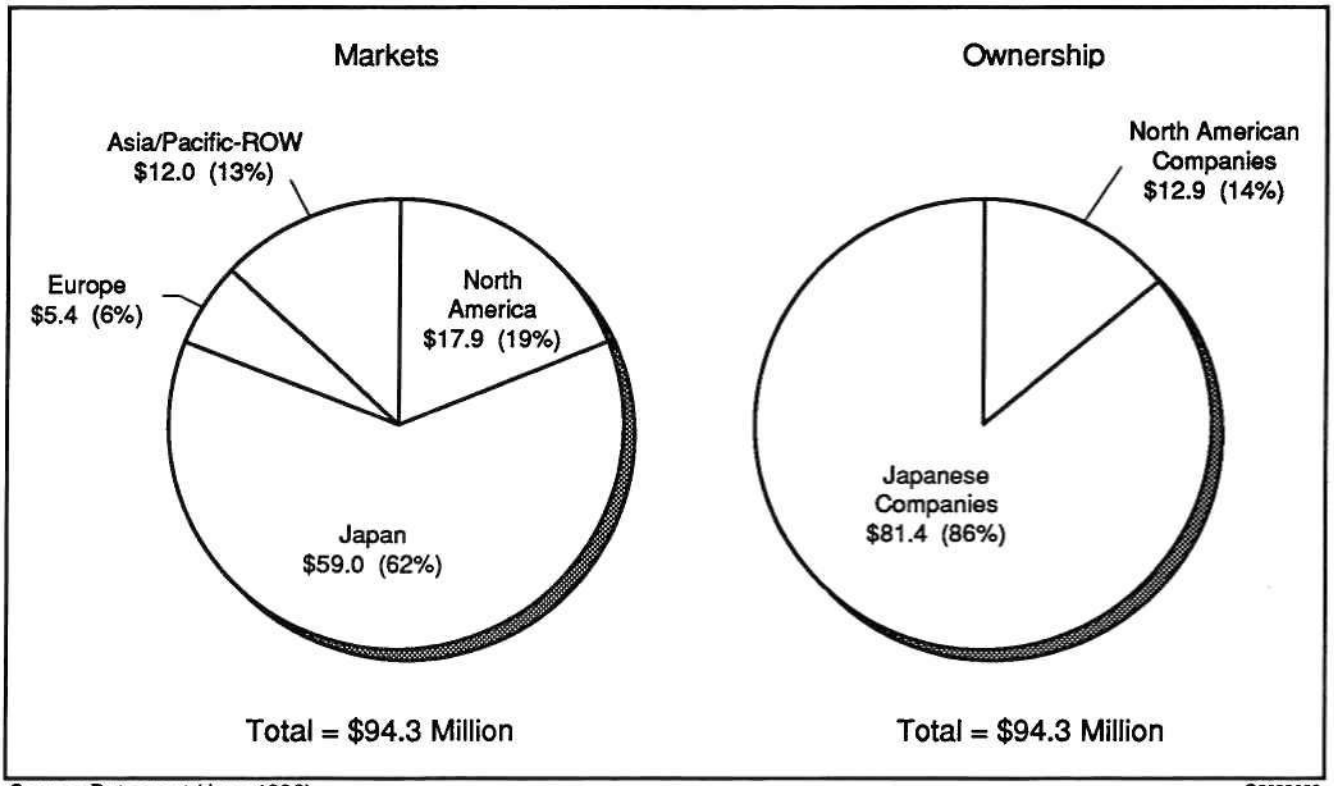
The worldwide critical dimension (CD) measurement equipment market was $154 million in 1991, up 5 percent from its 1990 level of $147 million. The CD SEM equipment segment of the market continued to outpace optical CD system demand. The CD SEM market represented $94 million of the $153.6 million total, and grew 8 percent in 1991 over its 1990 level of $88 million. The CD SEM equipment market has been on a steady growth path since this market segment first emerged in the mid-1980s. The continued market growth of this equipment segment reflects that CD SEM tools have become the established tool choice for CD measurement technology in submicron applications, particularly in the sub-0.8-micron regime.

In contrast to market growth in the CD SEM equipment segment, the optical CD equipment market was essentially flat in 1991 at a level of $59 million, after suffering declines of 12 percent in 1989 and 15 percent in 1990. The new emerging market for dedicated overlay tools was a key factor in preventing further erosion in the size of the total optical CD equipment market since the demand for optical CD tools with joint linewidth/overlay measurement capability continued down a path of decline last year.

Regional Markets and Ownership

Figures 1 and 2 present the worldwide 1991 CD SEM and optical CD equipment markets segmented by region and ownership. As these figures clearly illustrate, Japan continues to strongly dominate the CD SEM arena, accounting for 62 percent of worldwide demand last

Figure 1
1991 CD SEM Equipment Regional Markets and Ownership



Source: Dataquest (June 1992)

G2000699

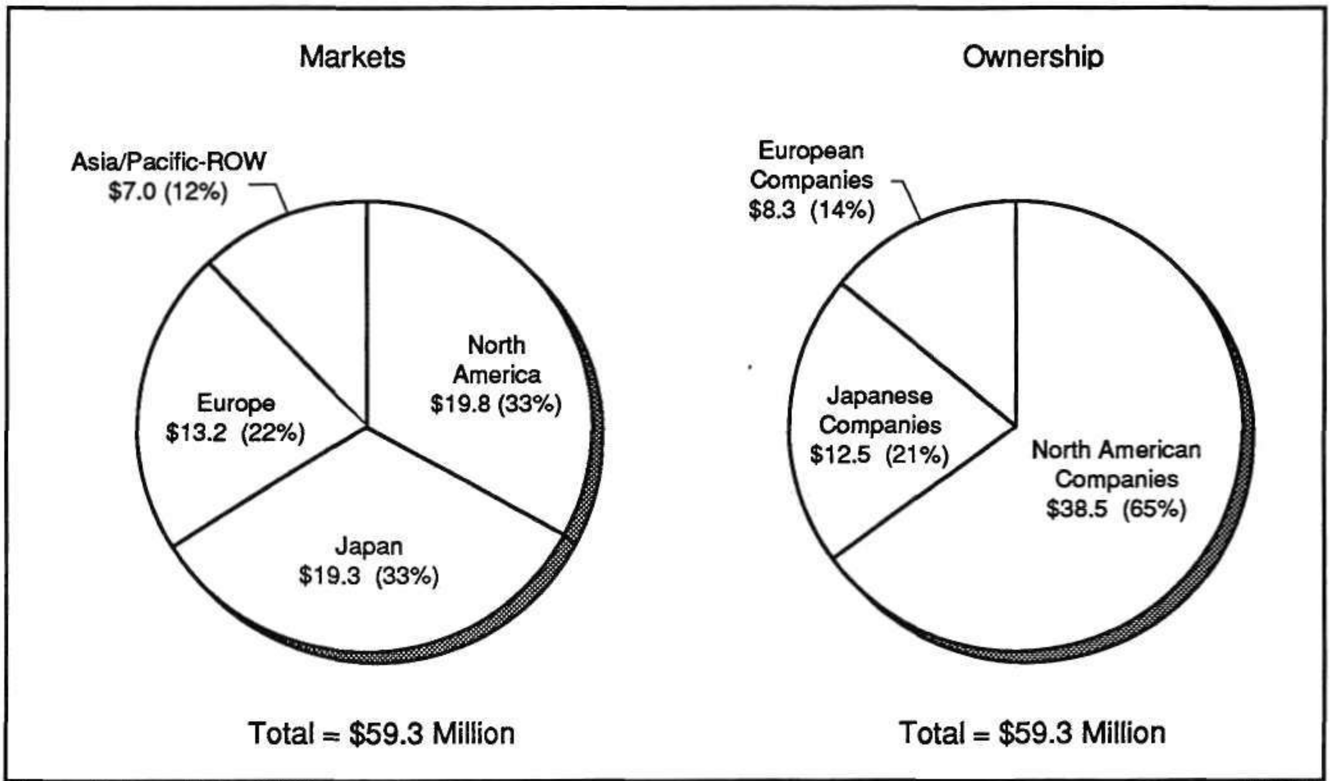
year. This bias toward CD SEM equipment in large part is because of the prevalence of DRAM manufacturing in Japan, which is the technology driver for processing smaller and smaller feature sizes. At the same time that Japan represented the largest regional demand for CD SEM systems, Japanese equipment suppliers maintained their strong position of dominance with 86 percent share of the market. This dominance in large part is because of the commanding presence of Hitachi, which accounted for 74 percent share of the worldwide CD SEM equipment market.

In contrast to the strong bias toward CD SEM, Japan accounted for only one-third, or $19 million, of the worldwide optical CD equipment demand in 1991. Dataquest estimates that dedicated overlay tools represented more than 60 percent of that amount of optical CD tools purchased in Japan last year. This strong preference for dedicated optical overlay systems is because CD SEM measurement systems are not particularly well-suited for overlay measurements. The physics of the CD SEM measurement procedure restrict it to the measurement of surface features. An optical tool, however, can "see" through a transparent film to the alignment marks on an underlying layer.

North America represented 33 percent of the optical CD equipment market in 1991, while CD SEM system purchases in North America represented only 19 percent of worldwide demand. It is not surprising that device manufacturers in North America demonstrate a purchase preference for optical CD systems, as they have a strong domestic base of equipment suppliers to support their needs. North American companies dominate the optical CD arena, accounting for 65 percent of the worldwide market.

Like their counterparts in North America, semiconductor device manufacturers in Europe favor optical CD tools more strongly than CD SEM systems. Europe represented 22 percent of the optical CD equipment market and a mere 6 percent of the CD SEM market. Semiconductor manufacturers in Asia/Pacific-ROW purchased a fairly even balance of optical CD and CD SEM systems last year, and accounted for 12 percent and 13 percent, respectively, of

Figure 2
1991 Optical CD Equipment Regional Markets and Ownership



Source: Dataquest (June 1992)
G2000700

worldwide equipment demand of these two categories of equipment.

It is interesting to note that the distribution of revenue on a regional basis for the combined optical CD and CD SEM equipment markets closely mirrors the regional distribution of the total wafer fabrication equipment market. So while there are regional preferences for a given measurement technology, overall CD equipment expenditure follows a well-behaved pattern of wafer fabrication spending.

Company Rankings

Table 1 presents the worldwide company rankings for the CD equipment market based on combined revenue of optical CD and CD SEM equipment. Company revenue for optical CD systems is further segmented into tools with joint linewidth/overlay measurement capability and dedicated overlay measurement systems. The following sections discuss several key observations to note when evaluating the company revenue and ranking estimates presented in Table 1.

Relatively Few Companies Offer both Optical CD and CD SEM Equipment

The CD equipment market has remained relatively fragmented over the years. In 1991, only 2 companies of the 15-plus suppliers offered both CD SEM and optical CD product offerings. These two companies—Hitachi and Biorad—ranked No. 1 and No. 2, respectively, in the 1991 total CD equipment market. Hitachi's total CD revenue of $74 million is strongly dominated by CD SEM equipment. This is a market where Hitachi has dominated the market since it emerged in the mid-1980s. It has enjoyed an enviable position of more than 70 percent worldwide market share for the last three years. Hitachi's optical CD revenue is derived from its LAMU system, a dedicated overlay tool that complements the company's strategy and focus on CD SEM equipment.

Biorad ranked No. 1 in the optical CD equipment market with revenue of $10 million. Its CD SEM equipment revenue of $5 million last year placed it third in the CD SEM

Table 1
1991 Worldwide CD Equipment Company Rankings (Millions of Dollars)

Companies	Total	% Share	Total CD SEM	Total Optical CD	Optical CD: Joint CD/ Overlay	Optical CD: Dedicated Overlay
Hitachi	73.8	48.0	69.6	4.2	0	4.2
BioRad	14.8	9.6	4.9	9.9	9.9	0
KLA Instruments	9.3	6.1	0	9.3	4.9	4.4
Holon	8.0	5.2	8.0	0	0	0
IVS, Inc.	7.6	4.9	0	7.6	7.6	0
Nano-Master	6.0	3.9	0	6.0	6.0	0
Nikon	5.9	3.8	0	5.9	3.3	2.6
Optical Specialties	5.7	3.7	0	5.7	0.7	5.0
Amray	3.4	2.2	3.4	0	0	0
Nanometrics	2.4	1.6	0	2.4	2.4	0
Opal	2.4	1.6	2.4	0	0	0
Angstrom	2.2	1.4	2.2	0	0	0
SiScan Systems	2.2	1.4	0	2.2	2.2	0
Topcon (formerly ABT)	2.1	1.4	2.1	0	0	0
Leica	1.8	1.2	0	1.8	1.8	0
JEOL	1.7	1.1	1.7	0	0	0
Ryokosha	0.7	0.5	0	0.7	0.7	0
Other Companies	3.6	2.3	0	3.6	3.6	0
Total	153.6	100.0%	94.3	59.3	43.1	16.2

Note: Spares and service not included.
Source: Dataquest (June 1992)

equipment market ranking. Biorad's optical CD and CD SEM equipment revenue historically has been focused on the North American and European markets. The company has yet to establish much of a presence with semiconductor manufacturers in Japan and Asia. Dataquest believes that it is essential for Biorad to expand its regional focus to the Far East because these two regions represent more than 60 percent of the worldwide demand for CD measurement equipment.

At the beginning of 1992, IVS, a key player in the optical CD arena, announced that it would acquire Angstrom Measurements, a start-up CD SEM equipment supplier. IVS has been an important player in the optical CD equipment market by virtue of having a relatively strong position in each of the regional markets, with the exception of Japan. IVS has yet to ship any equipment into this region. With the Angstrom CD SEM product, IVS is now well-positioned to continue to maintain its ranking as a top player in the various regional markets. Although fierce competition from domestic suppliers will always make Japan a difficult market to penetrate, the high-throughput capability of Angstrom's advanced CD SEM should garner IVS much attention from the Japanese semiconductor device manufacturers. Finally, Angstrom Measurements will provide IVS with some incremental amount of critical mass, which is vital to the survival of any small semiconductor equipment company. We note that the combined CD revenue of IVS and Angstrom would have ranked third, ahead of KLA Instruments, in the overall CD equipment market last year.

Dataquest believes that this balanced approach to CD product mix adopted by Hitachi, Biorad, and IVS is a distinct benefit because it allows the equipment supplier to offer a migration path of measurement technologies as well as a broader scope of measurement solutions to the device manufacturer.

The Growing Presence of Dedicated Overlay Tools in the Optical CD Product Mix

Traditionally, optical CD tools have been used to perform both linewidth and overlay measurement. However, as CD SEM equipment has become a larger portion of the overall CD product mix, a number of companies have designed systems that are specifically optimized for overlay measurement. Table 1 includes Dataquest's estimates for the 1991 dedicated overlay revenue of four companies: Hitachi, KLA Instruments, Nikon, and Optical Specialties (OSI). We believe that the dedicated overlay equipment revenue of these four companies was $16 million, or more than one-fourth of the total optical CD equipment market last year.

Hitachi has been a longtime supplier of a dedicated overlay system with its LAMU measurement system. Although Hitachi enjoys a strong market presence in every region with its CD SEM product offerings, it has not been able to effectively expand the sales of its overlay measurement system beyond customers in Japan.

KLA's current dedicated overlay product offering, the 5010, emerged from the KLA 5000 product family, which utilizes a patented KLA measurement technique known as coherence probe imaging. The KLA 5000 with joint CD/overlay capability was introduced in 1988; the company began shipments of a dedicated overlay system based on this same technology in 1990.

Nikon is a relatively newcomer in the dedicated overlay arena. The company's Instrument Group introduced its new dedicated overlay tool, the NRM-1, at SEMICON/West in May 1991. It is interesting to note that this tool was developed by the Instrument Group of Nikon, a different division than that which manufactures and markets Nikon's LAMPAS line of laser-based optical CD measurement systems.

OSI has been providing its Metra family of products to the marketplace since 1990. In particular, a focused strategy toward dedicated overlay equipment has benefited OSI, which has been a relatively small player in the market. Dataquest believes that OSI garnered the No. 1 position in this new emerging market segment last year with an estimated $5.0 million in dedicated overlay system revenue. The company has benefited from a close working relationship with Toray Industries of Japan. Last year, almost 70 percent of OSI's optical CD equipment revenue came from Japan. In May of this year, OSI announced that it will acquire Insystems, a manufacturer of advanced defect inspection tools. This acquisition will provide OSI with advanced process control equipment to complement its existing product offerings and will also benefit the company by adding much needed critical mass.

Make Note of a Newcomer to the CD SEM Arena

One company not shown in Table 1 is a new North American CD SEM start-up called Metrologix. This Silicon Valley-based company shipped its first CD SEM system, dubbed Metrostep TM 2001, in early 1992. This tool's measurement system incorporates a proprietary mixed-signal technique that mixes secondary electrons with other electrons to achieve excellent operation in a very linear regime. The company claims measurement capability in a production environment of 0.1μ with the potential to measure 0.05μ geometries. The system is reported to have a very impressive throughput level of 40 wafers per hour at five sites per wafer, substantially faster than the 12- to 15-wafer-per-hour rate reported by several vendors. With this level of tool performance, Metrologix has the capability to move to the head of the pack of that group of smaller CD SEM vendors (Angstrom, Biorad, and Opal) targeting high-throughput operation in a bid to wrest market share from Hitachi.

Dataquest Perspective

The clear trend in CD measurement technology over the last several years has been toward CD SEM systems. With its sub-0.5-micron measurement capability and tool performance designed for the production environment, CD SEM equipment has become the preferred measurement technology for many semiconductor device manufacturers focused on advanced device fabrication. The two perceived disadvantages of CD SEM tools today, however, are their relatively low throughput and inability to measure overlay. Dataquest believes that within the next two years low throughput will no longer be considered a significant issue for CD SEM because of new high-throughput product offerings coming into the market.

The concern with CD SEM tools and overlay measurement is currently being addressed by optical CD tools. Several equipment companies have developed dedicated overlay measurement systems for the marketplace, while other optical CD vendors have refocused their marketing strategies to emphasize overlay measurement capability of their joint linewidth/overlay measurement tools. It has even been suggested that CD SEM tools also can be adapted to overlay measurement with proper process modifications that leave the area above alignment marks open. This approach is being investigated because it is believed that the transparent layers that prevent CD SEM tools from "seeing" alignment marks will also become a problem for optical-based overlay measurement tools in the 64Mb/256Mb DRAM processing regime. The transparent film is part of the total optical path, and at some point process-induced distortions in this transparent film will become so significant that an alternative method for overlay measurement will need to be established. If device manufacturers opt for the additional process steps to modify the area above alignment marks, CD SEM applications will expand beyond strictly linewidth measurements, which could well have a significant impact on future optical CD tool demand.

By Peggy Marie Wood (San Jose)
Kunio Achiwa (Tokyo)

Japan Saves the Epi Equipment Market: 1991 Silicon Epitaxy Equipment Market in Review

The worldwide silicon epitaxial reactor market was $89 million in 1991, up 30 percent from its 1990 level of $68 million. The sales of epi equipment pushed ahead in 1991 because of strong sales in Japan and to a lesser extent Asia/Pacific. The traditionally strong North American market declined precipitously and the European market struggled to keep its head above water.

Regional Markets and Ownership

Figure 1 presents the worldwide 1991 silicon epitaxial equipment market segmented by region and company ownership. Surprisingly strong demand in Japan buoyed worldwide epitaxial equipment sales in what was a lackluster year in most regions of the world. Resilient epi equipment sales in Japan last year totaled $46.1 million, up from $18 million in 1990. The Asia/Pacific market was $6.7 and also saw strong growth albeit on a very small base. The North American market achieved a level of $24.8 million last year, which represented a significant decline of 30 percent relative to its 1990 level, while the European market was essentially flat at $11 million. North American and European epi companies, with almost equal share, dominate the market.

In Japan, several of the large merchant silicon companies put new capacity in place. Major projects included the construction of a Chitose line by Mitsubishi Metal and capacity increases by Toshiba Ceramics and Shin-Etsu Handotai at the Tokuyama Ceramics (subsidiary) and Isobe plants, respectively. Other capacity increases in Japan were at Osaka Titanium's Saga plant and Komatsu Electronic Metals' Nagasaki plant. The only significant epi capacity addition outside of Japan was for Wacker Chemitronic's Wasserburg plant in Germany.

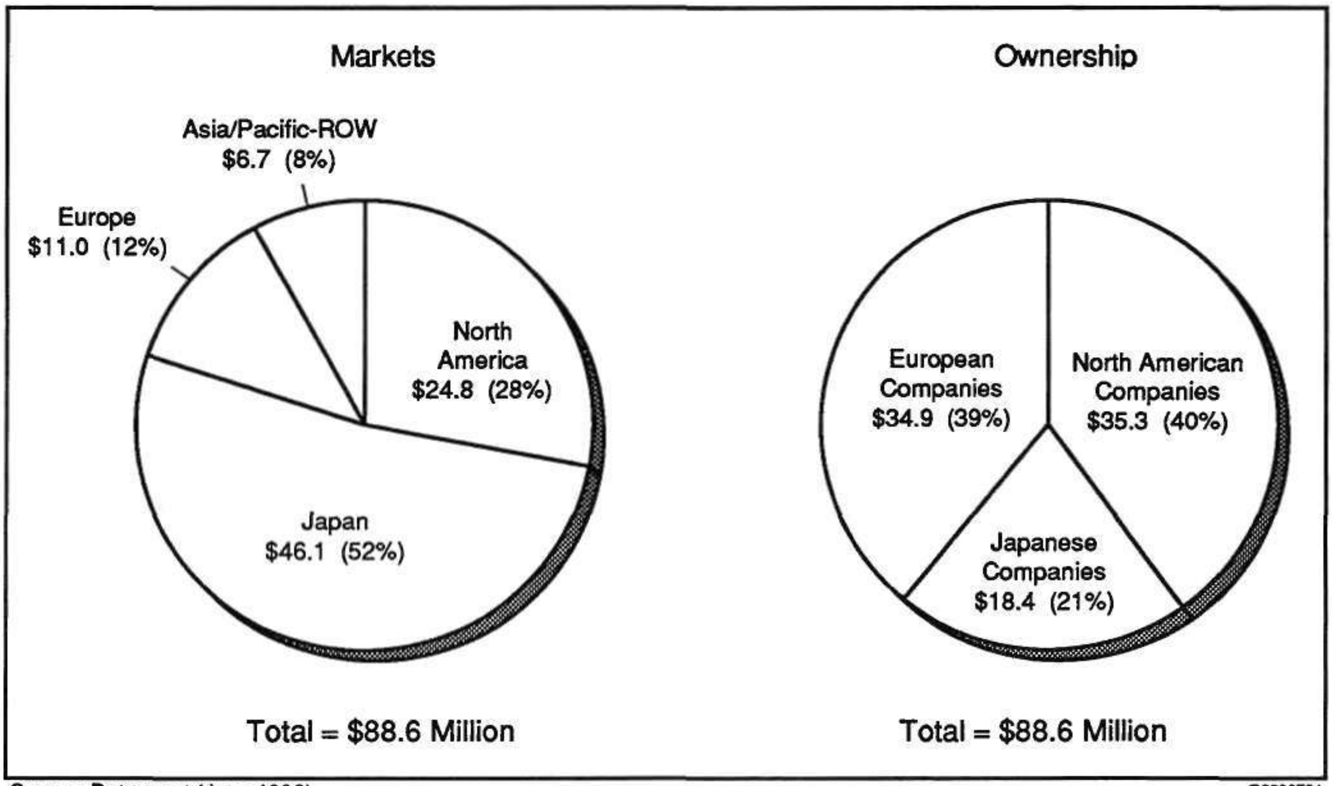
Epi Wafer Applications

Discrete and bipolar devices are the major application in the Japanese market. On the other hand, merchant epitaxial wafers are largely used for CMOS devices in the United States. Intel and Motorola use them for microprocessors, IBM for DRAMs, and Texas Instruments (TI) for MOS devices.

The relatively small demand for CMOS epi wafers in the Japanese market is because Japanese companies have designed around epi films. Unlike IBM, which produces DRAMs for captive use, Japanese DRAM makers face intensive price competition and cannot afford to use epitaxial wafers, which cost two to three times the cost of silicon substrate.

Epi wafers, however, are required for bipolar devices. Epi films are used to form buried/diffused layers for the purpose of decreasing

Figure 1
1991 Silicon Epitaxy Equipment Regional Markets and Ownership



Source: Dataquest (June 1992) G2000701

collector resistance. In MOS processing, the improved crystal structure of epi films prevents latchup and soft errors caused by alpha rays. In CCD applications, epi films provide improved gettering and uniformity, and in discrete applications, epi films are used solely for achieving film uniformity.

Japanese Drivers

The healthy growth of the Japanese epi equipment market last year can be attributed to several factors. The fastest growing application for epi films in Japan is the power IC market. The trend toward high-voltage and large-current IC designs is being driven by the increased performance and size reductions in consumer, information, and communications equipment.

The other major applications for epi films are insulated gate bipolar transistors (IGBTs), switching devices, and inverters, which control the speed of AC motors by varying the current frequency. From the equipment vendors' point of view, IGBT devices may be the largest application in terms of the number or reactors required because these devices require very thick epi films in the range of 100 to 150 microns. A relatively large amount of equipment is needed because of low throughput caused by the longer processing time required to grow a thick film.

On the CMOS side, Dataquest does not expect Japanese DRAM manufacturers to migrate to epi films until at least the 256Mb DRAM generation. As mentioned earlier, the cost remains prohibitively high for merchant DRAM applications. Japanese device companies have emphasized that they could only justify the use of epi wafers in current DRAM generations at a price 30 percent above that of prime wafer prices.

Another factor delaying the use of epitaxial wafers in DRAM applications is the use of high-energy ion implantation technology. Mitsubishi Electric has pioneered this application. The process is designed to improve latchup characteristics and soft error resistance by forming retrograde wells by ion implantation. Although the same effect can be achieved by using epitaxial wafers, ion implantation has the added benefit of reducing wafer processing by two mask steps.

Of course, there is the additional expense of purchasing the implanter, which costs on the order of $3 million.

Company Rankings

As shown in Table 1, two companies—Applied Materials and ASM Epitaxy—dominate the worldwide epi equipment market. Both companies showed strong growth in year-to-year sales last year, and the combined sales of the two companies accounted for 70 percent of the worldwide epi equipment sales.

Applied Materials' strength in epi equipment goes back to the beginning of the company. Epi equipment was the first process equipment offered by Applied Materials. The workhorses of their product line today are the 7800 and 7700 series reactors. Both systems are barrel reactors. Applied is also working on a multichamber single-wafer system.

ASM Epitaxy quickly rose to prominence with the introduction of its Epsilon I system in the late 1980s. The Epsilon I was the first single-wafer epi reactor offered in the market. The company has since introduced another version of the reactor Epsilon as well as a poly reactor called Paragon. The fast ramp of ASM Epitaxy's sales is a barometer of the demand for single-wafer reactors in the CMOS and BiCMOS epi markets, which require very thin epi films.

Toshiba Machine and Kokusai are the next largest vendors of epi equipment. Toshiba's $12.5 million sales in 1991 are largely captive; the company is the major supplier to Toshiba Ceramics, a sister company involved in the production of silicon and epi wafers. Kokusai, also a Japanese vendor, offers a pancake-type epi reactor. Kokusai's technology is older but ironically it may prove to be better suited for the high-growth market segment of thick film epi applications.

Dataquest Perspective

The epi equipment market is relatively mature. Its fortunes are tied very closely to existing applications and epi wafer capacity expansions. Because of the high cost of epi wafers, device makers are very reluctant to adopt epi films in any designs other than those that absolutely require it. This trend is preventing the market from growing much beyond the $100 million level.

Table 1
1991 Worldwide Silicon Epitaxy Equipment Company Rankings (Millions of Dollars)

Company	Revenue	% Share
Applied Materials	32.0	36.1
ASM Epitaxy	29.9	33.8
Toshiba Machine	12.5	14.1
Kokusai Electric	5.9	6.7
LPE	5.0	5.6
Moore	3.3	3.7
Total	88.6	100.0

Note: Spares and service not included
Source: Dataquest (June 1992)

By Mark FitzGerald (San Jose)
Kunio Achiwa (Tokyo)

Semiconductor Manufacturing

Intel Flexes Its Muscles

Intel recently announced sweeping changes in its pricing for the 486SX microprocessor (see Table 1). The announcement was targeted directly at Advanced Micro Devices Inc.'s growing 386 business and the timing of the announcement was not lost on AMD, which will not have its own version of the 486 available until the first or second quarter of 1993. If the price cuts spur unit sales, as is widely expected, then Intel's plants will certainly have added pressure to lower costs and improve yields.

Impact of Intel's New Pricing Strategy

At Intel's new price of $119 for a 486SX in lots of 1,000, Dataquest estimates that the 486 price will dislodge the 386DX, which costs $104 per piece. Dataquest estimates that AMD currently has 50 percent of the 386DX business, so Intel's price decrease poses a threat to AMD's existing 386 business and may complicate AMD's transition to the 486.

Table 1
Recent Price Cuts in Intel's 486SX Products

Speed	Old Price	New Price
16 MHz	$144	$99
20 MHz	$201	$99
25 MHz	$282	$119

Source: Dataquest (June 1992)

To date, sales of the 486SX have been weak in slower speeds and firm in the higher-speed grades. However, the new price structure is expected to put wind in the sails of the 486SX, especially for PCs selling in the range of $1,200 to $1,500. Dell Computer, which uses Intel as sole source for 486 products, reported last quarter that 53 percent of its sales were 486 shipments. It expects that percentage to grow to 75 percent by year-end. The main factor driving this growth is Intel's lower prices. (Dataquest forecast just such a price cut for the 486 earlier this year. See "IC Pricing Pressure Mounts as Recession Persists," in the January 20 Semiconductor Procurement *Dataquest Perspective.*)

Intel Scrambles to Add Production

The size of the 486SX chip will be reduced because the math coprocessor will be lopped off. To date, the math coprocessor has been built on the chip but never enabled. Lopping off the math coprocessor will save silicon real estate. Even so, the 486SX will be 31 percent larger than the 386SX. As shown in Table 2, other products in the 486 family will also have considerably larger die sizes than those of the 386.

Dataquest believes Intel's decision to move to 8-inch wafers will pay off handsomely and give the company a strong cost advantage over its competitors as its percentage mix of 486 and 586 products increases. Current vendors of 8-inch wafers for Intel's 486 program are Osaka Titanium and SEH.

Intel also plans to move the 486SX to a 0.8-micron process by the end of the year, which will further increase the number of die per wafer. Dataquest believes that Intel will be converting critical mask steps to i-line lithography in conjunction with the move to 0.8-micron geometries. The less critical mask steps are expected to use g-line technology. Intel has been running extensive qualification tests on i-line stepper and resist products for a little more than a year now. Dataquest believes that Nikon has won the stepper business and Tokyo Ohka has won the resist business.

The growth of the 486 business is pressing Intel to move quickly to ramp new production capacity (see Table 3). Intel's Ireland facility will begin production in June 1993. Management last fall decided to upgrade the new Irish fab from a 6-inch to an 8-inch line. Wafer start capacity for the line measured in millions of square inches will almost double because of the upgrade. In the meantime, Intel is converting its 6-inch research facility in Santa Clara, California to an 8-inch production line and is building a new 8-inch pilot line in Portland, Oregon.

Dataquest Perspective

Intel is likely to maintain an 80 percent share of the X86 market through 1993 because of its

Table 2
Design Trends for Intel MPUs

Device	Die Size (square mm)	Geometry (Microns)	Number of Metal Layers
386SX	255	1.0	2-layer
386DX	257	1.0	2-layer
486SX	334	0.8	3-layer
486DX	520	1.0	2-layer
486DX	357	0.8	3-layer
486DX2	357	0.8	3-layer

Source: Dataquest (June 1992)

Table 3
Intel Chipmaking Locations

City	State	Fab Name	Type[1]	Year Production	Products	Geometry[2]	Monthly Capacity	Wafer[3] Size
Plants Under Construction or on the Drawing Board								
Rio Rancho	NM	FAB 9.4	F	1994	NA	0.7	17,000	8
Leixlip, Kildare	Ireland	FAB 10	F	1993	386 MPU 486 MPU	0.6	18,000	8
Aloha	OR	NA	F	1993	586 MPU	0.0	21,250	8
Rio Rancho	NM	FAB 9.3	F	1992	586 MPU EPROM	0.8	24,000	6
Plants in Production								
Rio Rancho	NM	FAB 9.2	F	1991	486 MPU EPROM	1.0	13,600	6
Santa Clara[4]	CA	D2	PR	1989	8Mb EPROM NVMEM Tech. Dev.	0.8	0	8
Rio Rancho	NM	FAB 9.1	NF	1988	386 MPU 486 MPU	1.0	13,600	6
Santa Clara	CA	FAB 1	NF	1987	FLASH 512K EPROM MCU PLD	1.5	16,800	4
Aloha	OR	D1 (FAB 5)	FR	1987	386 486 MPU LOG 64K SRAM	1.0	11,200	6
Jerusalem		FAB 8	DFAT	1985	386 MPU 286 MPU	1.5	21,000	6
Chandler	AZ	FAB 6	FAT	1984	MCU 286 MPU	1.5	31,000	6
Rio Rancho	NM	FAB 7	NF	1984	512K EPROM MCU MIL STD	1.0	31,500	6
Aloha	OR	FAB 4	F	1981	High-Vol. Commodity and Log	2.0	31,500	4
Santa Clara	CA	PED	P	0	NA	1.0	3,200	6

[1]Type Field Description
F = Production-based fab line
R = Semiconductor R&D
P = Pilot line
A = Assembly
T = Test
D = Design
[2]Linewidth geometry in microns
[3]Theoretical unit wafer start capacity per four weeks
[4]D2 line in Santa Clara is being upgraded from 6 to 8 inch.
NA = Not Available
Source: Dataquest (June 1992)

efforts to move the market upstream to the 486 and 586 products. It is evident that Intel will rely heavily on pricing to achieve its objective. Dataquest expects Intel to be very aggressive in lowering its manufacturing cost as part of the pricing strategy.

By Mark FitzGerald

Inquiry Summary

Dataquest's Semiconductor Equipment, Manufacturing, and Materials inquiry summaries are designed to inform our clients of commonly asked questions and Dataquest's respective answers. No confidential information provided by our clients is included in this material.

Joint Venture Wafer Fabrication Equipment Companies

Q. Why does Dataquest break out joint venture companies separately in its analysis of the wafer fabrication equipment market? Also, how do you account for the revenue of such companies? Do you split it between a joint venture company's corporate parents?

A. In Dataquest's 1991 wafer fab equipment market statistics, we identified five joint venture companies active in the marketplace last year: Alcan, m.FSI, Sumitomo/Eaton Nova, TEL/Varian, and Varian/TEL. Although the majority of these joint venture equipment companies are located in Japan and service that market exclusively, we choose to report these companies in a separate category rather than bundle them with the other Japanese companies. That is because the products offered by these joint-venture companies represent significant revenue and technological contributions of U.S. as well as Japanese corporations. All of the joint ventures represent joint ownership between U.S. and Japanese companies, with the exception of one Japanese/European joint venture (Alcan).

Dataquest attributes revenue directly to the joint venture companies rather than split the revenue between either corporate founder. We believe that it is very important to associate both the revenue and unit shipments to the joint venture company in order to avoid confusing market share and average selling price trends for given equipment segments. It should be noted that all revenue estimates in Dataquest's equipment market statistics reflect end-user revenue.

By Peggy Marie Wood

Dataquest Methodology

Q. Please describe the methodology and conventions that you use to establish market statistics of the worldwide wafer fabrication equipment market.

A. The foundation of Dataquest's methodology for establishing wafer fab equipment market statistics is primary research. As part of our annual compilation of wafer fab equipment market statistics, we contact knowledgeable individuals in wafer fabrication equipment companies to discuss their company's current activities in the marketplace. In addition, throughout the year, we regularly gather information on companies by visiting them directly, talking with their semiconductor manufacturing customers, attending the key equipment trade shows and technical symposia, and by utilizing secondary research sources such as company financials and financial analysts reports.

We employ a set of well-defined conventions in reporting market statistics. We estimate each company's revenue and unit shipments by product category by region of the world. Revenue estimates do not include spare parts or service but do include retrofits and upgrades. Our information represents end-user revenue for calendar year shipments. Particular attention must be paid to this issue because there can be significant variations between a company's calendar year and fiscal year revenue.

In addition, our market estimates focus exclusively on wafer fabrication equipment used in front-end semiconductor device manufacturing. We do not include equipment used in other market applications such as flat panel display manufacturing, thin film head manufacturing, or multichip module fabrication. Even though these other market applications utilize the same type of equipment, it is very important not to mix such market statistics together because the aggregated total may well mask very different market dynamics for the individual application markets.

Worldwide market share estimates combine data from many countries, each of which has different and fluctuating exchange rates. Estimates of non-U.S. company revenue are based upon the average exchange rate for the given year. As a rule, our estimates are calculated in local currencies, and then converted to U.S. dollars.

Finally, when all of our market statistics have been gathered, the information is scrubbed through a series of cross-checks that evaluate key tie ratios between the various wafer fab equipment segments. We also correlate our findings with other trends in the semiconductor industry such as fab activities, capital spending, semiconductor production, silicon consumption, and general macroeconomic trends.

Despite the care taken in gathering, analyzing, and categorizing the data in a meaningful way, careful attention must be paid to the definitions and assumptions used in our market statistics. Various companies, government agencies, and trade associations may use slightly different definitions of product categories and regional groups, or they may include different companies in their summaries. These differences should be kept in mind when making comparisons between data and numbers provided by Dataquest and those provided by other suppliers.

By Peggy Marie Wood

In Future Issues

Look for the following articles in future issues of *Dataquest Perspective:*

- 1991 wafer inspection equipment market in review
- 1991 wet processing equipment market in review
- U.S. specialty gas market update

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Dataquest Perspective

Semiconductor Equipment, Manufacturing, and Materials

SEMM-SVC-DP-9208 June 8, 1992

In This Issue...

In this issue of Dataquest Perspective, we present a special focus on macroeconomic factors and trends affecting the semiconductor industry, and in turn, the silicon wafer industry. We believe that the global silicon cycle bottomed out in 1991. However, prospects for the different regions of the world will vary markedly. The articles in this issue address the different regional trends both from a micro and macro viewpoint, using silicon wafers as a barometer of market activity. The five silicon forecast tables that pertain to all four regional articles are found in a separate section following the Asia/Pacific Market Pulse article.

Market Analysis

Semiconductor Materials

U.S. Market Pulse

Recap of 1991

The 1991 U.S. silicon market began on a weak note because of the Middle East crisis. Wafer demand picked up following the conclusion of the war and growth was moderate through May 1991. But as the industry moved into the summer months, typically a slow season for semiconductor manufacturers, wafer demand began declining more precipitously than could be explained by seasonal factors. The fourth quarter saw this summer decline turn into a full-fledged route and the fall turned out to be the worst quarter of 1991.

At the end of the year, it was apparent that silicon consumption had experienced its first negative growth since 1986. Dataquest's market survey indicates that the total U.S. silicon market declined 4.5 percent in 1991 (see Table 1). Epitaxial wafers increased 4.0 percent (see Table 2) and prime, test, and monitor wafers decreased 5.9 percent (see Table 3).

Wafer demand dropped off at most semiconductor companies as business uncertainty, weak employment statistics, and plummeting consumer confidence stalled the economic recovery. Particularly hard hit were those device makers with sales tied to large mainframe computers, midrange computers, and military applications. Companies such as IBM, Texas Instruments, Digital Equipment Corporation, and Harris cut way back on their purchase of wafers at the end of 1991.

The turmoil in the PC industry because of pricing pressures did not slow down the demand for semiconductors in this segment. The real strength in the PC industry appeared to come from MOS logic and analog devices with workstations, high-end 486DX-based PCs, and low-end 386SX-based notebook PCs being the major driving forces. In fact, we believe that the collapse of desktop PC prices has slowed the decline in PC unit growth rates since more affordable machines are now on the market.

The weak market for semiconductors in 1991 and a fab overcapacity problem is prompting many companies to close marginal fabs. AMD, Intel, Seeq, and Western Digital have closed fabs or announced closings in 1991. Dataquest expects this trend to continue into 1992 with National already announcing the closure of three California lines. Our new silicon wafer forecast reflects this decrease in wafer start capacity, which is primarily in fabs running smaller-diameter wafers.

Forward to 1992

The first quarter of 1992 has seen wafer demand improve along with the rest of the U.S. economy. Dataquest's 1992 forecast calls for total silicon consumption to increase 5.0 percent; epi wafers by 8.0 percent; and prime, test, and monitor wafers by 4.5 percent. Nevertheless, these growth rates are very moderate by historical levels, especially for a postrecession year, which typically results in a surge in demand.

The strength of the recovery in the U.S. economy hinges on the consumer, who accounts for two-thirds of the U.S. gross domestic product. However, we believe that consumer spending will be modest because of the cloudy outlook for decent consumer income growth. We expect income to pick up moderately as the economy recovers. Rapid growth remains unlikely. The absence of fiscal stimulus (remember those big federal deficits), the slowdown in growth abroad—which will limit the growth of U.S. exports—and the reluctance of U.S. companies to hire new workers all should cap the rate of income gains in 1992 and keep the U.S. consumer cautious.

The U.S. Federal Reserve Board's discount rate cut in December 1991 laid the groundwork for a stronger first quarter. For the third consecutive month, both bookings and billings of semiconductors in April hit record highs.

Not surprisingly, semiconductor companies have reported first-quarter 1992 financials that look very good. Motorola's semiconductor revenue leaped 20.7 percent in the first quarter on a year-to-year comparison; the company's just-reported semiconductor revenue totaled $1.1 billion. AMD's microprocessor revenue (45 percent of total) was up 24 percent sequentially, driven by 386SX and 386DX sales. Other AMD revenue (55 percent of total) was up 3.5 percent sequentially.

These very bullish trends have caused us to raise our midyear forecast for silicon slightly. Even so, we are still cautious about 1992 semiconductor production in the United States, because the first-quarter burst in semiconductor ordering is largely attributable to inventory replenishment. Semiconductor distributor resales and orders have been strong—some of which is accounted for by seasonal factors.

On the other hand, OEM business, a much stronger indicator of a recovery, is firming but not as strong as distribution. Furthermore, over the last six years the annual book-to-bill has peaked in April four times and once in March and May. This historic trend may suggest that the industry has seen the strongest growth of the year in the first half. Until the OEM business gives more of a positive signal, we will stick with our current forecast.

We also expect the U.S. 200mm market to be up moderately in 1992 (see Table 4). Intel is moving aggressively on 200mm projects at Aloha, Oregon and Santa Clara, California, which will increase its demand mostly for test and monitor wafers. We are also more positive about wafer demand at IBM and have increased our epi forecast. On a negative note, Motorola's MOS 11 line is ramping very slowly.

On the 200mm supply side, we expect intensified Japanese competition in the United States because of the delays in the ramp of the Japanese 200mm market. Much of the 200mm wafer production capacity installed in Japan will now be searching for international markets.

Dataquest Perspective

All in all, we expect U.S. wafer demand to be tepid in 1992. It is this climate that has historically produced fierce pricing pressures in the industry and we do not expect 1992 to be an exception to the rule. The distinguishing factor for successful wafer vendors in 1992 may be the quality of their customer base, as the rising tides of recovery are not expected to raise all boats.

By Mark FitzGerald

Japanese Market Pulse

Recap 1991

The demand for silicon in Japan was robust through the first half of 1991. However, consumption began to fall off in the fourth quarter, and total consumption of silicon wafers in Japan grew 5.4 percent in 1991. The strongest demand was in epitaxial wafers, which grew 11.6 percent, pushed ahead by the power module market. The demand for prime, test, and monitor wafers grew 4.8 percent.

For most of 1991 Japan's economy appeared to have escaped the grip of recession that slowed Western economies. The Middle East crisis proved to be more of a political hot potato than a stumbling block for Japanese industry. Oil prices fluctuated widely before and during the crisis, causing a great deal of concern for Japanese industry. But with the successful conclusion of the crisis the threat of higher oil prices faded and the unprecedented expansion of the Japanese economy appeared on track.

However, by summer the first cracks in the Japanese expansion could be seen. The Bank of Japan's tight monetary policy was having its intended effect on the excesses of the bubble economy. Real estate prices had collapsed, even if banks and investment companies failed to recognize the lower valuations. The stock market had fallen by more than a third from its historical peak and consumer confidence was beginning to wane.

For the semiconductor industry, concern began to mount as electronic equipment inventories continued to build. Many companies had expected the Western export markets to shake off the recession and soak up the growing inventory of consumer products. But Christmas season demand fell short of the mark as consumer confidence sank to new lows in the West.

In addition, deflation in the Japanese real estate sector and the decline of Japanese equities kicked the wind out of Japanese business. Companies that depended on the growth of equities or real estate to prop up their balance sheets quickly found that the rules of the game had changed. Retained earnings derived from operating profits would now be required to sustain growth, but earnings in the current environment were difficult to generate. Something had to give and it was capital spending.

By the fourth calendar quarter Japanese companies began to cut their FY1991 capital spending. The cuts particularly hit computer and office equipment purchases, which exacerbated the already high electronic equipment inventory levels. During SEMICON/Japan held in December 1991, it was quite evident to many silicon wafer vendors that 1992 was going to be a down year, the first since 1986.

Forward to 1992

Nearly halfway through the calendar year 1992, there appears little chance that silicon demand will turn up sharply in Japan. Industrial production dropped a seasonally adjusted 2.8 percent in March from February and fell 5.3 percent compared with year-ago levels. March was the sixth consecutive month in which production fell on a year-over-year basis. Worse yet, these declines are accelerating. From November through March production registered successive year-over-year declines of 1.0, 1.9, 4.0, 4.6, and 5.3 percent. For the entire first quarter, output plunged an adjusted 3.2 percent.

For April the Ministry of International Trade and Industry (MITI) forecast a 0.9 percent decline in industrial output. MITI has described the outlook for industrial production as "considerably severe," saying that Japan is likely to see output drop in the second quarter of 1992.

On the positive side, Japanese electronic equipment manufacturers are cutting back production and are continuing to bring inventories into line. Inventories had been building up through January 1992 and have since been declining. From a fundamental point of view this means that Japanese electronic manufacturers are turning the corner. Silicon demand, which has been down sharply in the first calendar quarter of 1992, is expected to bottom in summer and see modest growth in the second half of the year. Even so, demand in 1992 is expected to shrink 3.2 percent year-to-year.

Over the longer term, there is a chance that the downturn will impact Japanese semiconductor production more severely than other sectors of industry for two reasons. First, we expect trade friction caused by mounting trade deficits to aggravate the already weak export picture for semiconductors. Because Japan is a net exporter of devices, the mounting trade deficit with the United States and especially Europe is reigniting the call for protectionist measures. It is possible that this problem will haunt the Japanese semiconductor industry well past 1992 and cause slower growth in silicon demand once the general economy turns up.

Second, there is some risk that the downturn in capital spending is the beginning of a structural change in the Japanese semiconductor industry. Early in the last decade Japanese companies made a conscious decision to pursue the commodity memory market. It was a strategy that proved very successful because of the PC boom and U.S. companies' abdication of the memory market.

However, the Achilles heel of this strategy is becoming apparent. Squeezed from below by low-cost Asian memory producers and from above by the increasingly fragmented application-specific nature of the MOS microcomponents and MOS logic makers in the United States, Japanese device companies are scrambling for a strategy. Complicating their dilemma is the large capacity they have installed and the slower adoption of the advanced memory products in end-use applications.

These problems threaten the long-term growth of the Japanese silicon market, and consequently we have lowered our five-year compound annual growth rate (CAGR) for silicon in Japan to 4.8 percent.

We have also cut back our growth rate for 200mm wafer consumption in Japan. Many Japanese companies continue to push out their plans for adding 200mm capacity and it is now likely that some of these fabs will not be built at all. We expect capital spending on 200mm lines to pick up in the fourth quarter of 1992 at reduced levels. Based on this timing we are forecasting 200mm wafer demand to grow rapidly in 1994.

Dataquest Perspective

Japan will remain the largest market for silicon. However, structural problems threaten to derail the historical growth this market has enjoyed over the last 10 years. The dilemma for the Japanese semiconductor industry would be resolved if there was a surge in demand for consumer electronics, which would soak up the excess capacity in the electronic food chain. But slower economic growth in the industrialized nations and the lack of any product driving device demand has caused us to be more cautious about the Japanese silicon market.

By Mark FitzGerald

European Market Pulse

Recap 1991

The demand for silicon in Europe started out on a weak note in 1991 and got worse. Silicon consumption declined 11.7 percent in 1991, the worst year on record since the 1985 recession. The domestic European companies whose semiconductor programs were suffering deep losses closed facilities and cut production, accounting for the lion's share of the decline in silicon demand.

In addition, slower silicon demand at transplant fabs hurt the demand for silicon. Texas Instruments' Avezzano, Italy line experienced delays and the ramp of the fab, beginning in the fall of 1991, was slow because of the global downturn in TI's business. The weak market for the 4Mb DRAM also caused Japanese operations, NEC, and Fujitsu to cut their silicon usage.

The European economy was arguably the biggest drag on silicon demand. At the beginning of 1991 only the United Kingdom was in recession, but as the year ground on the other Western European economies began to decelerate. Higher interest rates were the main culprit.

The true cost of German unification gradually became apparent to the Bonn government over the course of the year. In response to the inflationary pressures of unification the Bundesbank pursued a tight monetary policy, driving interest rates to the highest levels in the European community. These high rates rippled across the rest of Europe because the other European community members' currencies are tied to the deutsche mark.

As a result, growth rates in most countries declined and the slower growth had a deleterious impact on the entire electronic food chain in Europe, including silicon.

Forward to 1992

The decline in 1991 silicon consumption was more severe than we had forecast. Consequently, we are revising our growth rate for 1992. At the beginning of the year we had estimated that silicon consumption would shrink 2.8 percent in 1992. However, because of the steep decline in 1991 we now expect consumption in 1992 to grow 3.2 percent.

It looks as if European silicon consumption has hit bottom and may eke out slight gains in 1992. We are encouraged by the improving signs in the economy, which will benefit industrial production. The headway made by the Bundesbank on inflation is at the top of the list.

Consumer price inflation eased to 4.5 percent in April from 4.8 percent in March. The March inflation rate probably represents a peak, and we expect inflation to decline through most of 1992. A clear trend on inflation is one of several developments the Bundesbank will look for before easing monetary policy.

If German rates begin falling in the second half of 1992, then we would expect a moderately strong upturn in industrial production and silicon demand in 1993. As we look further out to the middle of the decade, we believe that Eastern Europe will become more of a positive factor in driving semiconductor demand.

If this were to happen, then it is reasonable to expect additional investment in new fab capacity, which would drive the demand for silicon higher. But it is necessary to emphasize that the timing of this trend on silicon demand is very speculative today.

Dataquest Perspective

We remain positive about the long-term prospects for European silicon demand, even if we are less sure of its timing. Europe accounted for 17 percent of the worldwide semiconductor consumption in 1991 and 12.3 percent of the production. It is a net importer of devices. The European Community (EC) is expected to try to close this gap by encouraging additional investment in domestic production.

Though the formation of a unified Europe in 1992 is certainly not the compelling reason for investing in new fabs that many people thought it would be several years ago, we believe that it may yet prove to be a boon to European device production. Western Europe will certainly be a unified market larger than the United States, as has been well advertised by the EC. But more important we believe will be the European communities' access and cultural ties to Eastern Europe and the former Soviet states. As these regions begin to develop, we expect Western European semiconductor production to benefit.

By Mark FitzGerald

Asia/Pacific Market Pulse

Recap 1991

The 1991 growth of silicon consumption in Asia/Pacific fell below our expectations. Demand posted a respectable 7.5 percent growth, though down from the historic double-digit growth rates. The deceleration can be attributed to recession in the Western economies, which this region's semiconductor manufacturers rely on for the export of devices.

Also contributing to the single-digit growth rate was the inventory buildup of wafers that took place in fall 1990. Several large Korean semiconductor device makers purchased large inventories at that time because the supply of silicon was tight. These inventories were then carried over into 1991, resulting in lower purchases of wafers, which did not reflect the actual production starts.

Even so, growth in Asia/Pacific silicon demand was the highest in the world. The region is highly leveraged on DRAM production and continues to make inroads into the major Western markets. Samsung, the largest device vendor in Asia/Pacific, increased market share in the flat U.S. market largely because of stronger penetration of the 1Mb market.

The primary silicon consuming countries—Korea, Taiwan, Hong Kong, and Singapore—sustained strong growth rates in 1991. The growth was fueled by a strong construction sector and a surge of internal consumption and exports to other Asian countries.

Korea's Gross National Product (GNP) expanded by 8.6 percent last year. However, the strong growth hides some serious problems. Korea's trade deficit worsened, the won lost ground against other major currencies, and inflation stubbornly hovered in the 10 percent range. In addition, the European Community began investigating allegations that Korean companies were dumping DRAMS.

Taiwan's economy showed the most resilience among the four tigers. GNP is estimated to have grown 7.2 percent in 1991. The trade surplus widened to U.S.$13.3 billion. Many of Taiwan's industries benefited from strong exports to trading partners in Southeast Asia and China, which were not impacted by the recession in the West.

The export of electronic equipment did increase 4.7 percent to U.S.$7.8 billion, which is respectable considering the downturn in the worldwide computer industry. One industrial segment that saw its weak exports to the West offset by strong sales to other countries within Southeast Asia was Taiwan's low-cost clone manufacturers. As a result, silicon consumption held up throughout the year.

Trends in Hong Kong and Singapore have a very small effect on the Asia/Pacific silicon cycle. Hong Kong's economy is increasingly tied to the economic boom under way in the southern provinces of China, especially Guangdong. Hong Kong's GNP grew 3.9 percent in 1991.

Singapore on the other hand is tied much closer to the United States; 21 percent of its nonoil exports go to the United States. In 1991 Singapore's GNP grew 6.5 percent. Both countries are increasing their participation in the PC clone and disk drive industry. We believe that the rate of investment in semiconductor fabs to support these system businesses also will increase.

Forward to 1992

Silicon consumption in Asia/Pacific is expected to pick up in 1992, benefiting from the stronger demand in the United States for semiconductors. We are estimating that the Asia/Pacific consumption of silicon will grow 12.4 percent in 1992. Capital investment in fabs continues at a breakneck pace, which bodes well for strong wafer demand over the next several years. Our five-year compound annual growth rate (CAGR) for Asian/Pacific silicon consumption is 12.4 percent.

The lion's share of the current capital spending on new fabs is taking place in Korea. This spending trend will benefit silicon consumption over the next several years. We are forecasting Korea consumption of silicon to grow 11.4 percent CAGR through 1996 (see Table 5).

But it is unlikely that the boom in capital spending can be maintained. It is becoming increasingly more difficult to maintain the huge capital outlays for new fabs with local interest rates in the 17 percent range and Korean equity prices tumbling. Even the overseas markets are backing away from Korean paper as Samsung realized recently when its convertible bond offering received a chilly reception in the Euromarkets.

Korean electronic products are also losing their competitive edge. They lack the brand awareness and quality of Japanese and U.S. products and are no longer cost competitive with products coming out of Southeast Asia and China. In addition, the semiconductor industry is increasingly feeling the heat from trade friction. Micron

Technology has just filed dumping charges against the major Korean DRAM makers and Japanese companies are being more aggressive in negotiating royalty payments for intellectual property rights.

Perhaps the biggest detriment to the long-term growth of the Korean economy is the strong hand of the Korean economic planners. The government is favoring the high-technology sector with preferential rates for borrowing to the exclusion of other sectors of the economy. This policy has resulted in a capital spending boom on new semiconductor plants. But it is questionable whether exports and the local markets can absorb this capacity. Consequently we expect the capital investment boom to peak either this year or next.

Taiwan's market-driven economy is in many respects much healthier than is Korea's. Though its silicon consumption is much smaller than is Korea's, its semiconductor industry is better balanced. Taiwan has a thriving computer market, which provides device makers a domestic market for their product. As a result we forecast silicon demand to grow at 8.3 percent over the next five years.

However, the real star performer in terms of growth in silicon consumption will be the group of countries that fall under the rubric rest of world (ROW). We estimate that silicon consumption for this group will push ahead at a 22.3 percent CAGR. Countries that will benefit from this growth are Hong Kong, Singapore, China, and the newly industrializing nations in the Pacific rim such as Thailand and Malaysia. Much of the growth in the ROW category will be fueled by investment and technology transfers from Japanese and to a lesser extent U.S.-based companies.

Dataquest Perspective

The Asia/Pacific region remains the most vibrant in terms of growth rates in silicon consumption. However, we do expect some rotation in the growth of silicon consumption away from the current leaders within the region to those countries just beginning to build their industrial infrastructure. The ultimate growth opportunities will be China and India because of the sheer size of the markets. But political turmoil, fragile legal systems, and underdeveloped infrastructures make the timing of these opportunities difficult to gauge.

By Mark FitzGerald

Table 1
Forecast of Captive and Merchant Silicon* and Merchant Epitaxial Wafers
(Units—Millions of Square Inches)

	1991	1992	1993	1994	1995	1996	5-Year CAGR (%)
United States	611	642	689	746	789	824	6.2
Percentage Growth	-4.5	5.0	7.3	8.2	5.8	4.6	
Japan	1,046	1,012	1,081	1,161	1,239	1,319	4.8
Percentage Growth	5.4	-3.2	6.9	7.4	6.7	6.5	
Europe	208	213	227	246	267	296	7.3
Percentage Growth	-11.7	2.3	7.0	8.0	8.8	10.5	
Asia/Pacific	194	218	248	283	316	353	12.7
Percentage Growth	7.5	12.2	13.6	14.3	11.6	11.8	
Total	2,059	2,085	2,245	2,436	2,611	2,793	6.3
	0.5	1.2	7.7	8.5	7.2	7.0	

*Includes prime, test, and monitor wafers
Source: Dataquest (June 1992)

Table 2
Forecast of Merchant Epitaxial Wafer Consumption by Region (Units—Millions of Square Inches)

	1991	1992	1993	1994	1995	1996	5-Year CAGR (%)
United States	92	99	111	123	130	137	8.4
Percentage Growth	4.0	8.0	11.8	11.4	5.8	5.0	
Japan	104	106	118	124	128	133	5.0
Percentage Growth	11.6	2.3	11.5	5.2	2.5	4.0	
Europe	20	21	26	30	33	36	12.1
Percentage Growth	7.4	5.4	21.5	16.4	9.0	9.0	
Asia/Pacific	7	8	9	10	13	17	20.6
Percentage Growth	43.5	17.9	16.7	11.7	27.9	30.0	
Total	222	234	264	288	304	322	7.7
	8.7	5.4	12.7	9.1	5.5	6.1	

Source: Dataquest (June 1992)

Table 3
Forecast of Captive and Merchant Silicon* Wafer Consumption by Region (Units—Millions of Square Inches)

	1991	1992	1993	1994	1995	1996	5-Year CAGR (%)
United States	520	543	578	622	658	688	5.8
Percentage Growth	-5.9	4.5	6.4	7.6	5.8	4.5	
Japan	942	906	963	1,037	1,111	1,186	4.7
Percentage Growth	4.8	-3.8	6.3	7.7	7.2	6.7	
Europe	188	191	201	215	234	260	6.7
Percentage Growth	-13.3	1.9	5.4	6.9	8.8	10.8	
Asia/Pacific	188	210	239	273	303	336	12.4
Percentage Growth	6.6	12.0	13.5	14.4	11.0	11.0	
Total	1,837	1,850	1,981	2,148	2,307	2,470	6.1
	-0.4	0.7	7.1	8.4	7.4	7.1	

*Includes prime, test, and monitor wafers
Source: Dataquest (June 1992)

Table 4
Forecast of 200mm Wafer Consumption by Region (Millions of Units)

	1991	1992	1993	1994	1995	1996	5 Year CAGR (%)
United States	0.5	0.6	0.8	1.2	1.4	1.8	30.2
Japan	0.3	0.4	0.6	2.4	3.3	3.5	61.9
Europe	0.2	0.2	0.3	0.4	0.7	0.8	34.7
Asia/Pacific	0.1	0.1	0.2	0.4	0.6	0.6	56.1
Total	1.1	1.4	1.9	4.3	6.0	6.7	44.9

Source: Dataquest (June 1992)

Table 5
Asia/Pacific Row Forecast Silicon Wafer Consumption (Millions of Square Inches)

	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
Total Prime, Test, and Monitor Wafers	187.8	210.3	238.7	273.1	303.2	336.5	12.4
Korea	126.0	137.0	157.0	180.0	199.0	216.0	11.4%
Taiwan	39.0	48.0	52.0	55.0	57.0	58.0	8.3
ROW	22.8	25.3	29.7	38.1	47.2	62.5	22.3
Total Epitaxial Wafers	6.6	7.8	9.1	10.1	13.0	16.9	20.6
Total Silicon	194	218	248	283	316	353	12.7

Source: Dataquest (June 1992)

Company Analysis

Posco-Hüls: The Race for the Asian Silicon Market

Posco-Hüls, the joint venture between Pohang Iron and Steel, MEMC Electronic Materials, and Samsung, is investing U.S.$110 million in a silicon wafer plant south of Seoul, Korea. Dataquest believes that the investment marks a change in strategy for MEMC in its struggle for market share with other major silicon vendors.

In addition, the Posco-Hüls joint venture signals a fundamental change in the global silicon business, which was first dominated by U.S. and European companies through the 1970s. In the 1980s the Japanese companies rose to prominence. For the 1990s the ascent of Asian companies is the theme most likely to dominate. As the industrializing nations in Asia build their semiconductor infrastructures, the region is expected to win a larger share of the new investment in silicon wafer production.

MEMC's Gamble

MEMC's participation in Posco-Hüls is a strategy to stay ahead of the Asia/Pacific silicon growth curve. MEMC is transferring its leading-edge eight- and six-inch wafer technology to the joint venture. The technology transfer includes crystal growing. The big risk for MEMC is that it may lose control of the technology by transferring the process to a joint venture company in which it has a minority position (see Table 1). In the worst-case scenario, MEMC could very well end up putting a competitor into business if the joint venture was to go sour.

MEMC in the mid-1980s was involved in a similar joint venture company in Korea called Korsil. The joint venture was dissolved in 1989 and most of the assets were acquired by Siltron (formerly Lucky Advanced Materials). Little technology was transferred to Korsil because the joint venture was a slicing and polishing operation. But the failure of Korsil points to the potential downside of MEMC's strategy.

On the other hand, the upsides for MEMC are considerable. The Asia/Pacific silicon wafer market is the fastest-growing wafer market in the world and Korea has by far the largest demand within the region. It is unlikely that Korea will relinquish its leadership in semiconductors anytime soon.

In addition, MEMC has a well-matched partner in Pohang. From a business point of view, Pohang is expected to bring valuable relations critical in doing business throughout the Pacific

Table 1
Equity Positions in Posco-Hüls

	Percentage	Type of Investment
MEMC Electronic Materials	40	Capital and Technology
Pohang Iron and Steel	40	Capital
Samsung Electronics	20	Capital

Source: Dataquest (June 1992)

Rim. (Parenthetically, 35 percent of Pohang is owned by the Korean government. The government's equity position is a key point, considering the Korean style of doing business at senior levels.)

Pohang is also a source of highly educated and motivated metallurgists. If the company's rapid ascent in steel is any kind of barometer, then the joint venture could easily push the current MEMC technology further and faster than MEMC could by itself.

On its face, Samsung's involvement in the joint venture is as an end user. It is the largest user of silicon in Korea. It is also one of MEMC's largest customers, accounting for an estimated 13 percent of MEMC's 1991 sales. But from a business point of view Samsung's involvement is probably more important in providing balance to the joint venture. In fact, it is unlikely that MEMC, after its experience with Korsil, would have agreed to a joint venture where Pohang held majority ownership.

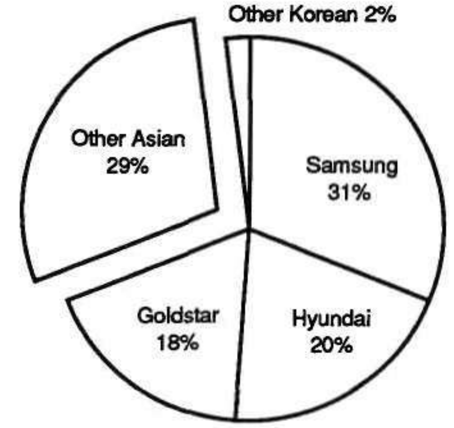
Korean Semiconductor Industry

Korean capital investment in front-end semiconductor facilities will defy economic gravity in 1992. Though Dataquest is forecasting worldwide capital spending to decrease 2 percent in 1992, we believe that Asia/Pacific capital spending will buck the trend and increase 22 percent. Korean companies will account for the lion's share of that spending, U.S.$1.8 billion out of a total U.S.$2.5 billion (see Figure 1). Within Korea, the chaebols (conglomerates) Samsung, Goldstar, and Hyundai will account for more than 95 percent of the semiconductor capital spending. The three top companies are investing U.S.$1.76 billion in 1992 as they push ahead with plans for advanced DRAM lines.

Samsung is adding an MOS 5 line that will be a 0.5-micron, 8-inch CMOS fab with a monthly capacity of 10,000 wafers. Goldstar and Hyundai are late to the 4Mb DRAM game but are determined to get a piece of the action. Both companies will add two 4Mb DRAM lines. These investments will rapidly increase the demand for silicon.

Because the semiconductor industry is a cornerstone of the Korean government's industrial policy, Dataquest expects the pace of investment in new semiconductor technology to remain strong.

Figure 1
1992 Asia/Pacific Semiconductor Capital Spending



Source: Dataquest (June 1992) G2000013

Domestic silicon wafer production is not only a natural extension of the government's vertically integrated semiconductor strategy but also is especially critical in light of the country's mounting trade deficit. In 1991, Korea imported 78 percent of its wafers, accounting for about U.S.$140 million of its U.S.$9.5 billion trade deficit.

The Korean Silicon Market

As a result of growth in domestic demand for silicon, investment in silicon wafer plants has increased rapidly in the last several years. In addition to the Posco-Hüls investment, two local companies are expanding their production. Siltron is expanding its domestic crystal growing capacity, and Oriental Electronic Metals, a newly formed company, is also building a silicon wafer plant for slicing and polishing. All three plants will begin ramping production (see Table 2) within the next 12 months.

Local production will come online just in time to take advantage of the next upturn in the silicon cycle. Dataquest forecasts the demand for silicon in Korea to grow at an 11.3 percent compound annual growth rate from 1991 to 1996 (see Table 3). Though prime, test, and monitor wafer demand showed only moderate growth in 1991 and is forecast to grow only 8.2 percent in 1992, we expect demand to pick up in 1993 because of

Table 2
Korean Silicon Wafer Production, by Plant (Millions of Square Inches)

Plant	Capacity/Year	1988	1989	1990	1991	1992	1993	1994	1995	1996
Siltron	60 msi/1991	32	29	31	32	33	43	45	50	50
Posco-Hüls	90 msi/1993	NA	NA	NA	NA	NA	16	27	45	59
Oriental Electronic Metals	60 msi/1992	NA	NA	NA	NA	5	26	36	41	41
Total		32	29	31	32	38	86	108	136	150

NA = Not applicable
Source: Dataquest (June 1992)

Table 3
Korean Silicon Consumption (Millions of Square Inches)

	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
Total	56	80	100	120	131	142	163	187	206	223	11.2
Silicon Wafer*	53	77	95	116	126	137	157	180	199	216	11.3
Percentage Change		26.4	23.9	21.7	8.9	8.2	15.1	14.6	10.2	8.7	
Merchant Epi	2.7	3.3	4.2	4.4	4.7	4.9	5.8	6.8	7.4	7.3	9.4
Local Production		32	29	31	32	38	86	108	136	150	
Imports		50	72	92	102	112	111	125	122	125	
Exports		1	1	3	3	8	33	46	51	51	
Local Consumption		80	100	120	131	142	163	187	206	223	

*Prime, test, and monitor
Source: Dataquest (June 1992)

stronger Western economies and a ramping of new DRAM lines. All three of the new plant expansions will be in place to take advantage of this growth.

An important point to note is that Dataquest has increased its estimate of the overall size of the Korean silicon market based on information we collected during a recent visit to South Korea. Conversations with suppliers and users lead us to believe that we underestimated the market by 35 million square inches (msi) in 1990. Table 3 shows the current adjusted totals for silicon consumption from 1987 through 1991. These adjustments mean that silicon consumption data for the Asia/Pacific region were understated in earlier publications. All future regional data will reflect the new information.

Domestic production of silicon will increase over the next several years. We expect local production to total 150 msi by 1996. Even so, we estimate that Korea will still import 125 msi to meet local demand. Imports will still be required because the current investments in capacity are not expected to meet the growth in demand. Also, device manufacturers will still second source from vendors overseas in case domestic production is interrupted.

SEH and Wacker are the two foreign-based vendors that stand to lose the most because of Posco-Hüls' move. By installing leading-edge crystal-pulling technology in Korea, MEMC hopes to grab significant share of the Asian market and to keep SEH and Wacker, the other market share leaders in the region, on the defensive. The two domestic competitors—Siltron and Oriental Electronic Metals—are not currently focused on the high-end markets and are not expected to compete directly with Posco-Hüls in the immediate future.

However, it is unlikely that SEH or Wacker will abdicate market share without some spirited defense. There probably will be additional investment in Asian wafer lines as foreign competitors move to secure a position in the Asia/Pacific market. These potential investments may not necessarily be made in Korea. Even now there are rumors that China Steel—a Taiwan-based company—has plans to enter the silicon business in Taiwan.

Dataquest Perspective

The challenge for established silicon companies is to win a piece of the Asian market. The days when a silicon vendor could simply ship wafers into these countries are waning. Future investment in world-class Asian plants will most certainly be necessary. The Posco-Hüls joint venture marks the first of these investments.

Though Korea is the largest consumer of silicon in the Asian market today, the really big opportunity over the long term is China. So, investments made today may prove to be more strategic than tactical by paving the way for participation in a much larger Asian market.

By Mark FitzGerald

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Dataquest Perspective

Semiconductor Equipment, Manufacturing, and Materials

SEMM-SVC-DP-9207 June 1, 1992

In This Issue...

In this issue of Dataquest Perspective, we continue our special coverage and discussion of the general trends in the wafer fab equipment market and those specific issues that characterize the market for the major segments of wafer fabrication equipment.

Market Analysis

Semiconductor Equipment

Multilevel Metal Mania: 1991 Sputter Equipment Market in Review

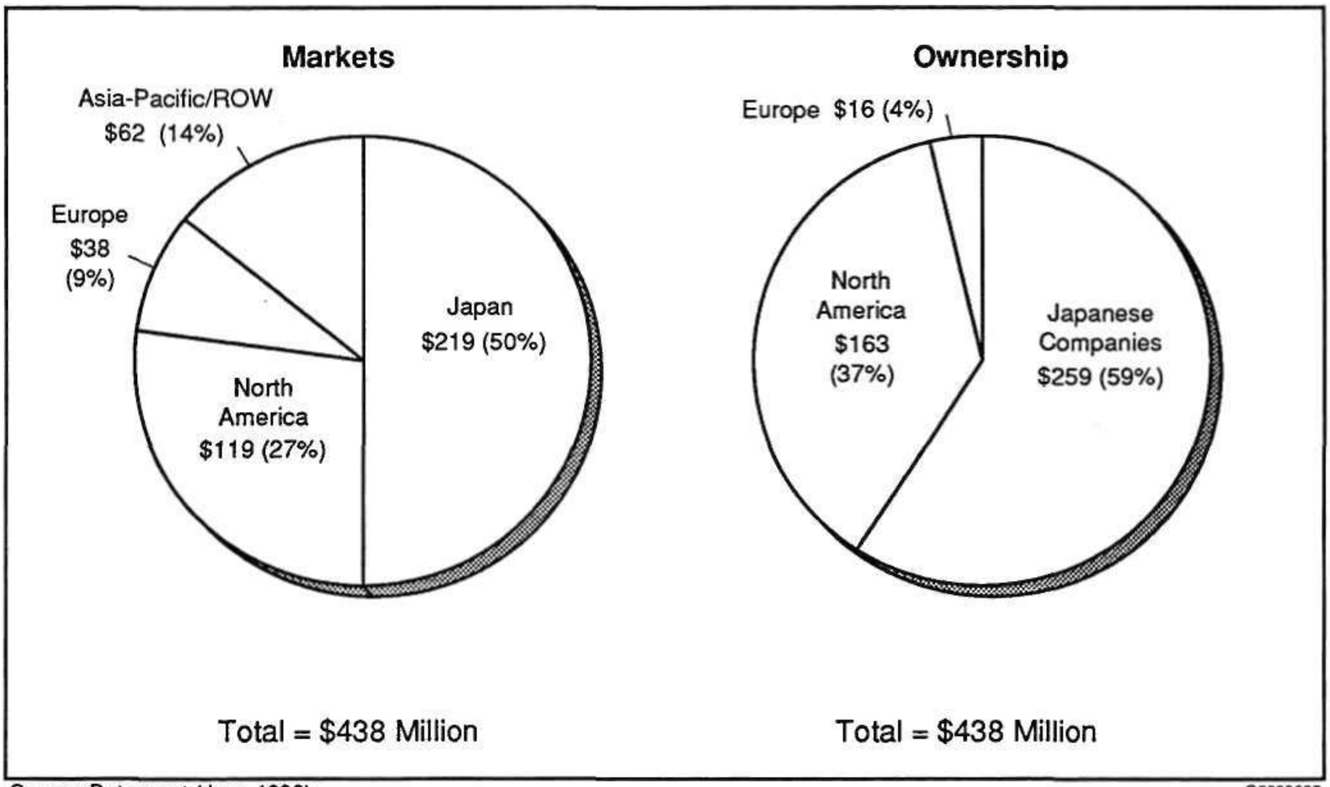
The 1991 physical vapor deposition (PVD) market represented a bright spot in an otherwise lackluster wafer fab equipment market. The PVD market grew by 16 percent from $408 million in 1990 to $474 million in 1991. The sputtering equipment segment, which constitutes 93 percent of the 1991 PVD market, grew dramatically by 22 percent from $359 million in 1990 to $438 million in 1991.

Steep increases in sputtering equipment average selling prices (ASPs), together with enhanced unit demand for multilevel interconnect applications in advanced 4Mb DRAMs and microprocessor/ASIC devices, were responsible for robust growth in the 1991 sputtering equipment market. In contrast, the mature evaporation equipment market, which represents only 7 percent of the 1991 PVD market, actually declined 24 percent in 1991.

Regional Markets and Ownership

Figure 1 shows the worldwide 1991 sputtering equipment market segmented by region and ownership. Japan, with 50 percent ($219 million) of the 1991 sputtering market, represented the largest regional market. In 1991, semiconductor capital investment in Japan was focused on 150mm and 200mm advanced 4Mb DRAM shrink production and 16Mb DRAM pilot line production. Japan-based semiconductor manufacturers attempted to leapfrog competitive advances from lower-cost Korean DRAM producers such as Samsung by rapidly migrating to high-speed, premium DRAM products that were implemented in double-level metal. Japan-based fabs also focused on more flexibility and ASIC/microprocessor/memory multiproduct capability. The new focus on interconnect technology-driven products stimulated the expansion of the high-end flexible, cluster-tool sputtering equipment market in Japan.

Figure 1
1991 Regional Sputtering Equipment Markets and Ownership



Source: Dataquest (June 1992)

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The vigorous expansion of 4Mb DRAM and advanced logic fabs in Korea and Taiwan also stimulated the growth of the Asia/Pacific sputtering equipment market. Companies such as Samsung migrated to double-level metal versions of their shrink 4Mb DRAM production. In general, the migration from single- to double-level metal in the Japanese and Asia/Pacific markets stimulated the growth of the worldwide sputtering equipment market. Companies such as Digital Equipment Corporation, IBM, Intel, Motorola, and Texas Instruments migrated to triple-level metal for their advanced microprocessor and VLSI logic devices, thus sustaining the demand for advanced cluster-tool-based sputtering equipment in the North American market. The lack of major interconnect-intensive device production in Europe, coupled with overall anemic demand for wafer fab equipment, resulted in a generally weak European sputtering equipment market in 1991.

Japanese companies, with 59 percent ($259 million) of the worldwide market, retained their leadership position in the sputtering equipment market. North American companies, with 37 percent ($163 million) of the market, gained market share in 1991 at the expense of European equipment companies. Applied Materials, a newcomer to the market, augmented the North American company group performance because of its strong showing in the 1991 sputtering equipment market. The transfer of the Europe-based Balzers PVD business to the Japan-based MRC/Sony business favorably impacted the 1991 Japanese sputter company group performance.

Table 1
1991 Worldwide Sputtering Equipment Company Rankings (Revenue in Millions of Dollars)

Company	Revenue	Market Share (%)
Anelva	114.5	26.2
Varian	90.9	20.8
MRC (Sony)	84.5	19.3
Applied Materials	55	12.6
Ulvac	54.5	12.5
E.T. Electrotech	12	2.7
CVC Products	7	1.6
Leybold-Heraeus	4.4	1.0
Shibaura Engineering Works	4	0.9
CPA	2	0.5
Novellus Systems, Inc.	1.8	0.4
Denton Vacuum	1.8	0.4
Sputtered Films	1.5	0.3
Others	3.8	0.9
Worldwide Market Total	437.7	100.0

Note: Spares and service are not included.
Source: Dataquest (June 1992)

Company Rankings

Table 1 ranks the 1991 worldwide sputtering equipment companies.

Anelva

Anelva, with 26.2 percent of the market, retained its leadership position. Anelva's strong position in the large Japanese market, together with its experience in isolated-chamber Ti/TiN/aluminum alloy sputtering applications on its popular Series 1051 cluster tool, has enabled the company to remain the top player in sputter systems. Dataquest believes, however, that Anelva will need to globalize its operations at an accelerated pace in order to overcome its excessive dependence on the Japanese market.

Varian

Varian, with 20.8 percent, retained its No. 2 position in the market. Varian continued to aggressively penetrate the market with its advanced M2000 cluster-tool system for submicron device applications. Varian's strong presence in Asia/Pacific allowed it to capitalize on the 1991 boom in that region. The step-coverage enhancement provided by the Quantum source, together with Varian's pioneering efforts in collimation-based step-coverage enhancements, allowed the company to secure design wins at several major 4Mb DRAM production/16Mb DRAM pilot lines. Varian also continues to benefit from its cash-cow Series 3000 multichamber tool that cost-effectively addresses more mature device fab applications and capacity expansion programs.

Materials Research Corporation (MRC)/Sony

MRC/Sony, with 19.3 percent of the market, ranked third in the worldwide sputtering equipment market in 1991. MRC/Sony continued to proliferate applications for its successful Eclipse systems with enhancements such as improved throughputs, enhanced step-coverage, low-damage soft precleans, loadlock options, and particle-reduction kits. MRC/Sony's acquisition of the Balzers Clusterline sputtering family and its integration into the new Galaxy open-architecture cluster tool will allow MRC/Sony to address future needs of sub-0.5-micron devices. MRC/Sony's prior acquisition of the BCT/Spectrum metal CVD business also positions the company well in offering integrated PVD/CVD interconnect solutions on its Galaxy cluster tool.

Applied Materials

Applied Materials, a newcomer to the sputtering equipment market, demonstrated meteoric success in rapidly gaining 12.6 percent of the 1991 market. The company's flagship Endura cluster tool was very successful in capturing several key design wins at leading 200mm submicron device fabs. Dataquest attributes the phenomenal success of the Endura system to Applied's emphasis on exceptional reliability, low-particle performance, global customer support, process support, and migration path to integrated metal CVD/PVD solutions. Dataquest expects Applied to face intense competition in subsequent PVD market battles as competitive flexible cluster tools that offer staged, high-vacuum capability for 200mm submicron applications hit the market.

Ulvac

Ulvac accounted for 12.5 percent of the 1991 sputtering equipment market. Ulvac continued to market its flagship MLX-3000 cluster-tool sputtering system for isolated chamber sputtering applications. Ulvac is also bringing new cluster tools to market that address the integrated metal CVD/PVD/dry etch applications market. Ulvac will attempt to integrate its pioneering selective tungsten CVD and soft plasma preclean technologies with its sputtering film capabilities in order to offer a complete interconnect solution to its customers. Ulvac is also aggressively globalizing its operations in order to minimize its overdependence on key DRAM-driven Japanese customers such as Toshiba.

Dataquest Perspective

The worldwide sputtering equipment market represented a bright spot in the 1991 wafer fab equipment market, posting aggressive growth of 22 percent. The market was driven by the accelerated conversion to double-level metal 4Mb DRAM shrink products and the continuing trend in microprocessor/VLSI logic devices toward triple- and quadruple-level metal. New entrants to the sputtering equipment market such as Novellus, together with the growing dominance of newly established players such as Applied Materials, may completely recast the balance of power in the sputtering equipment market. Incumbent market leaders such as Anelva, MRC/Sony, Ulvac, and Varian will fiercely defend their entrenched positions. A shakeout may be coming in the crowded sputtering equipment market.

By Peggy Marie Wood and
Krishna Shankar (San Jose)
Kunio Achiwa (Tokyo)

Riding the Roller Coaster: 1991 Ion Implantation Market in Review

The dynamics of the ion implantation equipment market can be compared to an amusement park roller coaster ride complete with thrilling heights and gut-wrenching depths. Plagued by an overall sluggish capital spending environment, the worldwide implant equipment market last year was $343 million, down 7 percent from its 1990 level of $370 million. Clearly, this percentage change was relatively modest when compared with the peak year of 1988 when the market grew 103 percent. Nor was last year's decline as severe as 1986 when ion implantation equipment revenue plummeted 60 percent. Fundamentally, the implant market is driven by capacity demands rather than technological innovation and this has contributed to a market environment characterized by sharp surges and subsequent drop-offs in activity.

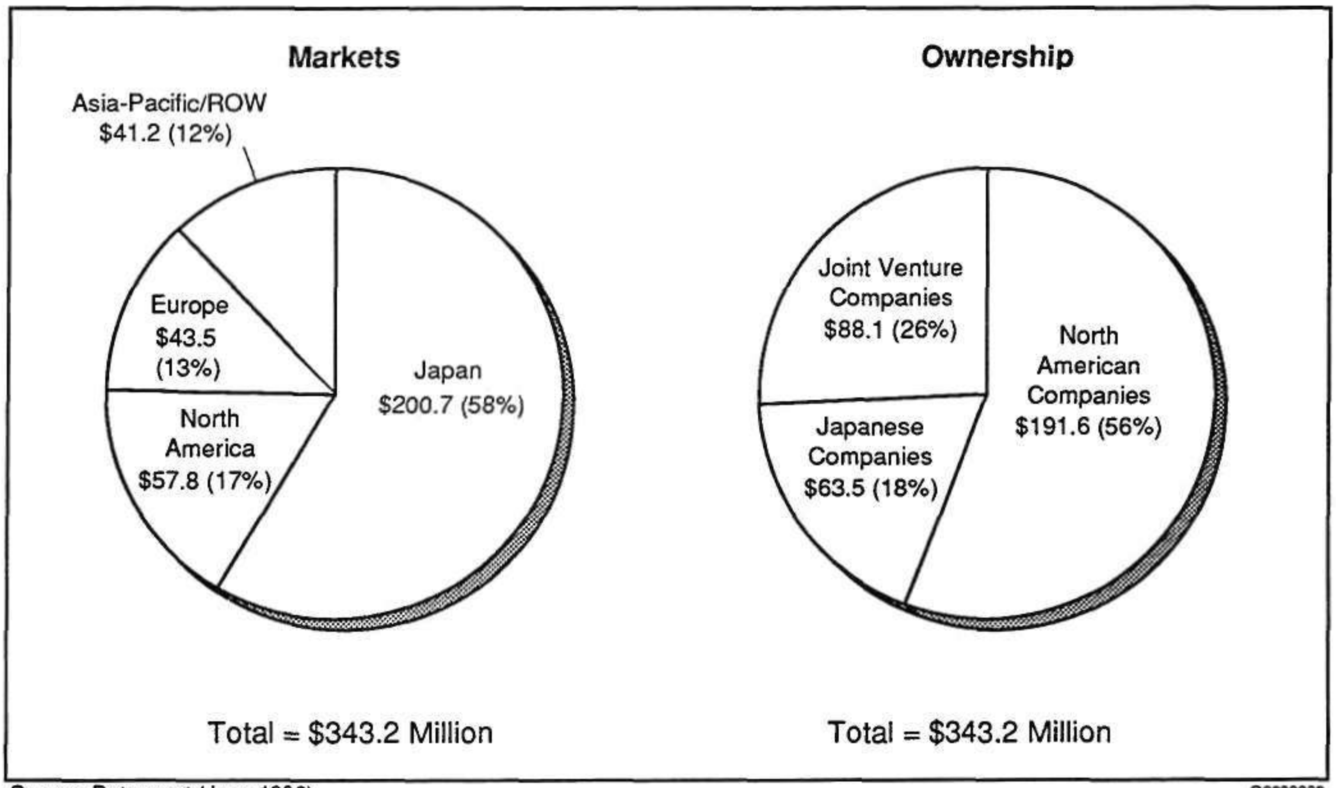
Both medium- and high-current tools suffered a decline in shipment levels and revenue in 1991. Unit shipments for medium- and high-current implanters tumbled 19 percent and 18 percent, respectively. The corresponding decline in medium- and high-current implant market revenue was minimized by increasing average selling prices (ASPs) as newer advanced systems became a larger portion of the total product mix. The medium-current implant market was about $108 million in 1991, down 5 percent from the previous year's level of $114 million, while the high-current implant market dropped to $218 million, a decline of 13 percent from its 1990 level of $250 million.

The high-voltage implant market experienced a significant increase in revenue last year, growing from about $7 million in 1990 to almost $18 million in 1991. However, one must keep in mind that this category of equipment represents only a small, niche segment. Unit shipments last year totaled only six systems as compared with three the year prior. A hefty increase in average selling price from $2.3 million to $2.9 million accounted for a significant portion of the revenue increase for high-voltage implanters in 1991.

Regional Markets and Ownership

Figure 1 presents the worldwide 1991 ion implantation equipment market segmented by region and ownership. Japan, with 58 percent share of the world market, continues its dominant position in the marketplace, driven by its need to equip advanced high-volume manufacturing facilities. North American companies, however, continue to hold their dominant position in all three segments of the implant market and together command 56 percent worldwide market share. Further influence of U.S. company technology in the implant market is also evident in the success of the two U.S./Japanese joint venture companies, TEL/Varian and Sumitomo/Eaton Nova, much of whose technology historically has flowed from their U.S. partner companies. In 1991, these joint venture companies represented 26 percent share of the worldwide implant market. The implant market is unlike most other segments of the wafer fab equipment industry because Japanese companies hold a relatively small minority position with only

Figure 1
1991 Regional Ion Implantation Equipment Markets and Ownership



Source: Dataquest (June 1992)

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18 percent share. This market share level has held essentially constant for the last three years.

Company Rankings

Table 1 presents the worldwide company rankings for the ion implantation equipment market in 1991, along with worldwide company revenue by segment of the implant market. In order to better illustrate the influence and market positioning of companies providing the same ion implant product offerings, we have combined the revenue of Varian with its joint venture company, TEL/Varian. Similarly, we present the combined implant revenue of Eaton and Sumitomo/Eaton Nova.

Please note that all revenue reported in Table 1 is end-user revenue. This distinction is of particular importance in understanding Dataquest's revenue estimates for the implant joint venture companies. The revenue associated with implant kits sent from one company (say Varian or Eaton) to be fabricated and assembled by its joint venture partner (TEL/Varian or Sumitomo/Eaton Nova) is valued at the full system shipment price to the semiconductor manufacturer, rather than at the value of the kit. Dataquest attributes the end-user revenue from assembled kits to the appropriate joint venture company.

Varian and TEL/Varian

Varian and TEL/Varian continue their leadership position in the ion implantation equipment market with combined revenue of $132 million (39 percent share). At SEMICON/Japan in December 1991, Varian formally introduced its new medium-current implanter, the E-500, to complement its core product offerings for 200mm processing (the E-220, single-wafer medium-current implanter, and the E-1000 and 180XP high-current, batch-processing systems). The E-500, like the E-220, is a parallel-beam scanning system. In addition to medium-current applications, the E-500 is also suited for certain high-energy applications that have more moderate energy requirements than traditional high-voltage implants. Such applications include charge-coupled devices and programmable ROMs.

Eaton and Sumitomo/Eaton Nova (SEN)

The combined activities of Eaton and Sumitomo/Eaton Nova (SEN) ranked second in the 1991 implant equipment market with revenue of $102 million and share of 30 percent. Eaton and SEN, together, rank first in the high-current implant market with 40 percent share. High-current implant has been the traditional strength of the Eaton and SEN organizations. This particularly strong market position in 1991 was fueled in large part by the success of the NV-GSD high-current system. Contrary to the historical practice of shipping kits from the United States to Japan, this tool was developed jointly in Japan by Sumitomo/Eaton Nova and Eaton. The technology for the NV-GSD has been transferred back to Eaton's facility in the United States,

Table 1
1991 Worldwide Ion Implantation Equipment Company Ranking
(Revenue in Millions of Dollars)

Company	Revenue	Share (%)	Medium Current	High Current	High Voltage
Varian and TEL/Varian	132.3	38.5	55.8	76.5	0
Eaton and Sumitomo Eaton/Nova	102.2	29.8	12.6	86.3	3.3
Nissin Electric	42.2	12.3	28.0	11.2	3.0
Applied Materials	33.9	9.9	0	33.9	0
Genus	11.3	3.3	0	0	11.3
Ulvac	11.1	3.2	11.1	0	0
Hitachi	10.2	3.0	0	10.2	0
Worldwide Market Total	343.2	100.0	107.5	218.1	17.6

Note: No revenue associated with spares and service is included.
Source: Dataquest (June 1992)

and the system now can be manufactured in either region of the world.

Nissin Electric

Nissin Electric ranked third in the worldwide ion implantation equipment market in 1991 with revenue of $42 million (12 percent share). Nissin continues to expand its export activities in the implant market segment with almost one-fourth of its 1991 revenue coming from customers outside of Japan. In contrast, fellow Japanese implant suppliers Hitachi and Ulvac only ship systems in their home market of Japan. Nissin introduced several new models of implant equipment in 1991, including its medium-current NH-20SP system, its high-current Exceed-8000, and an MeV implanter, NT-1000P. Nissin traditionally has held a strong position in medium-current implant but is currently a relatively small player in the high-current arena. With its new high-current product offering, the Exceed-8000, Nissin has focused on the features of low charge-up, low particulate contamination, less shadowing effect, higher throughput, and longer source lifetime.

Applied Materials

Applied Materials had ion implantation equipment sales of about $34 million in 1991, which provided the company with a share of 10 percent of the total implant market. Applied only participates in the high-current implant segment of the market, of which Dataquest estimates the company had 16 percent share. At SEMICON/West in May 1991, Applied introduced an enhanced version of its high-current product offering, the Precision Implant 9200XJ. This tool provides improved system performance and process capability and a new ion source. New beamline components and wafer-handling materials have also helped reduce particulate contamination, while new filtering techniques have helped to reduce BF_2 contamination. Dataquest believes that contamination problems with Applied's earlier high-current implanter (Precision Implant 9200) contributed to some erosion of Applied's market position in high current from 18 percent in 1990 to 16 percent in 1991.

Genus

While Genus claims only 3.3 percent share of the worldwide implant market, the company remains the dominant player in the high-voltage implant equipment segment with sales of $11 million. One of the most significant events in this implant segment last year was Mitsubishi Electric's adoption of high-voltage implant for volume production of 16Mb DRAMs. Dataquest believes that Genus was the vendor to supply Mitsubishi Electric with its high-voltage implant system. High-voltage implant is used to form retrograde wells and channel stoppers under LOCOS structures, as well as to avoid latch-up. Although high-voltage tools carry an impressive ASP of $2.9 million, the use of such systems can eliminate two mask layers from a 16Mb DRAM process and thus reduce the need for additional steppers, track systems, and strippers. One additional advantage of high-voltage implant is an improvement of soft error reduction by a factor of 20.

Ulvac

Dataquest estimates that Ulvac had implant sales of $11 million in 1991, all of which were medium-current systems shipped to customers in Japan. The company introduced a new medium-current tool last year, the IPZ-9000, which is the next-generation tool design of Ulvac's IPX family of products. Dataquest understands that this system adopts a unique multielectrostatic scanning method and creates a parallel beam that covers 150mm and 200mm wafers with a high degree of accuracy. The beam angle can be varied from 0 to 60 degrees, and the wafer can be rotated up to 80 revolutions per minute, which improves device symmetry while reducing shadowing effects. Recently, Ulvac's new system was adopted for GaAs applications in addition to traditional silicon wafer processing.

Hitachi

In 1991, Hitachi had implant sales of $10 million, representing 3 percent share of the world market. Hitachi only participates in the high-current segment of the market, and to date has only shipped systems to customers in its home market of Japan. The company's major advanced product offering, the IP-2500, was introduced at SEMICON/Japan in December 1990.

Dataquest Perspective

The worldwide market for ion implantation equipment declined 7 percent last year. This was the most significant revenue decline for any major category of wafer fab equipment excluding those mature segments currently being phased out in favor of newer technologies. Total unit shipments of ion implanters of all three types declined 17 percent from 249 units in 1990 to 206 units in 1991. This 1991 shipment level is comparable to the 201 units shipped back in 1982!

Clearly, the roller coaster ride that traditionally characterizes ion implantation equipment market dynamics still appeared to be holding true last year. The reason behind the stunning highs and significant lows in implant unit shipments over the years is that the implant market fundamentally has been driven by capacity demands more so than technological innovations in the equipment. The question is whether ion implant equipment companies can expect their roller coaster market dynamics to evolve into a much more stable pattern as the semiconductor industry itself moderates its own binge/bust cycle of capital spending.

By Peggy Marie Wood (San Jose)
Kunio Achiwa (Tokyo)

Vertical Turf Wars: 1991 Diffusion Equipment Market in Review

The worldwide diffusion equipment market grew modestly by 3 percent to $335 million in 1991. Steep increases in diffusion tube average selling prices (ASPs) were the main contributing factor for the slight market growth. Dataquest includes diffusion, wet/dry oxidation, anneal, implant drive-in, and BPSG reflow processes within the diffusion equipment market applications. The categories of low-pressure tube CVD and horizontal plasma-enhanced tube CVD market are not included within the diffusion market, but rather are included in Dataquest's estimates of the CVD equipment market. This article highlights the growth dynamics of the vertical- and horizontal-tube diffusion market.

Regional Markets and Ownership

Figure 1 shows the worldwide diffusion equipment market, segmented by region and ownership. Japan, with 46 percent ($154 million) in 1991, has represented the largest regional diffusion equipment market over the last few years. The Asia/Pacific market grew rapidly in 1991 to 19 percent ($65 million) of worldwide demand. Japanese equipment companies also dominate ownership of the diffusion market: In 1991, they accounted for 61 percent share ($204 million) of the worldwide market. Japanese diffusion equipment companies are significant exporters of advanced diffusion tube equipment, especially in the category of vertical thermal reactor (VTR) tube products. North American companies captured 27 percent ($89 million) of the 1991 worldwide diffusion market.

Company Rankings

Table 1 presents the worldwide company rankings for the horizontal and vertical diffusion equipment market. Dataquest notes that sales of vertical diffusion equipment have grown rapidly and now comprise 60 percent ($200 million) of the 1991 worldwide diffusion market of $335 million. The horizontal diffusion equipment market is in a state of rapid decline. These systems are being implemented only in mature fab expansions and noncritical applications. Vertical diffusion furnaces have the advantages of easier automation, improved uniformity across 200mm wafers, tighter process control, and lower defect levels compared with horizontal diffusion furnaces. The downside to vertical furnace products is their higher ASP, which reflects more value-added automation and process control features.

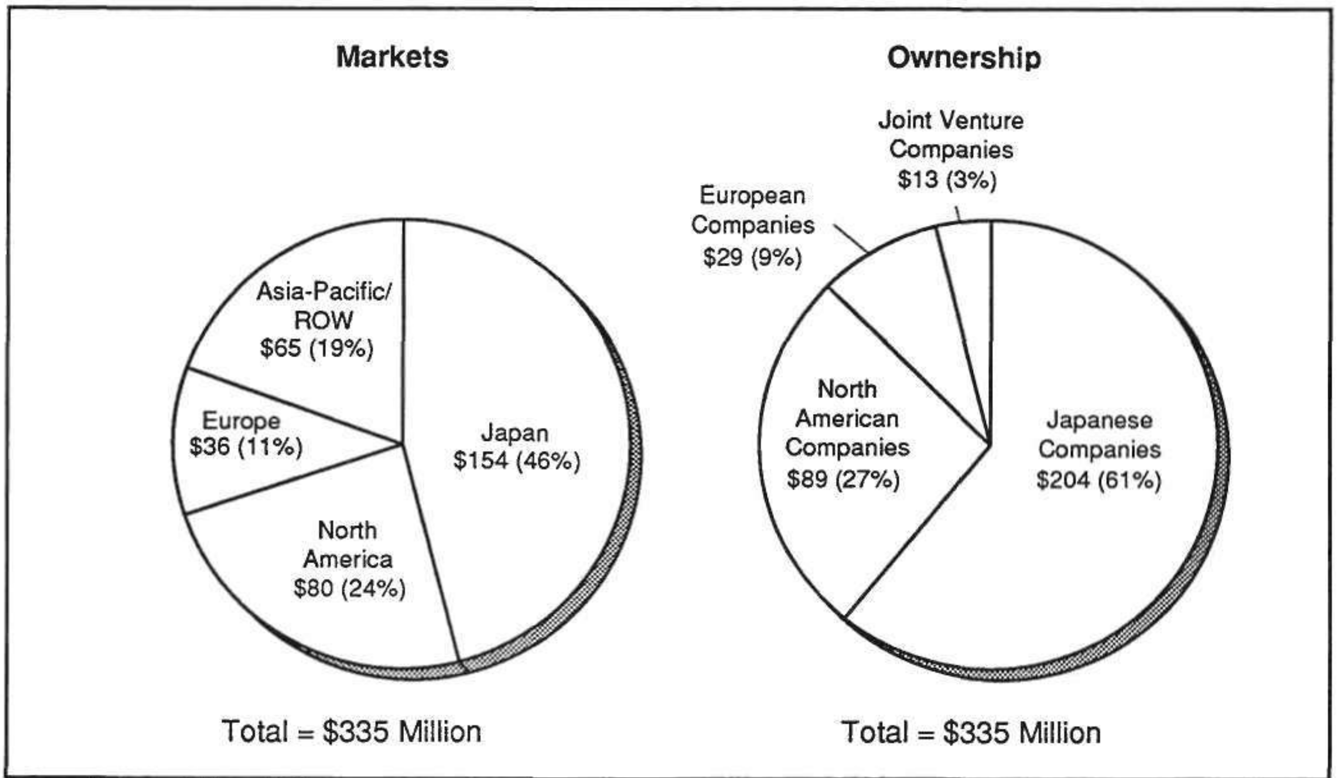
Tokyo Electron (TEL)

TEL, with 27.7 percent of the 1991 market, retained its leadership position. TEL's vertical diffusion tube shipments comprised 60 percent of the company's total diffusion revenue. TEL also has a mature cash-cow portfolio of horizontal diffusion furnace products that account for the remaining 40 percent of its diffusion business. TEL continues to offer evolutionary improvements to its diffusion product line, such as enhanced automation, loadlocks, clustered VTR products, and in situ pre-cleans. Dataquest believes that TEL's strategy of offering value-added process features will enable it to continue its premium pricing policy as competition intensifies in the VTR business.

Kokusai Electric

Kokusai Electric, with 20.3 percent, captured the No. 2 position in the diffusion equipment

Figure 1
1991 Regional Diffusion Markets and Ownership



Source: Dataquest (June 1992)

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market in 1991. Kokusai Electric's diffusion shipments are much more heavily skewed toward vertical furnaces: more than 90 percent of the company's diffusion revenue was obtained from vertical furnaces. Kokusai Electric's recent majority investment position within the Bruce Technologies front-end furnace division of BTU International is aimed at globalizing Kokusai's technology and obtaining rapid access to the installed base of BTU International's furnaces in North America and Europe. Kokusai Electric will also benefit from Bruce Technologies' expertise in process control and automation software. Dataquest believes that Kokusai Electric and TEL are caught up in a fierce battle for market supremacy within the large, technologically demanding Japanese diffusion market.

Silicon Valley Group (SVG)

SVG, with 16.1 percent of the 1991 market, is the third-largest supplier of diffusion equipment in the world. SVG is in the midst of a major product transition from its horizontal furnace product line to its newer VTR product family. The company has been quite successful in ramping up its VTR shipments. SVG's VTR diffusion business is now almost at the same level as its older horizontal furnace business. Dataquest believes that SVG is also in the final stages of development for its advanced vertical processor family for sub-0.5 micron diffusion applications. With BTU International's exit from the diffusion equipment business, SVG is the last major U.S. diffusion equipment company.

Dataquest Perspective

The worldwide diffusion equipment market grew modestly to $335 million in 1991. Japanese diffusion equipment companies, which pioneered the adoption of VTR technology, own a major portion (61 percent) of the market. The diffusion equipment market is now dominated by VTR technology with VTR tube systems, which account for 60 percent of 1991 diffusion market revenue. Horizontal diffusion furnace companies that were caught off guard by the rapid shift to VTR technology are undergoing painful restructuring in order to stay in the

Table 1
1991 Worldwide Diffusion Equipment Company Rankings
(Revenue in Millions of Dollars)

Company	Revenue	Market Share (%)	Horizontal Diffusion	Vertical Diffusion
Tokyo Electron Ltd.	92.7	27.7	37.0	55.7
Kokusai Electric	68.1	20.3	5.6	62.5
Silicon Valley Group	54.0	16.1	28.0	26.0
ASM International	21.7	6.5	11.7	10.0
BTU International	19.0	5.7	13.0	6.0
Varian/TEL	13.8	4.1	5.7	8.1
Ulvac	13.0	3.9	10.4	2.6
Koyo Lindberg	12.6	3.8	5.9	6.7
Disco	10.0	3.0	0	10.0
Gasonics	8.7	2.6	8.7	0
Shinko Electric	7.4	2.2	0	7.4
Centrotherm	6.7	2.0	6.7	0
Semitherm	3.0	0.9	0	3.0
General Signal Thinfilm	3.0	0.9	1.0	2.0
Wellman Furnaces	0.5	0.1	0.5	0
Tystar	0.5	0.1	0.5	0
Pacific Western	0.4	0.1	0.4	0
Worldwide Market Total	335.1	100.0	135.1	200.0

Note: Spares and service are not included.
Source: Dataquest (June 1992)

diffusion business. The standardization of diffusion VTR product features may make it difficult for new companies to recoup their investment in development of advanced VTR products as commodity product pricing and margin erosion practices invade the hitherto lucrative VTR turf.

By Peggy Marie Wood and
Krishna Shankar (San Jose)
Kunio Achiwa (Tokyo)

Track Triumvirate Prevails: 1991 Automatic Photoresist Processing Equipment Market in Review

The worldwide market for automatic photoresist processing equipment (track) was $369 million in 1991, up 13 percent from its 1990 level of $326 million. This healthy growth rate is of significance in light of the fact that the track equipment market is closely tied to purchases of lithography equipment, whose market declined 5 percent last year. This article highlights some of the key trends behind the healthy growth in last year's market and discusses the activities of the top three players, who have continued their decade-long position of dominance in the worldwide track arena.

Dataquest attributes the healthy growth rate in the 1991 track market to several factors. First, we believe that the average selling price (ASP) associated with a given track system increased at an accelerated pace last year. From a market research perspective, reliable information on track unit shipments is difficult to gather—the definition of what constitutes a unit of track equipment varies from vendor to vendor because of the modular and custom nature of a given customer's requirement. However, it is clear that track manufacturers are including more and more advanced modules and subsystems on their leading-edge product offerings, including vertical hot plates, random-access robotics, environmentally controlled chambers, and improved chemical dispense nozzles with sophisticated fluid volume controllers. In addition, continued emphasis is being placed on achieving tighter particle control throughout the entire track system. All of these elements are essential in order to achieve the same physical, chemical, and temporal environment for every wafer being processed. These factors all directly contribute to a higher ASP for track equipment.

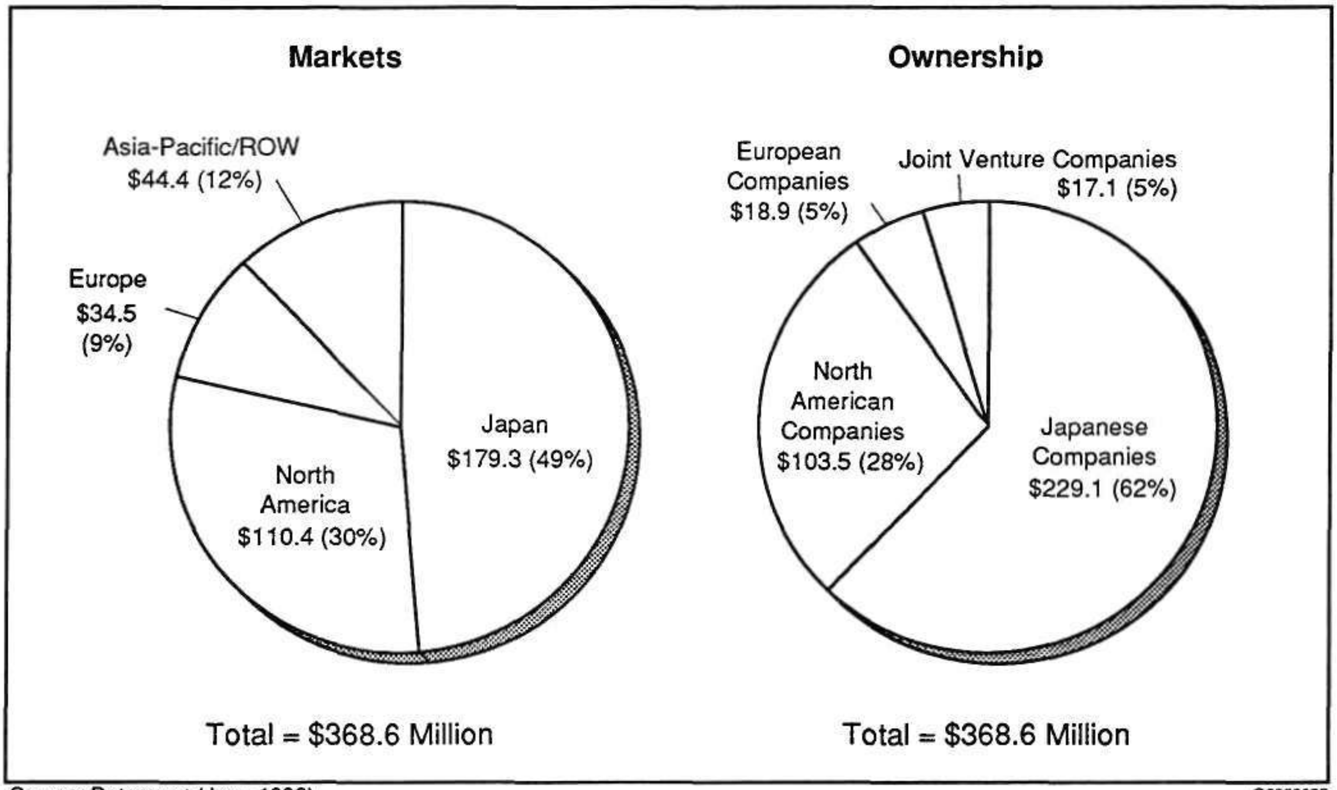
In addition, Dataquest believes that a significant level of replacement systems was purchased for volume production lines and advanced R&D facilities last year. This is because the newer advanced track tools available in just the last few years have undergone substantial improvements relative to many tools currently in the installed base. These older tools at volume production lines and R&D facilities are not particularly well-suited for the advanced processing requirements of devices such as 16Mb DRAMs. Not only do the newer track systems provide improved process performance but random-access systems can typically save from 25 to 30 percent on floor space. This reduction in footprint directly impacts cost of ownership and has contributed to an acceleration in the replacement activity in track.

Finally, the sluggish DRAM market has led many manufacturers to shift their product strategy from DRAMs to ASICs and other advanced logic products. As a result, we speculate that the market opportunity for standalone track systems last year expanded at a faster pace than might have otherwise been expected if DRAM activity had not been so slow. Standalone track systems provide an additional level of process flexibility that is well-suited for ASIC manufacturing. That flexibility typically is not required for high-volume DRAM manufacturing where the track system is directly interfaced to the lithography tool.

Regional Markets and Ownership

Figure 1 presents the worldwide 1991 track market segmented by region and ownership. As with other major categories of front-end processing equipment market, Japan represented the

Figure 1
1991 Regional Automatic Photoresist Processing Equipment Markets and Ownership



Source: Dataquest (June 1992)

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largest regional market for track equipment, accounting for 49 percent of world demand in 1991. Japanese companies continued to hold a particularly strong position in the track market with 62 percent share last year. This dominant share position in the world market in large part is attributed to the fact that the Japanese track companies have "owned" their home market of Japan, accounting for more than 98 percent share of the market every year since 1985. In 1991, only one non-Japanese track vendor had sales in Japan and that was Machine Technology (MTI). Dataquest believes that MTI's business activity in this region was directly related to the shipment of two SVG Lithography Micrascan step-and-scan tools to customers in Japan. (To date MTI has been the primary supplier of track systems interfaced to Micrascan tools worldwide.) In addition to dominating the largest regional market for track equipment, Japanese companies have also been focused on expanding export activities over the last several years, either by going direct, through representatives and distributors, or through joint-venture activity.

Table 1
1991 Automatic Photoresist Processing Equipment Company Ranking (Revenue in Millions of Dollars)

Company	Revenue	Share (%)
TEL and Varian/TEL	143.3	38.9
Dainippon Screen	69.5	18.9
Silicon Valley Group	48.9	13.3
Machine Technology	26.6	7.2
Convac	18.9	5.1
Tazmo	15.2	4.1
Semiconductor Systems, Inc.	14.0	3.8
Canon	12.3	3.3
Yuasa	5.9	1.6
Solitec	4.9	1.3
FSI International	4.8	1.3
Eaton	4.3	1.2
Worldwide Market Total	368.6	100.0

Note: No revenue associated with spares and service is included.
Source: Dataquest (June 1992)

Company Rankings

Table 1 presents the worldwide company rankings for the track equipment market in 1991. In order to better illustrate the influence and market positioning of companies providing the same track product offerings, we have combined the revenue of Tokyo Electron Ltd. (TEL) with its joint venture partner, Varian/TEL. This joint venture, established in 1989, is specifically focused on providing track, diffusion, and etch products from TEL in Japan to semiconductor manufacturers in the United States and Europe. The Varian/TEL joint venture is supported by the sales, marketing, and service organization of Varian.

Please note that Dataquest's estimates of the track equipment market include only those systems used in semiconductor device fabrication. Many of these same track companies supply systems that are used in other applications, such as compact disk coating and flat panel display manufacturing. We have excluded any such revenue associated with these nonsemiconductor manufacturing activities.

TEL and Varian/TEL

TEL and Varian/TEL claimed the No. 1 ranking in the track equipment market in 1991 with $143 million in revenue and 39 percent share of the world market. The combined activities of TEL and Varian/TEL have maintained this ranking since 1987. TEL was the first company to introduce a random-access track system, the Mark II, back in 1987. The company has continued to capitalize on that early lead in advanced track systems. Its leading-edge product offering today is the Mark V.

The TEL and Varian/TEL operations have established a significant presence in all regions of the world. Dataquest estimates that TEL's 1991 share of the Japanese market was 55 percent and that the company accounted for 64 percent of the Asia/Pacific market last year. Varian/TEL, which has only been shipping track systems since 1989, garnered 23 percent share of the European market in 1991. Varian/TEL's share of the North American market last year was only 8 percent, but this relatively small position in the United States is not unreasonable considering that there exist a number of North American suppliers with well-entrenched positions in their home market.

Dainippon Screen (DNS)

Dainippon Screen ranked second in the 1991 track equipment market with sales of $70 million and 19 percent share of the world market. The company has continued to emphasize its export activities and in 1991, track revenue from customers outside of Japan accounted for about one-fourth of total sales. DNS was delayed in introducing a random-access track system and as a consequence suffered a loss in worldwide market share in 1990. However, in 1991, the company regained a percentage point of share as sales of its random-access D-SPIN 60A system became a larger portion of the company's total product mix. In addition, Dataquest believes that DNS' gain in market share was in part attributed to the company's new developer solution nozzle (dubbed "soft impact nozzle") that can reduce dispense volumes of developer chemicals from 100cc to 35cc for 200mm wafer processing. The new nozzle also provides improved process uniformity.

Silicon Valley Group (SVG)

SVG ranked third in the 1991 track market with $49 million in sales. The company has suffered a decline in market share over the years because it has been unsuccessful in breaking into the world's largest regional market, Japan, and has had to face increasing levels of competition from Japanese competitors in the other parts of the world, including its home market of the United States. In 1987, SVG accounted for 20 percent of the worldwide track market. Five years later (1991), this market share position had eroded to 13 percent.

SVG still holds its No. 1 ranking in North America and garnered 34 percent share in its home market last year. An important component of SVG's 1991 North American revenue came from shipments to Motorola's MOS-11 facility. SVG's major advanced product offering is its 90 Series, a random-access track system introduced at SEMICON/West in May 1990. Dataquest estimates that the 90 Series product line accounted for about half of SVG's total track revenue in 1991.

Dataquest Perspective

The top three players in the track market—TEL (including Varian/TEL), Dainippon Screen, and Silicon Valley Group—have dominated the track market throughout the 1980s. In 1982, they accounted for a combined share of 52 percent, which by last year had increased to a combined share of 72 percent. Ten other companies split the remaining 18 percent of the 1991 market. Clearly, the combination of advanced technology and random-access product offerings coupled with sufficient critical mass to support a global customer base have been key to the success of these larger players.

The midsized track players such as Machine Technology and Convac have advanced product offerings but will need to expand their global presence if they ever hope to gain membership to the upper echelons of the track market. The smaller track companies face a significant challenge in developing their long-term strategy for success in this marketplace. Some companies, such as FSI International with its TI-designed Polaris system, are aggressively marketing an advanced product offering designed to go head-to-head with the big guys. Other smaller players, however, may well be relegated to pursue noncompetitive niche applications or remain content with a single-region marketing focus for their business activities. The three major players in this marketplace show no sign of abdicating their positions of leadership anytime soon.

By Peggy Marie Wood (San Jose)
Kunio Achiwa (Tokyo)

News and Views

OSI and Insystems Consolidate Operations

Dataquest understands that, in a move that has been rumored for weeks, a binding contract recently has been signed between Optical Specialties Inc. (OSI) and Insystems whereby OSI (Fremont, California) will acquire the assets of Insystems (San Jose, California). The joint operations of the two companies will be consolidated under the OSI name. Dataquest understands that as part of the agreement all Insystems employees, products, and technology will be transferred to OSI. OSI is a publicly traded company with reported 1991 fiscal year revenue of $6.7 million and net income of $1.2 million. Insystems is privately held, but

Dataquest estimates that the company's 1991 calendar year revenue of wafer inspection equipment was $13 million.

Insystems has suffered financial problems over the past several years as it has attempted to compete head-to-head with KLA Instruments in the advanced defect inspection equipment arena. Although Insystems has leading-edge technology, it has been burdened by having only a single product offering. In contrast, Insystems' major competitor KLA has been better able to balance the effect of the industrywide slowdown by dispersing the impact on its business activities over a much wider mix of products.

OSI, like Insystems, provides process control equipment to the industry and is relatively small in size. OSI has experienced its own financial woes over the years, reporting multiple consecutive quarterly losses. In the last year, however, the company pulled itself into a profitable position. Dataquest believes that, in particular, OSI's new dedicated overlay measurement product line has played a significant role in turning around the company's position in the marketplace. The Insystems' inspection technology will greatly complement the current product offerings of OSI and will improve the company's overall critical mass. Dataquest speculates that the new larger operation will most likely continue the development work that had been pursued by Insystems in the area of defect inspection of flat panel displays.

We note an additional interesting point with regard to this latest acquisition in the process control arena. At the end of 1991, Toray Industries of Japan acquired majority ownership of Thermawave, another supplier of process control equipment. It turns out that Toray also has an established relationship with OSI. In 1989, Toray entered into R&D and licensing agreements with OSI to allow the company to complete advanced product development. It has provided marketing support for OSI products in Japan. Now, through the acquisition of Insystems by OSI, Toray might well be involved in future projects associated with the advanced defect detection technology of Insystems, and thereby further increase its presence in the process control arena.

By Peggy Marie Wood

Inquiry Summary

Dataquest's Semiconductor Equipment, Manufacturing, and Materials inquiry summaries are designed to inform our clients of commonly asked questions and Dataquest's respective answers. No confidential information provided by our clients is included in this material.

Multilevel Interconnect Technology for Advanced DRAMs

Q. What are the likely candidates for multilevel interconnect technology for the 64Mb DRAM?

A. Please refer to Table 1 on page 15.

By Kunio Achiwa (Tokyo)

In Future Issues

Look for the following articles in future issues of *Dataquest Perspective:*

- 1991 wafer inspection equipment market in review
- 1991 critical dimension equipment market in review
- U.S. specialty gas market

Table 1
Multilevel Interconnect Technology for 64Mb DRAM Manufacturing

Word Line	W-polycide
	Poly-Si
Intermetal Dielectric	LPCVD (TEOS-BPSG)
	APCVD (TEOS-BPSG)
	APCVD (TEOS)
	HTO
Bit Line	W-polycide
	WSi
Intermetal Dielectric	LPCVD (TEOS-BPSG)
	APCVD (TEOS-BPSG)
	APCVD (TEOS)
Contact Hole	Sputter TiN/blanket W
	Selective W
First Metallization	TiN/AlCu/TiN
	TiN/AlSiCu
	Sputter W/blanket W
	TiN/blanket W
	AlCu/W/TiN
	AlSiCu/TiN
Intermetal Dielectric	Plasma (TEOS-oxide)/SOG/plasma (TEOS-Oxide)
	TEOS/ozone-oxide
	Plasma oxide/SOG/PSG
	APCVD (TEOS/ozone-oxide)/SOG/APCVD (TEOS/ozone-oxide)
	Plasma (TEOS-oxide)/APCVD (TEOS/ozone-oxide)
Via Hole	Selective W
	TiN/blanket W
Second Metallization	TiN/AlCu/TiN
	TiN/AlSiCu
	TiW/AlSiCu/TiW
	AlCu
	AlCu/W/TiN
Passivation	Plasma SiN
	Plasma (TEOS-oxide)/plasma (SiN)

Source: Dataquest (June 1992)

CONFERENCE ANNOUNCEMENT

Dataquest's 11th Annual SEMICON/West Seminar: Status 1992
Wednesday, June 17, 1992

Wafer fab equipment and materials companies had a tough time in 1990 and 1991 as the industry faltered. Dataquest believes that 1992 will also be a difficult year because of the lack of capital investment in semiconductor facilities. Will this dismal scenario continue? We don't think so. This year's SEMICON/West seminar will explore some of the reasons why the equipment and materials industry slowed over the past several years and why we believe that the industry will pick up again to resume a more normal growth path.

Attendees will hear Dataquest speakers discuss the following topics, which will provide a cohesive picture of the wafer fab equipment and materials industry from both supply-side and demand-side perspectives:

- Wafer fab equipment market status and forecast
- Wafer fab equipment company trends
- Semiconductor fab overview
- Capital spending forecast
- Changing strategies for materials companies
- Is there a future for the 1Gb DRAM?
- Portable PCs: A hot demand-side application

The seminar covers a lot of ground but it is specifically designed to provide the kind of high-level status and trend information that semiconductor equipment and materials industry executives need to support their decision-making. Industry executives have full and hectic schedules during SEMICON/West, but we believe that attendance at our acclaimed annual seminar will be an excellent investment of your time that will pay dividends to you and your company.

Dataquest's Status 1992 Seminar will be held on Wednesday, June 17 at the ANA Hotel (formerly Le Meridien) in San Francisco, just a few minutes' walking distance from Moscone Center, site of the SEMICON/West trade show. The seminar will begin at 8:30 a.m. and conclude by 11:40 a.m. Registration and continental breakfast will commence at 7:30 a.m. The fee for this seminar is $145. Please contact Dataquest's Conference Department at (408) 437-8245 for further information.

For More Information . . .

On the topics in this issue .... Peggy Marie Wood, Sr. Industry Analyst (408) 437-8631
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Dataquest Perspective

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Semiconductor Equipment, Manufacturing, and Materials

SEMM-SVC-DP-9206 May 18, 1992

In This Issue...

In this issue of Dataquest Perspective, we continue our special coverage and discussion of the general trends in the wafer fab equipment market and those specific issues that characterize the market for the major segments of wafer fabrication equipment.

Market Analysis

Semiconductor Equipment

Slide in U.S. Company Share Slows in 1991: Wafer Fab Equipment Market by Company Ownership

Trends in regional company market share are a perennial topic of interest in the semiconductor industry, be it for devices, equipment, or materials. Figure 1 shows that the steady increase in market share by Japanese companies throughout the 1980s was mirrored by a similar loss in share by North American companies for key segments of wafer processing equipment. Although North American companies still lost market share last year, the pattern of market share erosion appears to have slowed somewhat in 1991. This article examines several of the underlying reasons for the changes in regional company market share in 1991.

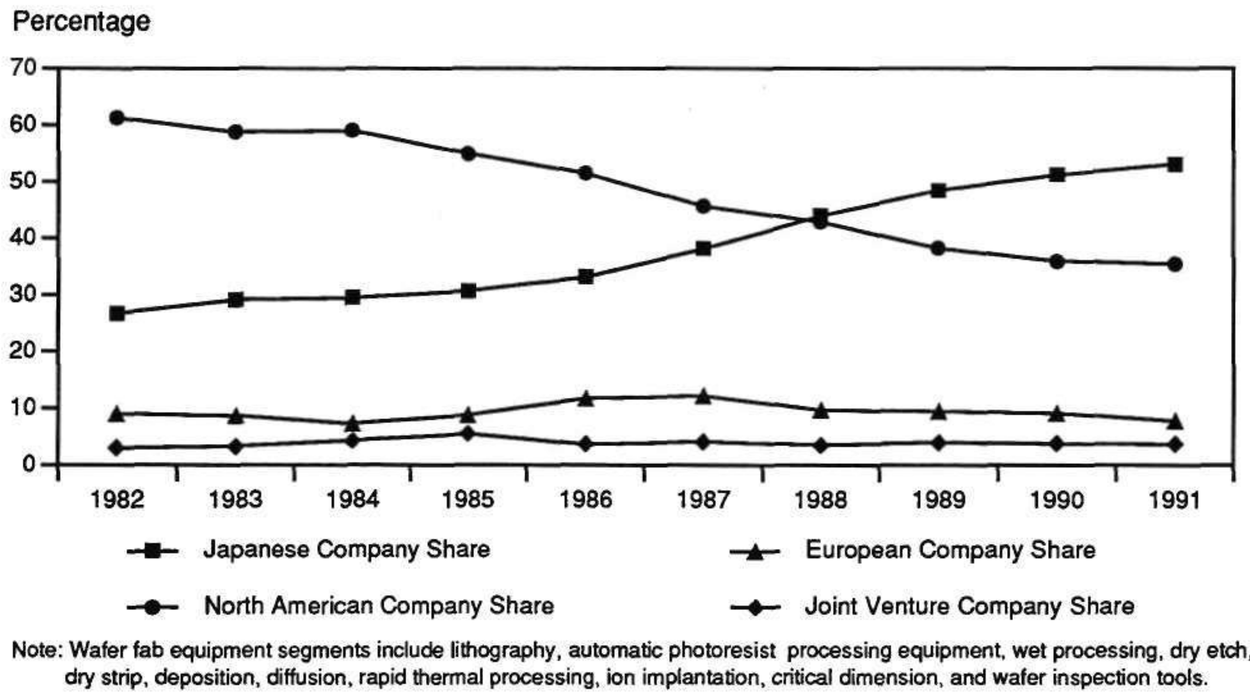
Changes in Regional Market Share

Japanese wafer fab equipment companies increased their share of the worldwide market to 53 percent at the expense of both European and North American wafer fab equipment manufacturers in 1991 (see Table 1). European company share declined by more than a percentage point to about 8 percent, while U.S. company share declined half of a percentage point to about 35 percent. Joint venture companies (the majority of which are joint ventures between U.S. and Japanese corporations) essentially maintained their 1990 share level with about 4 percent of the worldwide market in 1991.

Japanese Companies

In 1991, Japanese companies gained share in the world market because increased penetration in both the North American and Asia/Pacific-ROW markets generated enough of a balance to compensate for lost share in Europe and their home market of Japan. The gain in market share in North America was due primarily to increased

Figure 1
Worldwide Market Share of Regional Companies for Key Equipment Segments, 1982-1991
(Percentage Revenue in Dollars)*



Note: Wafer fab equipment segments include lithography, automatic photoresist processing equipment, wet processing, dry etch, dry strip, deposition, diffusion, rapid thermal processing, ion implantation, critical dimension, and wafer inspection tools.

Source: Dataquest (May 1992)

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Table 1
Changes in Regional Company Market Share in the 1991 Wafer Fab Equipment Market (Percentage Dollar Revenue)

Region	1991 World Share (%)	Changes in Regional Company Share as Compared with 1990: North America	Japan	Europe	Asia/ Pacific-ROW	World
North American Companies	35.4	-4.6	2.8	5.4	-9.4	-0.5
Japanese Companies	53.1	3.8	-1.5	-2.5	10.5	1.9
European Companies	7.8	-0.4	-0.2	-4.1	-1.8	-1.3
Joint Venture Companies	3.7	1.3	-1.0	1.2	0.6	-0.1
Total	100.0					

Source: Dataquest (May 1992)

sales of lithography equipment into a market that was actually experiencing an overall decline in wafer fab equipment sales. The Asia/Pacific region was a hotbed of activity in 1991 and Japanese companies enjoyed particularly strong revenue growth, more than doubling their sales from the prior year. Revenue increases were noted in every major category of wafer fab equipment. Through this higher sales volume, Japanese companies garnered an increase of more than 10 percentage points in share to achieve an overall position of 53 percent share in this region of the world.

The relative proximity of Japanese companies to semiconductor fabs in Asia/Pacific, coupled with advanced technology product offerings focused on high-volume manufacturing, and the significant emphasis that Japanese vendors place on customer support have allowed the Japanese equipment industry to grow its presence in this market from 10 percent share in 1982 to a dominant position of 53 percent in 1991. During this same time span, North American companies' share dropped from 78 percent to 36 percent share.

North American Companies

The worldwide market share of North American companies declined only a half of a percentage point in 1991, in contrast to the average 3 percentage point decline observed throughout the 1980s. Exactly opposite of the trend observed in Japanese company share, North American companies gained market share position in Japan and Europe, and lost share in Asia/Pacific and their home market of the United States. The gain in wafer fab equipment market share in Japan has garnered much interest in light of the market access disputes and trade friction that currently characterize U.S./Japanese relations. While the total Japanese equipment market experienced only modest growth of 1 percent in 1991, North American companies increased their sales in Japan by 19 percent. This increased sales activity covered a broad number of equipment categories including lithography, CVD, PVD, silicon epitaxy, ion implantation, and rapid thermal processing equipment.

Dataquest believes that North American company share gains in the Japanese market in the categories of CVD and PVD equipment are of particular interest. The Japanese semiconductor industry is currently diversifying its manufacturing product mix away from the heavily dominated high-volume DRAM manufacturing to include more ASIC and advanced logic products. DRAM manufacturing is driven to a significant extent by trends in advanced lithography. ASIC and advanced logic products, however, are strongly design-dependent on multilevel metallization, which is achieved through the advanced thin film processing techniques of CVD and PVD equipment. In contrast, it is only at the 4Mb DRAM shrink that double-level metal even begins to be used in DRAM manufacturing. North American companies have held a traditionally strong market position in advanced CVD and PVD processing equipment, and thus have benefited from this shift in manufacturing strategy with increased market penetration in Japan.

Although an increase in North American company share gain in Japan in 1991 is certainly laudable, it must be noted that North American companies also lost almost 5 percentage points of share in their home market and more than 9 percentage points of share in Asia/Pacific. In both of these regions, North American company share was lost while Japanese company share continued to grow.

European Companies

European companies lost market share in every regional market in 1991. On a worldwide basis, European company revenue declined in every major category of wafer fab equipment with the exception of silicon epitaxy and track equipment. Dataquest believes that European companies, in particular, fell victim to the depressed equipment environment in their home market of Europe, which declined by 17 percent in 1991. Throughout the 1980s, the European market on average accounted for about 44 percent of total European equipment company revenue. However, in 1991, the home market represented only 33 percent of total European equipment company business as total European company revenue plunged 30 percent from its 1990 level.

Another important component in the loss of share for the European companies is the relatively small sales level of wafer fab equipment companies as compared with their North American and Japanese counterparts. According to Dataquest estimates, only the three largest European wafer fab equipment companies in 1991—ASM International, ASM Lithography, and E.T. Electrotech—achieved worldwide wafer fab equipment sales in excess of $20 million. It is very difficult for companies with a small revenue base to stave off the triple foes of a sluggish business environment, increased competition, and escalating R&D costs, while coping with an increasingly global and increasingly demanding customer base.

Dataquest Perspective

Shifts in regional company market share grab both headlines and the attention of industry politicos. We believe that when evaluating the regional company share trends it is important to keep in mind that 1991 was a fairly sluggish year for the wafer fab equipment industry. Overall growth achieved only 3 percent, preceded by a 2 percent decline the year before. While we have noted some interesting changes in regional company market share for 1991, we caution that a single year does not necessarily define a trend. What is more important in establishing long-term market positioning and dominance is not just how companies fare when times are slow, but also the ability of companies to catch the tiger by the tail and ride out the next upswing in market growth.

By Peggy Marie Wood

The I-Line Lifeline: 1991 Stepper Market in Review

I-line steppers became the dominant tool choice for new purchases in 1991. Total stepper unit shipments to semiconductor manufacturers were 679 units in 1991, down 12 percent from the 1990 level of 771. Buoyed by the higher average selling price of advanced i-line systems, worldwide stepper revenue was $1.03 billion in 1991, reflecting a decline of a mere 2 percentage points from its 1990 level of $1.05 billion. This article presents the significant trends and highlights of the 1991 stepper equipment market.

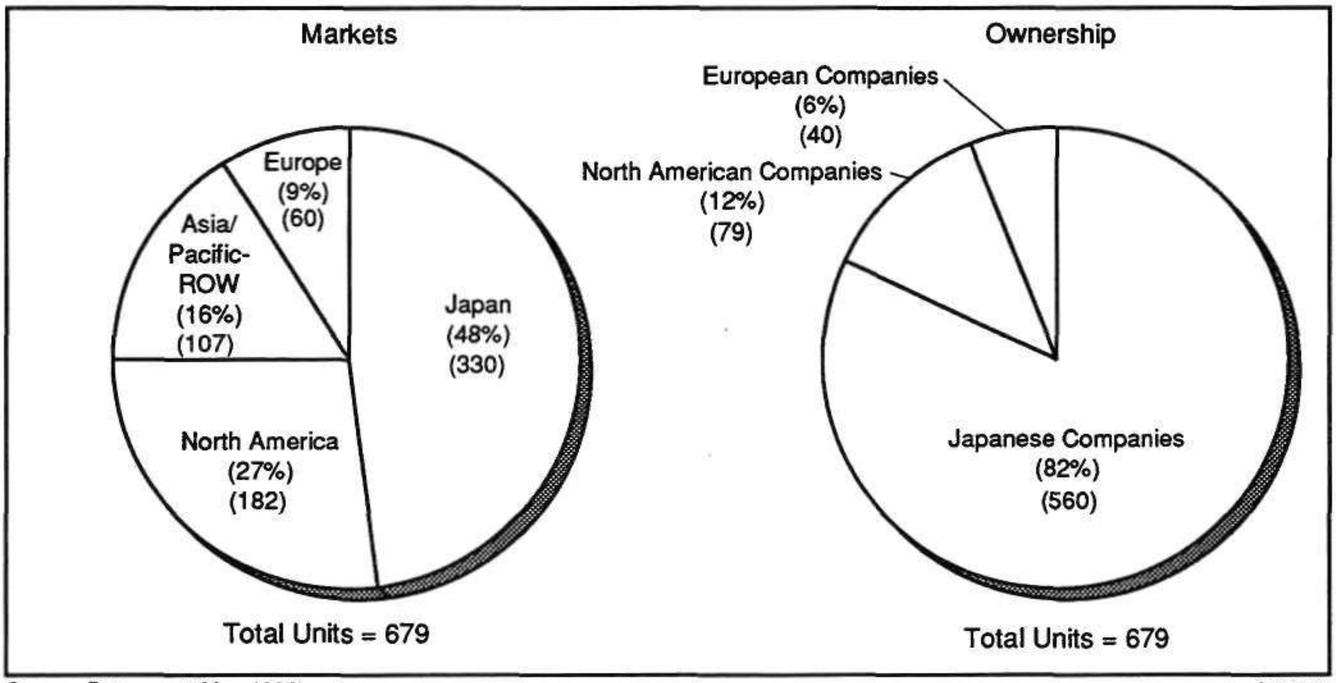
Regional Markets and Ownership

Figure 1 presents the worldwide 1991 stepper unit market segmented by region and ownership. As with other major categories of front-end processing equipment market, Japan continued its role as the largest regional market, accounting for almost half of 1991 stepper shipments. The Japanese stepper companies continued their dominance of the 1991 stepper market, accounting for more than 80 percent of worldwide shipments.

Stepper Market Highlights of 1991

Several key factors characterized the world of stepper lithography in 1991. I-line steppers continued to command a larger and larger portion of the stepper technology product mix. These tools constituted 21 percent of the stepper product mix in 1989 and 36 percent in 1990, but by last year had increased their share to 60 percent of total system shipments. I-line steppers

Figure 1
1991 Stepper Regional Markets and Ownership



Source: Dataquest (May 1992)

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are the predominant lithography tool choice for products with line geometries in the sub-0.8 micron regime, including such devices as 4Mb and 16Mb DRAMs as well as advanced ASIC and logic chips. The development of semiconductor phase shift mask technology and recently announced advanced stepper illumination techniques, both of which are optimized for highly repetitive device patterns, holds promise for extending the capabilities of i-line lithography to the 0.35-micron regime.

The phase shift mask fever that took hold of the industry in 1990 continued into 1991. The challenges associated with phase shift mask inspection and repair still remained formidable, however. At the end of 1991, Nikon and Canon announced new i-line stepper illumination techniques, dubbed SHRINC and QUEST, respectively, that achieve the benefits of phase shifting on the wafer without having to use a mask as the source of the phase-shifting pattern. These new techniques, targeted at the 64Mb DRAM generation, provide some breathing room for development work to continue on phase shift mask inspection/repair technology for latter generations of DRAMs and other highly repetitive device product families. At the same time, Nikon and Canon benefit by being well-positioned with their new i-line techniques to offer an alternative lithographic approach to 64Mb DRAM device manufacturers. (For additional information, please refer to "Phase Shift Masks: The Fever Begins to Break," in the February 10, 1992 SEMMS *Dataquest Perspective.*)

Finally, 1991 can clearly be named the year of the wide-field lens. The industry saw a veritable explosion of wide-field lens product offerings. A total of 15 new wide-field i-line and excimer lenses were introduced by stepper manufacturers ASM Lithography, Canon, GCA, Hitachi, Nikon, and Ultratech. Wide-field lens capability to accommodate more die per exposure field, as well as the large die size associated with advanced device designs, is a key competitive feature of today's advanced stepper systems. (For additional information, please refer to "It's A Wide, Wide World," in the November 18, 1991 SEMMS *Dataquest Perspective.*)

Company Rankings

Table 1 presents the worldwide company rankings for stepper unit shipments in 1991. In addition, Table 1 includes the percentage split by technology for each company's stepper shipment product mix in 1991.

Table 1
1991 Worldwide Stepper Company Rankings (Unit Shipments)

			Percent Stepper Technology Mix			
Company	Units	Share (%)	g-line	i-line	Excimer/ deep-UV	1x
Nikon	350	51	31	66	3	0
Canon	145	21	50	41	9	0
Hitachi	65	10	0	100	0	0
ASM Lithography	40	6	8	87	5	0
Ultratech	40	6	0	0	0	100
GCA	31	5	19	58	23	0
SVG Lithography	8	1	0	0	100	0
Total	679	100	28	60	6	6

Source: Dataquest (May 1992)

Nikon

In 1991, Nikon continued to maintain its leadership position in the stepper market, a position it has held since 1984. Nikon's worldwide unit shipments totaled 350 units, down about 9 percent from its 1990 shipment level of 384. One key factor that began to affect Nikon's business activities toward the end of 1991 was the decision by many Japanese manufacturers to downsize or delay their capacity plans for 200mm fabs in Japan. The majority of these planned or existing 200mm fabs are slated for 4Mb and 16Mb DRAM devices. This slowdown in DRAM equipment purchases will have significant impact on Nikon, more so than any other stepper manufacturer, because of Nikon's traditionally strong position in supplying DRAM facilities.

Nikon experienced a decline of stepper shipments in all regions of the world with the exception of the United States, where there was particularly healthy growth. Dataquest estimates that Nikon's shipments reached 80 units in 1991, up from 56 units the year before. Of particular note for Nikon in 1991 was the shift in the company's product mix toward i-line stepper systems. Nikon shipped its first i-line tools in 1989, a year in which i-line constituted only 10 percent of the company's product mix. In just two years, i-line has grown to represent two-thirds of Nikon's worldwide stepper shipments. As mentioned earlier, an important event for Nikon in 1991 was its announcement of its new advanced illumination technique for i-line steppers that allows DRAM manufacturers to achieve some of the benefits of phase shift masks while eliminating the problems associated with mask inspection/repair technology.

Canon

Dataquest estimates that Canon's 1991 stepper unit shipments were 145 units, down about 3 percent from its 1990 level of 150 units. This decline for Canon is smaller than that experienced by Nikon because Canon's customer base includes a large number of ASIC and advanced logic manufacturers and thus Canon has been somewhat more immune from the slowdown in DRAM fab activities. Last year marked the first year of significant shipments of Canon's first i-line product offering, the FPA-2000i. The success of that product offering allowed Canon to rapidly grow i-line steppers to about 40 percent of its product mix. As mentioned earlier, another significant event for Canon last year was its announcement of a new advanced illumination technique for i-line steppers that, like Nikon's technique, provides 64Mb DRAM manufacturers with a lithographic alternative to using phase shift masks.

Hitachi

Hitachi ranked third in worldwide stepper shipments in 1991 with 65 units, down from 84 units in 1990. Historically, Hitachi's shipments have been concentrated in Japan. However, Dataquest believes that the company shipped a substantial portion of its total 1991 stepper shipments to

Goldstar in Korea. The Hitachi and Goldstar organizations have had long-standing relationships in the consumer electronics arena since the 1950s. As part of a semiconductor agreement in 1989, Goldstar acquired the rights to Hitachi's 1Mb and 4Mb DRAM technology in return for a variable portion of its DRAM output going to Hitachi. Hitachi uses this output from Goldstar to balance the capacity utilization of its Japanese DRAM lines against overall market demand. Some industry watchers speculate that Goldstar's purchase of Hitachi steppers is somehow tied to the DRAM technology agreement. However, Dataquest notes that this is not entirely supported by the facts, since Hitachi's own semiconductor operations do not exclusively rely on Hitachi steppers for use in their manufacturing facilities. Hitachi's stepper activity in Korea may mark the beginning of a significant shift in the company's marketing strategy to expand its customer base beyond a handful of Japanese device manufacturers and internal operations at some of the Hitachi semiconductor facilities.

ASM Lithography (ASML)

ASM Lithography shipped a total of 40 units in 1991, down from 58 the prior year. The U.S. market continued to be the largest regional market for ASML in 1991, representing about 58 percent of total system shipments. However, for the first time, shipments to Asia/Pacific moved ahead of ASML's stepper shipments to Europe. Dataquest believes that this decline for ASML in its home market was due to a severely depressed stepper market in Europe last year (total European stepper shipments of 60 units compared with 95 units the year before) coupled with ASML's aggressive marketing strategy to increase its penetration in the Asia/Pacific market, in particular, Taiwan. ASML has yet to ship any steppers to Japan. However, Dataquest believes that the company is actively laying the groundwork for future business activities in that region.

The major event for ASML in 1991 was the introduction of a major new product family of steppers at SEMICON/West in May. The PAS 5500 stepper family, which includes three wide-field i-line and one wide-field excimer stepper, has been designed in a modular fashion so that the steppers can be easily upgraded with new illumination systems, lenses, reticle transfer systems, wafer transport systems, and other elements as technology advances the definition of state-of-the-art lithography. Other system components such as the machine frame, lens platform and exposure stage, alignment system, internal clean room environment, and image sensor and calibration remain the same throughout the 5500 family. This modular design approach effectively addresses one of the hot issues among semiconductor manufacturers today: controlling the cost of ownership of today's wafer fab equipment.

Ultratech

Ultratech was the only stepper manufacturer to enjoy increased unit shipments in 1991. The company's shipments totaled 40 units, up from 34 units the year before. The company's 1991 unit shipments included 9 systems to Japan, representing the majority of the total of 12 units shipped by non-Japanese stepper companies to this region. After all of the uncertainty that plagued Ultratech in 1990, including possible consolidation with sister company GCA, a failed management buyout proposal, and dwindling employee morale, 1991 was definitely a turnaround year for the company. A new management team with solid experience in the wafer fab equipment industry was put in place, and a strong marketing campaign was launched to promote the company's "trailing edge" marketing strategy for 1x mix-and-match lithography. Outside the semiconductor arena, the company also began to aggressively promote its position as a leader in providing lithography solutions for the thin film head manufacturing environment.

GCA

GCA's stepper shipments totaled 31 units in 1991, down from 52 systems in 1990. The United States remains the largest regional market for the company, accounting for more than 80 percent of system shipments last year. GCA was the first vendor to begin i-line stepper shipments back in the mid-1980s, and today the company's product mix still largely reflects its participation in that market segment. However, it is important to note that GCA has placed significant emphasis on its excimer laser product offerings. As shown in Table 1, almost one-fourth of GCA's product mix is in the excimer area, the highest percentage of any vendor currently offering excimer laser steppers. Dataquest believes that the goal of the company's current emphasis on excimer lithography is to establish an early foothold in this advanced stepper segment and to use this product offering as part of the company's long-term strategy to regain its former market presence in the highly competitive stepper arena. GCA introduced its long-awaited XLS family of steppers at SEMICON/West in May 1991. This family of products, developed in conjunction with SEMATECH, includes three i-line and two excimer stepper product offerings.

SVG Lithography (SVGL)

SVG Lithography's shipments of its Micrascan 90 product totaled 8 units in 1991. Shipments in 1991 included two units to Europe and two units to Japan, one of which was the highly publicized shipment to Toshiba in early 1991. In 1991, IBM continued to be SVGL's major customer for the Micrascan. With the exception of the Toshiba shipment, Dataquest believes that all other units were sent to IBM facilities including Corbeil-Essonnes, France, and Yasu, Japan. Much of SVGL's activities in 1991 were taken up with development of its new advanced Micrascan tool, which will be introduced at SEMICON/West in June 1992. The product acceptance of the new advanced Micrascan system by device manufacturers other than IBM is absolutely key to SVGL's long-term competitive position in the marketplace. (For additional information, please refer to "Next-Generation Micrascan Soon to Be Unveiled," in the April 13, 1992 SEMMS *Dataquest Perspective*.)

Dataquest Perspective

The worldwide stepper market was 679 units in 1991, down almost 30 percent from the peak year of 1989 when 954 units were shipped to the world's semiconductor manufacturers. The revenue decline (down 13 percent) was not nearly as precipitous because of the ever-escalating average selling price (ASP) of advanced stepper systems. Factors driving increasing stepper prices include new sources, new wide-field lens capability, and new alignment systems. Stepper ASP grew at a staggering compound annual growth rate (CAGR) of 16.8 percent between 1985 and 1990, and Dataquest anticipates that it will continue to increase at a rate of 12 to 13 percent CAGR between 1990 and 1995. Technology has always been king in lithography, but the 1990s will see cost of ownership emerge as technology's consort sharing the throne as an equal partner in future lithography buying decisions.

By Peggy Marie Wood (San Jose)
Kunio Achiwa (Tokyo)

Jockeying for Position in a Tight Race for Market Leadership: 1991 Dry Etch Equipment Market in Review

The worldwide 1991 dry etch equipment market grew a modest 2 percent to reach a size of $705 million. The growth in the dry etch market was roughly on par with the 1991 growth in the overall wafer fab equipment market. This article highlights the key trends in the 1991 dry etch equipment market.

Regional Markets and Ownership

Figure 1 shows the worldwide 1991 dry etch market segmented by region and ownership. Japan, with 51 percent ($357 million), continued to represent the single largest dry etch equipment market. North American companies, with 51 percent share ($356 million), continued to cling on to a leadership position in the global dry etch business.

Company Rankings

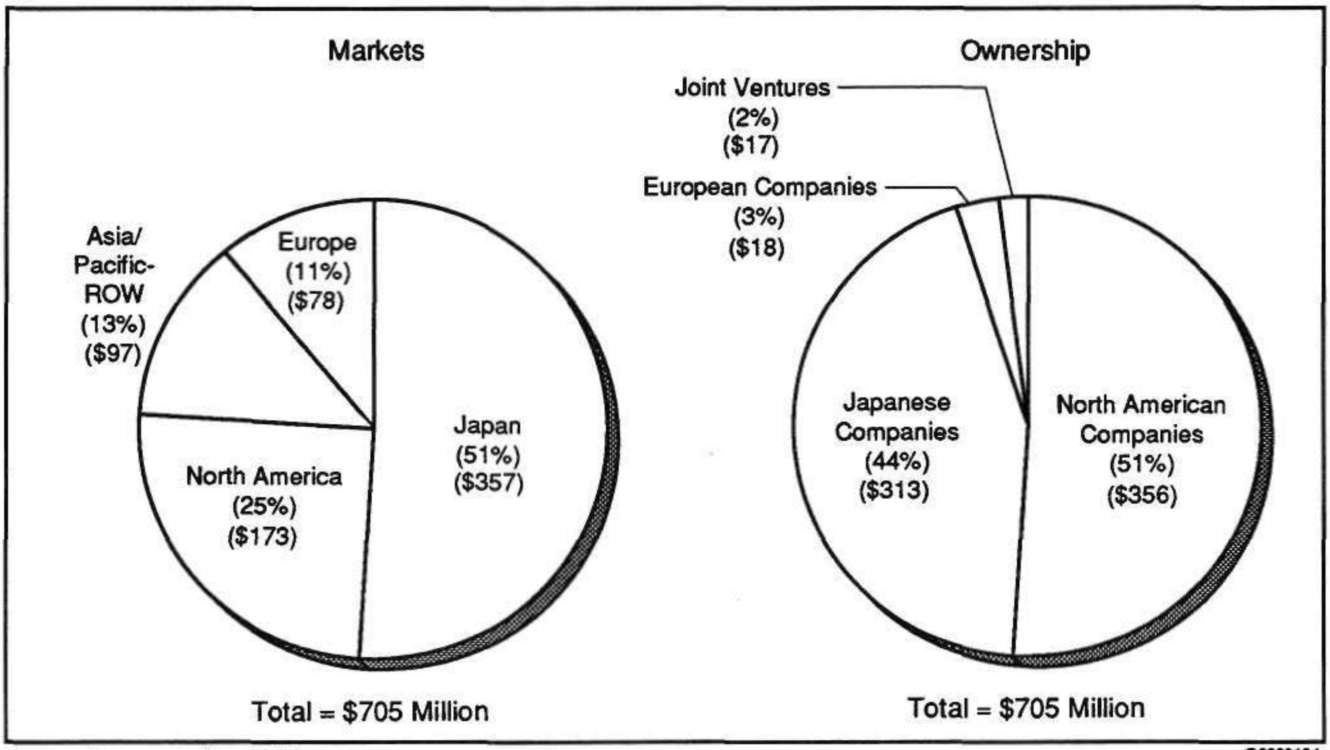
Table 1 highlights the dry etch company rankings based on the worldwide 1991 market. The table also identifies the various dry etch market segment activities for each company.

Applied Materials

Applied Materials, with 21.9 percent ($154 million) of the market, managed to retain its leadership position. The company, however, lost market share on a worldwide basis by almost 4 percentage points between 1990 and 1991. Applied's late transition to single-wafer dry etch technology, together with the inability of the P5000 magnetically enhanced RIE technology to crack the all important single-wafer oxide etch market, were significant factors in the erosion of Applied's dry etch market share. Vigorous global competition from Hitachi, Lam Research, and Tokyo Electron Limited (TEL) further weakened Applied's dry etch market position.

On the positive side, Applied has recently begun to focus on executing on its strengths in the single-wafer P5000 metal etch, polycide etch, and silicon trench etch market. Applied's cash-cow 8000 Series hexode batch systems continue to be a market share and profit leader in 4-inch through 6-inch metal and dielectric etch applications. Continuous improvements to the hexode etch technology such as improved automation, molecular backside helium cooling, and enhanced process chemistry extended the range

Figure 1
1991 Dry Etch Regional Markets and Ownership



Source: Dataquest (May 1992)

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of applicability for the hexode system. Dataquest believes that Applied has new advanced plasma etch source technologies under development that will transition the company to single-wafer dry etch solutions for the crucial dielectric etch market.

The benefits of continuous improvement in the P5000 mainframe performance and reliability that evolved into the Mark-II version also have had a positive effect on Applied's recent dry etch market performance. The success of the P5000 CVD and dry etch family illustrates the economies of scale in performance improvement and cost reduction that can be gained by delinking process chamber development from mainframe development. Applied, which recently began signaling its intentions to migrate to a new mainframe for dry etch and CVD applications, will continue to adopt the same successful unified mainframe strategy for future thin film applications.

Lam Research

Lam Research, with 18 percent ($127 million) of the market, represented the most dramatic market success story of 1991. Lam picked up almost 5 percentage points of market share from 1990 to 1991. Lam's Rainbow platform continued to pick up multiple, large-volume orders at leading global device fabs. The strengths of the Rainbow system in the dielectric and polycide etch market, together with the system's proven reliability and simple architecture, enabled it to pick up incremental market share. Lam's growing participation in the Japanese market through Sumitomo Metals and its traditional strengths in the Asia/Pacific market allowed the company to outperform the overall 1991 dry etch market.

On the cautionary side, Lam will encounter increased competition from new advanced-source dry etch systems. Lam's future success depends upon successful execution in the Rainbow migration path for sub-0.5 micron applications together with the development of the new Alliance cluster tool platform and inductively coupled plasma source technology based on the IBM license. Lam has also positively benefited from the incredible Samsung-driven Asia/Pacific expansion in 1991. However, future Asia/Pacific business growth will depend

Table 1
1991 Worldwide Dry Etch Equipment Company Rankings
(Revenue in Millions of Dollars)

Company	Revenue	Market Share (%)	Market Segment
Applied Materials	154.0	21.9	RIE, MERIE
LAM Research	127.1	18.0	RF plasma, RIE
TEL & Varian/TEL	120.9	17.2	RF plasma, RIE, MERIE
Hitachi	115.2	16.3	Microwave/ECR, RIE
Tegal	29.0	4.1	RF plasma, RIE, triode
Drytek	25.0	3.5	RIE, triode
Anelva	22.3	3.2	Microwave/ECR, RIE
Sumitomo Metals	15.4	2.2	Microwave/ECR
Tokyo Ohka Kogyo	15.3	2.2	Microwave/ECR, RF plasma
Shibaura Engineering Works	14.1	2.0	RIE
Plasma-Therm	13.8	2.0	RF plasma, RIE
E.T. Electrotech	12.0	1.7	RIE, triode
MRC (Sony)	9.6	1.4	MERIE
Oxford Plasma Technology	6.3	0.9	Microwave/ECR
Ulvac	6.2	0.9	RIE
Alcan Technology (Canon)	5.6	0.8	RF plasma, RIE
Gasonics	5.0	0.7	RF plasma
Others	7.9	1.0	
Worldwide Market Total	704.7	100.0	

Note: Calendar year 1991 systems revenue only; spares and service not included.
Source: Dataquest (May 1992)

upon the success of the Korean majors in the 4Mb/16Mb DRAM business. Lam needs to rapidly build up its applications and joint-development customer capabilities in Japan in order to gather firsthand information on the all-important Japanese dry etch market. Lam will need to weave a synergistic strategy that uses Sumitomo Metals' network in Japan while allowing Lam direct access to development efforts in Japan.

TEL and Varian/TEL

The TEL and Varian/TEL dry etch products accounted for 17.2 percent ($121 million) of the 1991 market. TEL continues to excel in delivering incrementally improved, cost-effective dry etch solutions that address the dielectric and polycide market segments. TEL is also successfully developing a market for its advanced magnetron etcher for sub-0.5 micron applications. TEL's extensive customer support network capability in Japan and Asia/Pacific, together with its U.S./European market presence through Varian/TEL, positions the company well in retaining its lead in the dry etch market. However, we caution that TEL's large dependence on the domestic Japanese market could be a negative factor given the current recessionary woes and capital spending freeze in Japan.

Hitachi

Hitachi, with 16.3 percent ($115 million) gained significant market share in 1991. Hitachi continued to excel in the metal etch market using its landmark microwave/ECR technology. The company's unique approach combining single-wafer dry etch, dry strip, and wet clean into the same platform has proven to be very successful in the Japanese metal etch and polysilicon gate etch market. Hitachi has effectively filled the void left in the market by the absence of a cost-effective single-wafer metal etch process. Dataquest believes that Hitachi will continue to expand its product portfolio to address the important dielectric etch market segment. Hitachi also appears to be focused on globalizing its capital equipment business in order to stay close to its increasingly globalized customers.

Dataquest Perspective

The worldwide dry etch equipment market showed modest growth in 1991 to reach $705 million in size. The dry etch competitive arena appears to be a wide-open race for market leadership as the key contenders narrow the difference between their market share positions. A plethora of plasma source technologies are being pursued in the quest for sub-0.5 micron dry etch dominance. Focused, new source companies such as Plasma Materials Technology could reshape the dry etch technology landscape by offering value-added building block solutions. Future dry etch equipment companies may become value-added process integrators that provide enabling, global solutions to their semiconductor customers.

By Peggy Marie Wood and Krishna Shankar (San Jose)
Kunio Achiwa (Tokyo)

Semiconductor Materials
Bulk Gases Defy Economic Gravity

Industrial gas sales (nitrogen, oxygen, hydrogen, and argon) to the semiconductor industry appear to be recession-proof. Volumes have grown year in and year out albeit at modest rates since Dataquest began tracking the market in 1985. On the face of it, this trend seems like good news for vendors, but marginal profitability and the need to maintain a strong investment program are creating a lopsided risk/reward scenario.

In 1991, bulk gas sales to the U.S. semiconductor industry pushed ahead even though silicon wafer consumption declined 4 percent for the year. Revenue totaled $213.1 million (see Table 1) and volumes 72.19 billion cubic feet (BCF) in 1991. Revenue was up 1.8 percent and volumes were up 1.6 percent when compared with 1990.

Dataquest does not expect this consumption trend to change anytime soon. Semiconductor process trends suggest that bulk gases and especially nitrogen consumption will continue to creep higher. Single-wafer processing using more purge cycles, process equipment using enclosure technology, pumpless chemical distribution systems, and a growing trend to keep the wafer under a nitrogen blanket throughout the manufacturing process guarantee that bulk gas volumes will increase with time.

Consequently, Dataquest expects the unit volume consumption of bulk gases in semiconductor applications to grow at a 3.2 percent compound annual growth rate (CAGR) through 1996. All this would seem like good news to industrial gas vendors if they could only get their prices higher and if the investment treadmill would slow.

Nitrogen

Nitrogen revenue is by far the largest segment of semiconductor bulk gas sales. Nitrogen sales totaled $161.5 million and volumes 68.85 BCF in 1991 (see Table 2), an increase of only 1.1 percent over 1990. Total nitrogen volumes grew for the seventh straight year (the entire span of Dataquest's coverage) (see Figure 1). On-site volumes were up slightly,

Table 1
U.S. Bulk Gas Market (Millions of Dollars)

	1991	1992
Total	213.1	209.3
Nitrogen	161.5	159.8
Hydrogen	28.6	28.5
Argon	15.5	14.4
Oxygen	7.5	6.6

Source: Dataquest (May 1992)

Table 2
1991 U.S. Nitrogen Market

	Revenue (Millions of Dollars)	Volume (Billions of Cubic Feet)
Total	161.5	68.85
Liquid	97.1	27.54
On-site	41.6	31.41
Pipeline	22.8	9.90

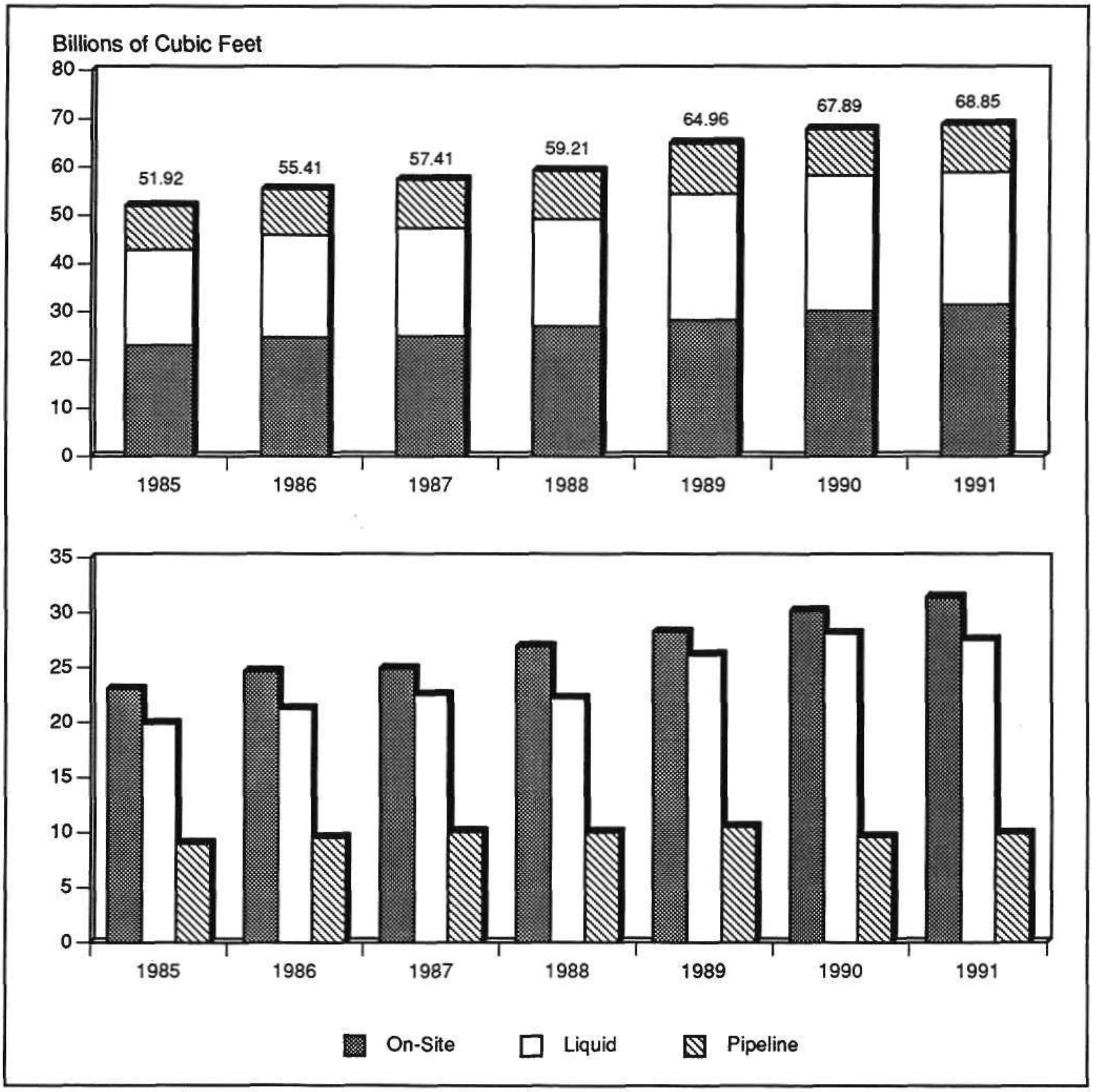
Source: Dataquest (May 1992)

whereas pipeline volumes were flat and liquid volumes were off. We believe that on-site volumes will continue to benefit from the trend to build larger fabs. Consequently, on-site nitrogen volumes are expected to grow faster than either liquid or pipeline volumes.

Other Bulk Gases

Volumes of the other bulk gas products used by device makers are small in comparison to nitrogen. Volumes of hydrogen, argon, and oxygen totaled 3.34 BCF (see Table 3) in 1991, or 4.9 percent of nitrogen volumes. However, on a

Figure 1
U.S. Use of Nitrogen



Source: Dataquest (May 1992)

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Table 3
1991 U.S. Hydrogen, Oxygen, and Argon Use

	Revenue (Millions of Dollars)	Volume (Billions of Cubic Feet)
Total	51.5	3.34
Hydrogen	28.6	1.98
Argon	15.4	0.55
Oxygen	7.5	0.81

Source: Dataquest (May 1992)

revenue basis these other bulk gases totaled $51.5 million or roughly one-third the nitrogen revenue.

Hydrogen volumes saw marginal growth of 2.6 percent in 1991 and tracked very closely with our preliminary epi wafer growth of 4.0 percent. Epitaxial wafer growth was very slow in 1991 relative to previous years when double-digit growth was the norm. Lower demand at IBM accounts for a significant share of the deceleration of the CMOS epi market in the United States.

Hydrogen volumes jumped in the late 1980s (see Figure 2) when epi substrate growth exploded. However, we are not forecasting the epi substrate market to return to double-digit growth in our five-year forecast. Consequently, the growth rates for hydrogen are expected to moderate.

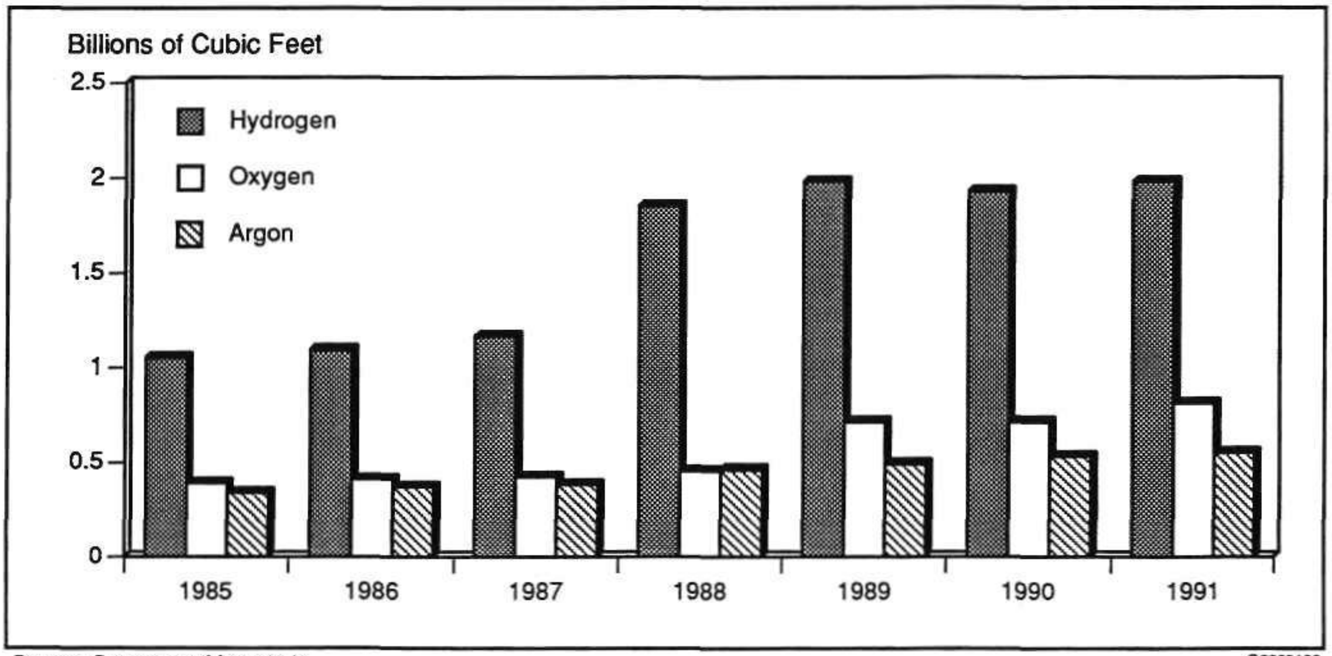
Oxygen and argon volumes are expected to track the overall market, which we are forecasting at 3.2 percent CAGR.

Prices

There was little increase in the price of nitrogen products in 1991. The average selling price for liquid products edged up a penny to $0.35 per hundred cubic feet (per hundred), but this price is still well below the plant replacement cost of $0.52 per hundred estimated by Dataquest. Pipeline and on-site nitrogen prices held constant at $0.14 and $0.23 per hundred, respectively.

There has been much speculation among financial analysts that air separation plant capacity in the United States is approaching 90 percent utilization and therefore pricing for atmospheric

Figure 2
U.S. Hydrogen, Oxygen, and Argon Use



Source: Dataquest (May 1992)

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products such as nitrogen, argon, and oxygen will increase. Data from the U.S. Department of Commerce show that the total unit production of atmospheric products (all industrial applications) in the United States has climbed slowly since 1989 (see Table 4). Nitrogen production has grown 2.8 percent CAGR since 1989; argon 3.7 percent; and oxygen 1.1 percent.

It is difficult to imagine that these type growth rates will tax the production capacity of industrial gas vendors. There may indeed be regional imbalances in supply and demand for liquid products, which would force prices higher for specific areas of the country. But Dataquest does not believe that regional trends will affect the areas of the United States with high concentrations of semiconductor plants such as Northern California, Oregon, Texas, and New York. In addition, our economic model calls for moderate inflation and stable energy prices throughout 1992. Therefore, we expect semiconductor manufacturers to see little upward pressure on industrial gas prices in 1992.

Total Gas Management

Semiconductor manufacturers in the United States are increasingly relinquishing the management of their industrial gas installations to vendors. Currently, there are 15 fabs in the United States where gas vendors have taken over, to varying degrees, the management of gas systems, both bulk and process gases. Gas companies place employees in the fab full-time typically under a 10-year or longer contract.

Total gas management is not well defined. The spectrum of services that fall under the total gas management rubric differ from one site to the next. But total gas management would include some or all of the falling services: off-site storage, just-in-time delivery, loading dock handling, U.S. Department of Transportation filings, piping system, purifier and tank installation and management, analytical, point-of-use purity guarantee, system maintenance, and safety. A full-blown total gas management contract typically requires five to eight people dedicated to one site filling shifts around the clock.

The advantage of total gas management for the device manufacturer is apparent insofar as the operation of the gas systems becomes transparent. For the industrial gas industry, which has seen very little shift in market share (see Table 5), total gas management enables companies to distinguish themselves from their competitors on much more than simply product specifications. In addition, gas vendors are gaining invaluable experience in the fab, which over the long term will add to their base of knowledge and help them to compete more successfully.

Table 4
Total U.S. Shipments of Atmospheric Industrial Gases (Millions of Cubic Feet)

	1991	1990	1989
Total Argon	12,914	12,860	12,819
Percentage Semiconductor	4.3	4.1	3.8
Total Nitrogen	786,727	749,525	744,068
Percentage Semiconductor	8.8	9.1	8.7
Total Oxygen	471,216	462,293	460,684
Percentage Semiconductor	0.2	0.1	0.2

Source: Commerce Department

Table 5
U.S. Market Share for Bulk Gases (Millions of Dollars)

	1991	1990	1989
Air Products	100.4	94.7	97.1
Linde/UCC	53.7	55.9	52.2
Airco/BOC	30.1	29.2	25.8
Liquid Air	23.3	23.7	23.0
Others	5.6	5.8	5.7

Source: Dataquest (May 1992)

Dataquest Perspective

Industrial gas volumes used in semiconductor applications will continue to grow, benefiting from shifts in manufacturing trends. But because volume growth is expected to be relatively small, the long-term opportunities for vendors will be tied more closely to the service component. Indeed, there may even be a multiplier effect to service. As gas vendors spend more time inside the fab, opportunities to take on the supply and management of other areas beyond gases will most likely arise.

By Mark FitzGerald

Inquiry Summary

Dataquest's Semiconductor Equipment, Manufacturing, and Materials inquiry summaries are designed to inform our clients of commonly asked questions and Dataquest's respective answers. No confidential information provided by our clients is included in this material.

Stepper Technology Split by Region

Q. What is the distribution of stepper shipments by technology for each region of the world in 1991?

A. Figure 1 indentifies Dataquest's estimates of the percentage of stepper shipments by technology (g-line, i-line, excimer/deep-UV, and 1x) for the four major regions of the world in 1991.

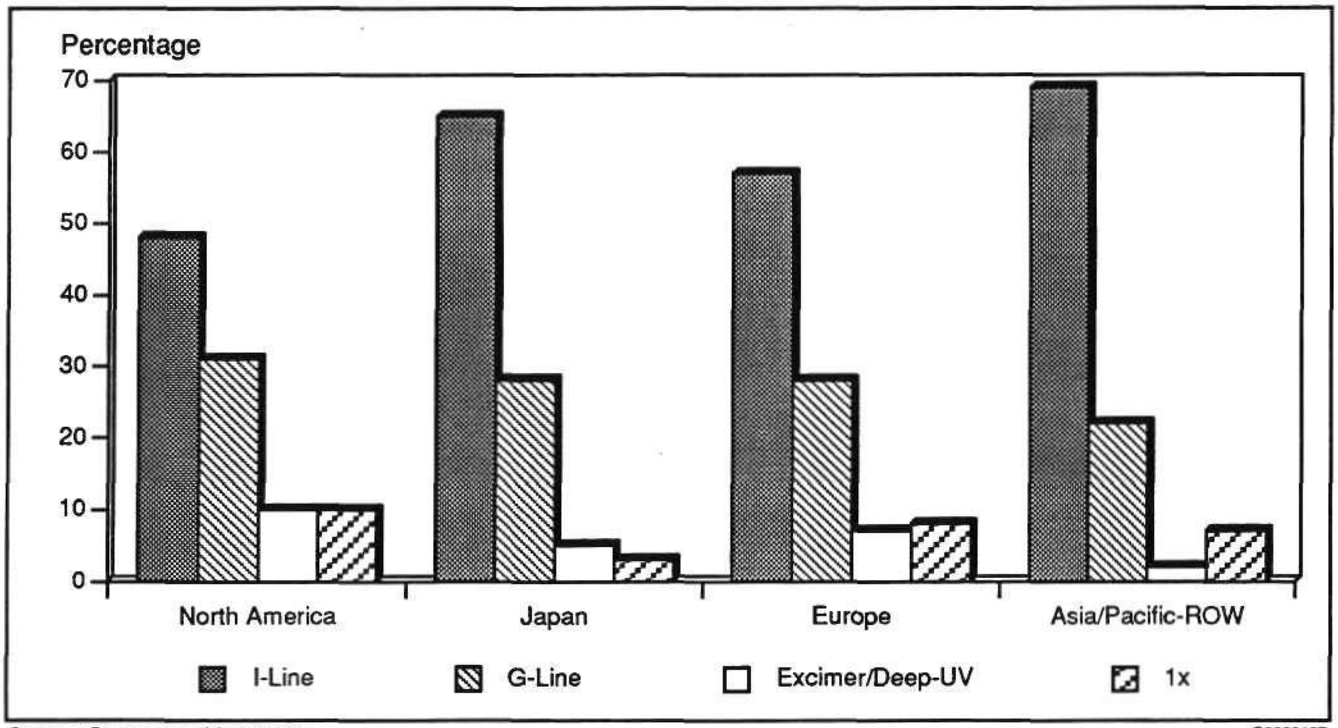
By Peggy Marie Wood

In Future Issues

Look for the following articles in future issues of *Dataquest Perspective:*

- 1991 PVD equipment market in review
- 1991 track equipment market in review
- U.S. silicon market
- U.S. specialty gas market

Figure 1
1991 Stepper Technology Split by Region (Percentage of Unit Shipments)



Source: Dataquest (May 1992)
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CONFERENCE ANNOUNCEMENT

Dataquest's 11th Annual SEMICON/West Seminar: Status 1992

Wafer fab equipment and materials companies had a tough time in 1990 and 1991 as the industry faltered. Dataquest believes that 1992 will also be a difficult year because of the lack of capital investment in semiconductor facilities. Will this dismal scenario continue? We don't think so. This year's SEMICON/West seminar will explore some of the reasons why the equipment and materials industry slowed over the past several years and why we believe that the industry will pick up again to resume a more normal growth path.

Attendees will hear Dataquest speakers discuss the following topics, which will provide a cohesive picture of the wafer fab equipment and materials industry from both supply-side and demand-side perspectives:

- Wafer fab equipment market status and forecast
- Wafer fab equipment company trends
- Semiconductor fab overview
- Capital spending forecast
- Changing strategies for materials companies
- Worldwide semiconductor device forecast
- Is there a future for the 1Gb DRAM?
- Portable PCs: A hot demand-side application

The seminar covers a lot of ground but it is specifically designed to provide the kind of high-level status and trend information that semiconductor equipment and materials industry executives need to support their decision-making. Industry executives have full and hectic schedules during SEMICON/West, but we believe that attendance at our acclaimed annual seminar will be an excellent investment of your time that will pay dividends to you and your company.

Dataquest's Status 1992 Seminar will be held on Wednesday, June 17 at the ANA Hotel (formerly Le Meridien) in San Francisco, just a few minutes' walking distance from Moscone Center, site of the SEMICON/West trade show. The seminar will begin at 8:30 a.m. and conclude by 11:40 a.m. Registration and continental breakfast will commence at 7:30 a.m. The fee for this seminar is $145. Please contact Dataquest's Conference Department at (408) 437-8245 for further information.

For More Information . . .

On the topics in this issue .... Peggy Marie Wood, Director/Principal Analyst (408) 437-8631
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Dataquest Perspective

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Semiconductor Equipment, Manufacturing, and Materials

SEMM-SVC-DP-9205 May 4, 1992

In This Issue...

Dataquest recently concluded its annual survey of the wafer fabrication equipment industry. Over the next several issues of Dataquest Perspective, we will discuss our analysis of general trends in the marketplace and those specific issues that characterize the market for each major segment of wafer fabrication equipment.

Dataquest

a company of The Dun & Bradstreet Corporation

File inside the *Dataquest Perspective* binder labeled **Semiconductor Equipment, Manufacturing, and Materials**

Market Analysis

Semiconductor Equipment—1991 Wafer Fab Equipment Market in Review

In 1991, the worldwide market for wafer fab equipment was $6.04 billion, up 3 percent from its 1990 level of $5.87 billion. Japan and North America each experienced a sluggish market environment in 1991, with growth of 1 percent and a decline of 4 percent, respectively, from 1990 levels. Substantially weaker business conditions in Europe contributed to a 17 percent decline for that region's wafer fab equipment spending in 1991. The one bright spot in worldwide wafer fab activities in 1991 was Asia/Pacific-ROW, which grew a healthy 64 percent from its 1990 level. Figure 1 presents the regional wafer fab equipment markets by percentage share for 1991. Even with its sluggish market environment in 1991, Japan still accounted for 50 percent of the worldwide wafer fab equipment market.

The wafer fab equipment market is decidedly in a slump. The market declined 2 percent in 1990 and was followed by only modest 3 percent growth in 1991. We expect the 1992 market, fed by a significant slowdown in the latter half of 1991, to be weaker yet and experience a decline of 8 percent from its 1991 level.

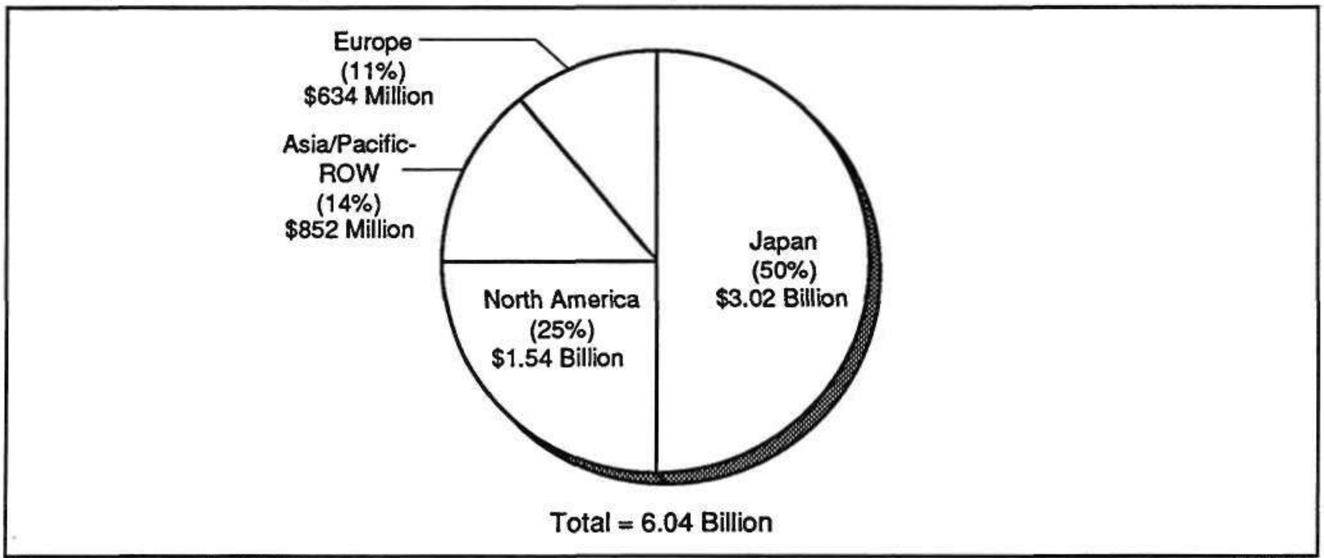
1991 Market Highlights

The following paragraphs detail several key characteristics of the wafer fab equipment market in 1991.

The mood of cautious optimism expressed by wafer fab equipment manufacturers at SEMICON/West in May 1991 turned to frank pessimism in the latter half of the year as the wafer fab equipment industry fell victim to the weakening condition of the world's major economies. The Japanese and German economies began to decelerate while the U.S. and U.K. economies remained firmly entrenched under their mantles of recession. The weakening macroeconomic climate had a significant impact on the capital spending plans of the world's semiconductor manufacturers. Many equipment companies saw orders being pushed out by as much as several quarters while some new business was canceled altogether.

One major factor that influenced the flat equipment market in Japan in 1991 was a growing concern regarding the profit pressures, overcapacity, and end-market uncertainty associated with the 4Mb and 16Mb DRAM. These concerns, coupled with the weakening macroeconomic climate in Japan, resulted in 16 of the 24 existing or planned 200mm fab lines being downsized or delayed. By the end of 1991, only 38 percent of

Figure 1
1991 Regional Wafer Fab Equipment Markets (Millions of Dollars)



Source: Dataquest (April 1992)

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the originally planned 200mm capacity had come online. These large DRAM facilities require significant equipment expenditure, thus the reduced capacity additions for 200mm fabs took a toll on the Japanese equipment market.

The European wafer fab equipment market was the weakest regional market in 1991. Much of the hype associated with the economic unification of Europe in 1992 had led to expectations that semiconductor companies would make significant investment in new fabs in order to meet local content rules. The anticipated growth spurt in the years prior to 1992 fizzled miserably. The European wafer fab equipment market grew only a modest 9 percent in 1989, followed by a mere 6 percent in 1990. The market declined 17 percent last year.

Asia/Pacific, growing an impressive 64 percent over its 1990 level, was a hotbed of activity for wafer fab equipment companies in 1991. Semiconductor manufacturers in Asia/Pacific are on an aggressive campaign to gain market share in DRAMs and other advanced semiconductor devices and thus are adding the necessary capacity to support this strategy. However, it is important to place the feverish 1991 market growth in perspective. This same equipment market suffered a decline of 37 percent just one year prior. These roller-coaster market dynamics highlight the fact that, with only a few major semiconductor companies in this region, a change in plans for just a handful of fabs can swing market growth wildly in either direction.

To add to the competitive quagmire in the wafer fab equipment industry, it is now clear that the Korean government is beginning to nurture its own embryonic domestic equipment industry to complement its strategy in semiconductors and silicon. Clearly, the potential of a new kid on the block won't have any impact on wafer fab equipment market dynamics in the short term, but it does contribute a whole new dimension to the future competitive market environment for wafer fab equipment.

Dataquest Perspective

The market environment for wafer fab equipment companies has probably never been tougher. Companies must cope with the presence of significant global competitors and the ever-escalating costs of advanced technology development on top of sluggish market conditions that have prevailed for more than two years. The companies that successfully emerge from this downturn in the industry with new product offerings and an increased emphasis on cost of ownership and aftersale service and support will be well positioned to take advantage of future growth opportunities in the wafer fab equipment market.

By Peggy Marie Wood

An "All-in-One" Summary Snapshot of the 1991 Wafer Fabrication Equipment Market

Dataquest's research of the wafer fabrication equipment market tracks the activities of more than 150 companies that participate in 40 different segments of the front-end equipment market. We have designed Table 1 to be an easy-to-use reference for summary market statistics of the 1991 wafer fabrication equipment market. Table 1 also reports our estimates of the 1991 worldwide markets for key segments of equipment and the percentage change of the size of each market relative to its 1990 level. The table also presents the percentage share for each market segment by region and by regional supplier.

Dataquest Perspective

Although the wafer fab equipment market is becoming more and more global, it is not entirely homogeneous with respect to equipment usage. Wafer fab equipment demand in Japan represented 50 percent of the worldwide wafer fab equipment market in 1991. However, semiconductor manufacturers in Japan accounted for 63 percent of worldwide CD SEM equipment demand, 65 percent of worldwide maskmaking equipment demand, and 83 percent of the 1991 worldwide demand for ECR etch equipment.

These variations in equipment demand can occur on a regional basis because of a concentration of activity in a specific region, such as maskmaking in Japan, or because of a specific manufacturing philosophy that favors a given type of tool technology, such as the preference by Japanese device manufacturers for CD SEM rather than optical CD systems. An especially strong domestic supplier base in a given tool technology can also influence the regional market dynamics for a specific equipment segment. Japanese companies account for 98 percent of the worldwide ECR etch equipment market,

Table 1
Summary Regional and Ownership Market Statistics of the 1991 Wafer Fabrication Equipment Market (Millions of Dollars)

			Percentage Regional Markets				Percentage Regional Ownership			
Equipment	1991 World ($)	(%) Change from 1990	North America	Japan	Europe	Asia-Pacific/ ROW	North American Comps.	Japanese Comps.	European Comps.	Joint Ventures
Contact/Proximity	21	-13	13	38	34	16	0	38	62	0
Projection Aligners	68	-27	22	45	11	22	31	69	0	0
Steppers	1,029	-2	27	49	9	15	11	82	7	0
Direct-Write	55	-27	13	64	13	9	0	81	19	0
Maskmaking	46	-3	21	65	7	8	56	39	5	0
X-Ray	4	163	57	43	0	0	57	0	43	0
Total Lithography	1,224	-5	26	50	10	15	13	79	8	0
Automatic Photoresist Processing Equipment	369	13	30	49	9	12	28	62	5	5
Wet Processing	405	1	26	51	9	15	30	67	3	0
Dry Etch	567	-2	30	43	13	15	63	31	3	3
ECR Etch	138	23	3	83	4	10	0	98	2	0
Dry Strip	119	1	27	52	8	13	33	50	0	18
Total Etch and Clean	1,229	2	25	51	10	14	42	52	2	3
Horizontal Tube CVD	85	-27	26	38	17	19	21	16	60	2
Vertical Tube CVD	192	34	17	57	6	20	13	71	12	4
Nontube CVD	471	3	28	48	11	12	80	10	5	6
Total CVD	747	4	25	49	10	15	56	26	13	5
Sputter	438	22	27	50	9	14	37	59	4	0
Evaporation	36	-26	40	37	14	9	30	35	35	0
Silicon Epitaxy	89	30	28	52	12	8	40	21	39	0
MOCVD	51	16	27	45	18	10	36	33	31	0
MBE	59	2	18	51	18	14	9	42	49	0
Total Deposition	1,420	10	26	49	11	14	46	37	15	3

(Continued)

Table 1 (Continued)
Summary Regional and Ownership Market Statistics of the 1991 Wafer Fabrication Equipment Market (Millions of Dollars)

			Percentage Regional Markets				Percentage Regional Ownership			
Equipment	1991 World ($)	(%) Change from 1990	North America	Japan	Europe	Asia-Pacific/ ROW	North American Comps.	Japanese Comps.	European Comps.	Joint Ventures
Horizontal Diffusion	135	-18	27	34	16	22	38	44	14	4
Vertical Diffusion	200	25	21	54	7	18	19	72	5	4
Total Diffusion	335	3	24	46	11	19	26	61	9	4
Rapid Thermal Processing	42	41	44	34	17	5	85	7	8	0
Medium Current Implant	108	-5	15	55	13	17	53	36	0	11
High Current Implant	218	-13	18	59	12	11	55	10	0	35
High Voltage Implant	18	159	16	65	19	0	83	17	0	0
Total Implant	343	-7	17	58	13	12	56	19	0	26
Optical CD*	59	1	33	33	22	12	65	21	14	0
CD SEM	94	8	19	63	6	13	14	86	0	0
Wafer Inspection	90	-1	29	46	17	7	45	42	13	0
Subtotal Wafer Fab Equip.	5,205	2	25	50	11	14	35	53	8	4
Macro Categories										
Ion Milling	17	28	23	42	13	23	NA	NA	NA	NA
Other Process Control	398	8	30	45	11	14	NA	NA	NA	NA
Factory Automation	227	5	16	58	10	16	NA	NA	NA	NA
Other Equipment	193	2	25	50	11	14	NA	NA	NA	NA
Total Wafer Fab Equipment	6,040	3	25	50	11	14	NA	NA	NA	NA

NA = Not applicable
*Includes dedicated registration measurement tools.
Percentage figures for regional markets and ownership may not add to 100 percent because of rounding.
Source: Dataquest (April 1992)

and thus, it is no surprise that semiconductor manufacturers in Japan purchase a disproportionately larger amount of this equipment because of their proximity to this strong domestic vendor base. Overall, though, Table 1 shows that for the majority of wafer fab equipment categories, regional trends for individual segments of equipment are quite similar to the percentage share represented by each of the regional wafer fab equipment markets.

By Peggy Marie Wood

1991 CVD Equipment Market in Review

The worldwide CVD equipment market grew 4 percent in 1991 and represented a $747 million market. This article presents the significant highlights of the 1991 CVD equipment market.

Regional CVD Equipment Market and Ownership

Figure 1 shows the worldwide 1991 CVD equipment market segmented by region and ownership. Japan, with 50 percent of the worldwide CVD market, continued its role as the largest regional market. However, North American companies continued their dominance of the 1991 CVD market, capturing 56 percent of the worldwide $747 million total.

CVD Equipment Company Ranking

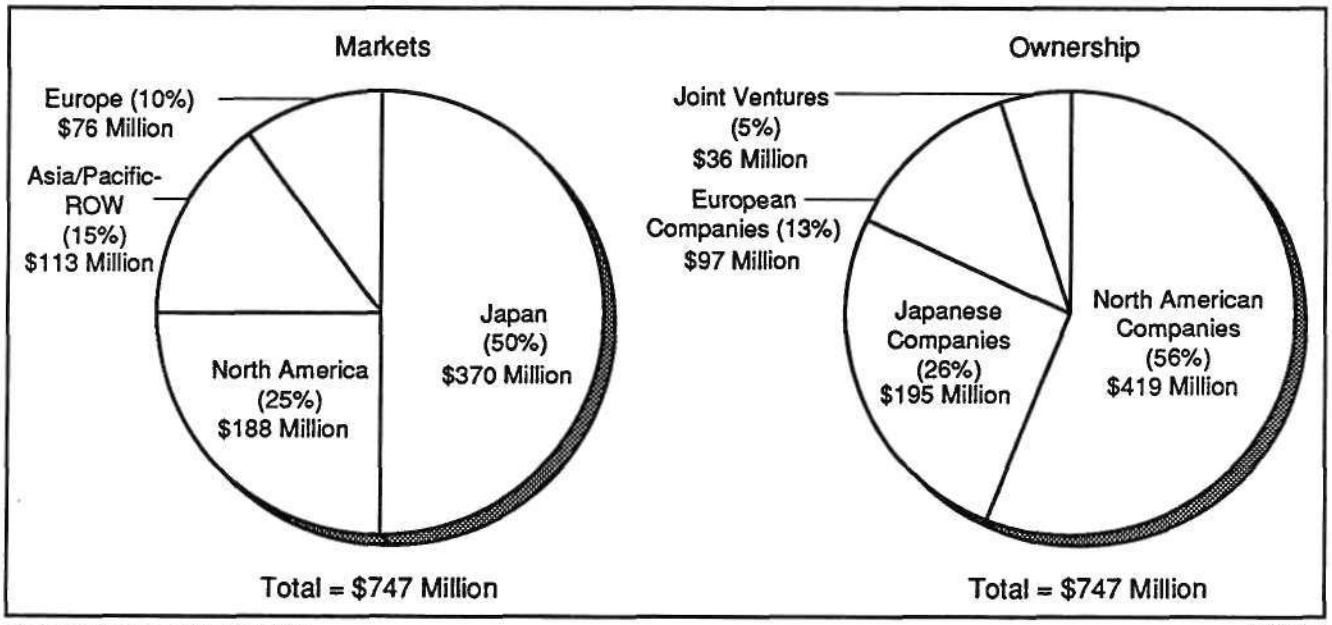
Table 1 lists the worldwide 1991 CVD equipment company market ranking, together with the market segment activities.

Applied Materials

Applied Materials, with 29.2 percent of the 1991 market, retained its position as the market leader. Applied's dielectric PECVD reactor business continued its strong thrust into intermetal dielectric and passivation applications. Applied has focused on designing its low-temperature TEOS-based oxide process into multiple applications within multilevel interconnect processes at leading device company fabs. The move toward double-level interconnect 16Mb DRAM processes and triple-level/four-level microprocessor/ASIC processes has allowed Applied to address a progressively larger total available market. Applied's metal CVD business, which addresses the tungsten and tungsten silicide interconnect market, also showed healthy growth in 1991.

Dataquest believes that Applied's CVD marketing strategy is currently focused on lowering cost of ownership across the board in its huge installed base of P5000 CVD systems. The combination of Applied's traditional strengths in process development, together

Figure 1
1991 CVD Regional Markets and Ownership



Source: Dataquest (April 1992)

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Table 1
1991 Worldwide CVD Equipment Company Rankings (Revenue in Millions of Dollars)

Company	Revenue	CVD Market % Share	Horizontal LPCVD Tube	Vertical LPCVD Tube	Horizontal PECVD	Reactor APCVD	Reactor LPCVD	Reactor PECVD	Reactor ECR CVD
Applied Materials	218.4	29.2	0	0	0	0	32	186.4	0
ASM International	70.5	9.4	7.9	22.6	40	0	0	0	0
Novellus Systems Inc.	69.7	9.3	0	0	0	0	5.7	64	0
Kokusai Electric	63.6	8.5	1.6	62	0	0	0	0	0
Tokyo Electron Ltd.	62.8	8.4	7.1	53	0	0	2.7	0	0
Watkins Johnson	48.5	6.5	0	0	0	48.5	0	0	0
Genus	34.8	4.7	0	0	0	0	34.8	0	0
Alcan Technology (Canon)	26.8	3.6	0	0	0	26.8	0	0	0
Silicon Valley Group	25.8	3.5	9.3	16.5	0	0	0	0	0
E.T. Electrotech	20	2.7	0	0	0	0	0	20	0
Ulvac	18.3	2.4	5.3	5	0	0	8	0	0
Amaya	12.3	1.6	0	0	0	12.3	0	0	0
BTU International	10.5	1.4	6	4.5	0	0	0	0	0
Varian/TEL	9.6	1.3	1.9	7.7	0	0	0	0	0
Others	55.8	7.5	4.8	20.3	1	4.3	6.7	11.4	7.3
Worldwide Market Total	747.4	100.0	43.9	191.6	41	91.9	89.9	281.8	7.3

Note: Calendar year 1991 systems revenue only; spares and service not included.
Source: Dataquest (April 1992)

with its stronger focus on user economics issues, positions the company well for growth in the CVD market.

ASM International

ASM International, with $70.5 million in 1991 CVD revenue, captured 9.4 percent of the market. Although ASM International's traditional horizontal PECVD tube business has shown signs of decline in the last two years, the company is attempting to reposition itself as a leading supplier of vertical LPCVD tubes, vertical LPCVD tube-based cluster tools, and PECVD single-wafer reactors. ASM International has been particularly successful in Japan with its 6- and 8-inch horizontal PECVD tube and its new vertical LPCVD tube for poly and thermal nitride applications.

ASM International faces its biggest challenges in the next few years as it attempts to crack the high-growth reactor CVD market and the vertical LPCVD tube market against entrenched rivals that forged into the market earlier. The company is betting that its small-batch and large-batch vertical tube loadlocked cluster tools will find market acceptance in emerging integrated applications such as integrated gate-stack formation and preclean/oxidation/diffusion applications.

Novellus

Novellus, with $69.7 million in 1991 CVD systems revenue, captured 9.3 percent of the market. Novellus continues to penetrate the low-temperature silane-based and TEOS-based oxide market using its elegant Concept-One system architecture. Novellus' marketing strategy, which emphasizes low cost of ownership coupled with advanced film qualities, has been very successful in winning large-volume, multiple orders from several global device manufacturers. Novellus was also very effective in continuing its penetration of the crucial Japanese market.

Dataquest believes that Novellus has elected to pursue a long-term policy of direct participation in the Japanese market through the establishment of a comprehensive customer support, applications, and development facility in Japan. Novellus continued its efforts toward penetrating the metal CVD market with the Concept-One-W system. The success of Novellus in the metal CVD market will play a crucial determining role in the company's efforts toward penetrating the integrated interconnect applications market on the new CVD/PVD Concept-Two hybrid platform.

Dataquest also notes that dry etch technology is conspicuous by its absence in the Novellus product portfolio. We predict that Novellus will speedily acquire dry etch technology capability either through an acquisition, alliance, or internal development efforts. In the era of integrated thin films applications, the lines between deposition and etch technologies are rapidly blurring. Only companies that offer a complete, global, best-of-breed solution can sustain growth and profitability. Novellus has recently been putting a new management team in place that will transition it from a single-product, regionally focused company into a multiproduct, global capital equipment company.

Kokusai Electric and TEL

Kokusai Electric and Tokyo Electron Ltd. (TEL) continue their dominance of the vertical LPCVD tube business. Both companies have been extremely successful in delivering high-performance, production-worthy platforms for poly, thermal nitride, and undoped high-temperature oxide applications in 4Mb/16Mb DRAM applications. Both companies recently introduced loadlocked 8-inch vertical thermal reactors (VTRs) targeted at integrated thermal processes such as gate-stack formation, capacitor formation, and preclean/diffusion/oxidation.

Because of significant value-added automation, process-control, and defect-reduction features, both companies have been able to obtain premium market prices for their VTRs, which can range in price from $300,000 to $600,000 per tube. TEL is aggressively marketing its VTRs globally through the Varian/TEL joint venture in the United States and Europe, and by itself in Asia/Pacific. Kokusai Electric recently bought a majority stake in BTU International's Bruce Systems division and hopes to gain from BTU International's installed base, customer support/service, and process-control software expertise.

Watkins-Johnson

Watkins-Johnson, with 6.5 percent of the worldwide CVD market, continued its dominant position in the APCVD market. The company is attempting to diversify beyond its traditional silane-based BPSG premetal dielectric business. By offering TEOS/ozone low-temperature conformal dielectric solutions, the company hopes to parlay its core APCVD technology into the larger, potentially more lucrative intermetal dielectric market.

Dataquest believes that Watkins-Johnson will vigorously attempt to carry over its production worthiness, APCVD simplicity, and low cost of ownership advantages into the intermetal dielectric market.

Genus

Genus, with 4.7 percent of the 1991 CVD market, retained its position as the market leader in the LPCVD-based tungsten silicide market. However, Genus experienced significant competition from companies such as Applied Materials and Novellus in the blanket tungsten CVD segment.

Dataquest believes that Genus will continue to focus on developing advanced films such as high-temperature dichlorosilane silicide (DCS silicide) and CVD titanium nitride. Genus continues its strong links with key customers such as IBM in the blanket tungsten CVD market. Genus faces the challenge of fending off larger, better-capitalized competitors such as Applied and Novellus in the high-volume blanket tungsten and tungsten silicide market. The company must simultaneously channel its limited resources wisely toward the development of leapfrog films such as CVD titanium nitride, CVD copper, and DCS tungsten silicide.

Alcan Technology (Canon)

Alcan Technology (Canon), with almost $27 million in 1991 revenue, nearly doubled its CVD product revenue based on its pioneering TEOS/ozone APCVD technology. Its low temperature APCVD technology represents a significant challenge to the hitherto unchallenged PECVD technology dominance of the lucrative intermetal CVD film market.

Dataquest believes that other leading CVD companies will focus on development of TEOS/ozone APCVD intermetal dielectric solutions that will compete with Alcan in the CVD market.

Silicon Valley Group

Silicon Valley Group, with almost $26 million (3.5 percent) of the market, continues its focus on the vertical LPCVD tube business. The company won several significant 8-inch VTR orders in 1991. With BTU International's diminished position within the wafer fabrication equipment business, SVG remains as the last U.S. participant of significant size in the VTR business.

Dataquest believes that SVG is poised to continue its quest for market share gain in the LPCVD VTR market through development of the advanced vertical processor (AVP) family of clusterlike loadlocked tube products.

Dataquest Perspective

The $747 million 1991 CVD equipment market represented one of the few growth spots in an otherwise lackluster wafer fabrication equipment market. Technology-driven market segments such as metal CVD, LPCVD VTR tubes, and TEOS/ozone APCVD continued to influence the growth of the CVD market. New CVD market players in areas such as APCVD and LPCVD VTR products may challenge the traditional dominance of the PECVD dielectric reactor companies. PECVD reactor companies, in turn, are scrambling to diversify their process applications into high-growth segments such as metal CVD, polysilicon LPCVD, and TEOS/ozone APCVD films. We expect the technology displacements to continue driving significant shifts in the quest for global CVD equipment market share.

By Peggy Marie Wood and Krishna Shankar (San Jose)
Kunio Achiwa (Tokyo)

Company Analysis

Chemical Titans Inherit the Resist Business

Rohm and Haas Company has announced an agreement to purchase the remaining 70 percent of the equity of Shipley Company. Rohm and Haas has owned 30 percent of the company since 1982. The transaction is expected to be completed in the second quarter of 1992.

The major shareholders, Charles and Lucia Shipley, prefer a tax-free transaction and will exchange their Shipley holdings for a new issue of 2.7 million shares of $50 million convertible preferred stock (paying a $2.75 per-share annual dividend) plus 700,000 common shares of Rohm and Haas (price $54.75 as of April 16, 1992). Dataquest estimates that the present value of the deal is worth $135 million to $200 million dollars.

Market Drivers

The acquisition marks another step in the consolidation and restructuring of the global photoresist industry, which has been under way for the last seven years (see Table 1). Prior to the acquisition, Shipley and Tokyo Ohka (TOK), the two largest players in the U.S. and Japanese markets, were the last vendors not owned by a large chemical company. But, as capital investment in leading-edge resists skyrockets, even Shipley and TOK are finding it difficult to match the spending programs of some of the large chemical companies that have entered the resist business.

Shipley's revenue in 1991 totaled about $200 million, slightly down from $212 million in sales in 1990. Dataquest believes that it was increasingly difficult for Shipley to finance its $100 million dollar, five-year building program because of the downturn in the semiconductor industry. Shipley is constructing two new facilities in Marlboro, Massachusetts and Niigata prefecture, Japan. In addition, the company plans to upgrade its recently completed manufacturing facilities in Coventry, England.

Compared with other resist manufacturers (see Table 2), Shipley spends a larger percentage of its sales on facilities and R&D. Dataquest estimates that Shipley spent about $30 million on new facilities in 1991, or 14.7 percent of sales. R&D spending accounted for another $14 million in spending, or 6.9 percent of sales. TOK and Shipley lead the industry in facility investment and R&D expense when measured as a percentage of sales.

Table 1
Photoresist Industry Consolidation

1992	Rohm and Haas acquires Shipley.
1992	OCG Microelectronics acquires KTI's resist lines.
1991	Olin Hunt and Ciba Geigy merge photoresist operations into OCG Microelectronic Materials, a joint venture company.
1991	Hoechst AG acquires manufacturing rights to IBM's g-line and i-line resists.
1990	Japan Synthetic Rubber and UCB form a joint venture company to market resists in Europe and the United States.
1990	Dynachem acquires MacDermid's semiconductor resist business in exchange for Dynachem's printed circuit board resist business.
1989	Shipley acquires Aspect Systems.
1988	E. Merck sells its photoresist line to Ciba Geigy.
1988	Spectrum Resist exits the photoresist business.
1987	B.F. Goodrich exits the photoresist business.
1986	Monsanto sells off its photoresist operation to Aspect Systems.
1985	Allied Chemical exits the photoresist business.

Dataquest (April 1992)

Table 2
FY1991 Financial Data on Selected Photoresist Suppliers (Millions of U.S.$)

		Facility Investment		R&D Expense	
	Revenue	Dollars	% Sales	Dollars	% Sales
Japan Synthetic Rubber[1]	1,600	185	11.6	85	5.3
Nippon Zeon[1]	1,250	99	7.9	45	3.6
Shipley[2]	204	30	14.7	14	6.9
Sumitomo Chemical[3]	7,926	518	6.5	296	3.7
Rohm and Haas[3]	2,763	265	9.6	183	6.6
Tokyo Ohka[1]	475	72	15.7	21	4.5

Note: 1991 exchange rate $U.S.1 = ¥134.68
[1]FY ends March 1992
[2]Dataquest estimates; FY ends December 1991
[3]FY ends December 1991
Source: Dataquest (April 1992)

But Dataquest believes that Shipley is being outspent in absolute dollar terms by the much larger companies, even recognizing that total spending at the larger companies is spread over many programs outside of the photoresist business. Japanese companies are especially aggressive in their level of photoresist spending even when they do not currently have a position in the photoresist business (for example, Nippon Zeon). With much larger competitors outspending Shipley, the purchase by a deep-pocketed company such as Rohm and Haas should permit Shipley to maintain its capital spending plans through the current industry downturn.

Table 3
TOK's Capital Expenditure (Billions of Yen)

FY1990	5.9
FY1991	9.7
FY1992	6.0 to 8.0 (including the following items)
	1.9 land purchase for new plant in Kooriyama
	1.5 for phase two of Aso plant
	1.5 for expansion of Gotenba plant

Source: Dataquest (April 1992)

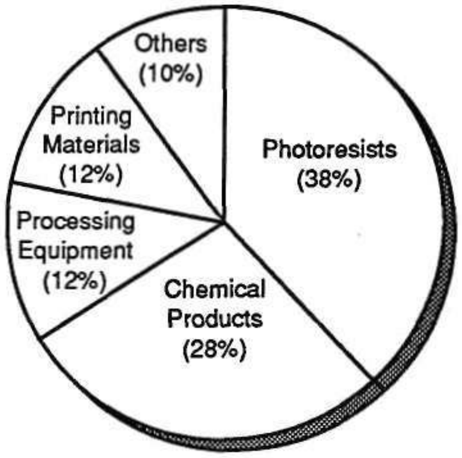
Tokyo Ohka

The acquisition of Shipley leaves TOK as the last resist supplier with revenue less than $500 million. This begs the question as to whether market dynamics will also force TOK into a merger with a larger company. TOK, like Shipley, will need to maintain an intensive capital spending and R&D program in order to sustain its leadership position in the resist industry (see Table 3). TOK currently has 60 percent of the positive resist market in Japan and 10 percent of the U.S. market. Yet the shift to i-line resist threatens to erode that market position.

New competitors, particularly Sumitomo Chemical and Japan Synthetic Rubber, are expected to erode TOK's share of the Japanese market as i-line resist volumes begin to ramp. Moreover, TOK's g-line products, which account for the largest share of its sales, are coming under pricing pressure and are not expected to experience much growth. Resist products and ancillary resist chemicals account for 66 percent of TOK's sales worldwide (see Figure 1), so price erosion or a loss of market share will certainly undermine TOK's ability to maintain its capital spending plans.

Unless TOK can turn these trends around or aggressively grow its printing materials or equipment business, the probability that TOK will remain independent will decrease. Dataquest believes that the company simply does not have the critical mass to maintain its

Figure 1
Tokyo Ohka Sales Breakdown (Half-Year Ending September 1991)



Source: Toyo Keizai

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momentum. In addition, like other Japanese businesses, it is facing higher capital costs that are an additional strain on sustaining the aggressive investment plans.

The wild card in this analysis is the fast-growing market for resist in liquid crystal displays. Japanese companies dominate this market. TOK has the advantage here in being the largest player in the Japanese market, an advantage which Shipley could not fall back on. If TOK can position itself in this application, then it will certainly benefit from the exponential growth forecast for the LCD market. Under this scenario, TOK could reach the critical mass to remain independent. However, winning a significant share of the LCD resist market, a share that would be comparable to its position in g-line resists today, appears impractical considering the number of other competitors in Japan targeting this application.

Rohm and Haas

Rohm and Haas is a Philadelphia-based chemical company. It is a major supplier of polymers, plastics, performance chemicals, and agriculture chemicals. Its 1991 revenue totaled $2.7 billion. Shipley is Rohm and Haas' second acquisition in the past six months. In 1991 it agreed to acquire the emulsion polymer business of Unical. The Unical transaction is awaiting FTC approval. Unical had sales of about $160 million and the estimated selling price was $150 million to $175 million. The two acquisitions will add about $400 million of specialty chemical revenue to Rohm and Haas' sales. In 1991, its specialty chemical sales were about $1.8 billion, so these acquisitions will expand Rohm and Haas' specialty chemical sales by more than 20 percent. Dataquest expects Rohm and Haas to continue to build its specialty chemical business through acquisitions.

Dataquest Perspective

The Shipley acquisition will most likely be one of the last few transactions, marking an end to an intense period of consolidation in the global photoresist business. The industry is now moving into a phase in which chemical titans will battle for world market share armed with advanced resists, which will cost small fortunes to bring to market.

By Mark FitzGerald (San Jose) and Kunio Achiwa (Tokyo)

Inquiry Summary

Dataquest's Semiconductor Equipment, Manufacturing, and Materials inquiry summaries are designed to inform our clients of commonly asked questions and Dataquest's respective answers. No confidential information provided by our clients is included in this material.

Wafer Fab Activity in Malaysia

Q. What is the status of wafer fabs in Malaysia?

A. Over the past few years, Malaysia has received increasing press coverage as the country has strived to attract leading semiconductor manufacturers to establish front-end operations. Historically, Malaysia has focused on back-end operations and has had an extensive number of foreign companies set up shop there.

One impetus for assembly and test operations locating to Malaysia has been the General System of Preference agreement. In short, this agreement provides tariff abatement for products brought into the European Community that are manufactured in selected southeast Asian nations. Under the broad definition of "manufacture," the value added through assembly and testing also provided manufacturers with a mechanism to more effectively meet market pricing demands.

The only major semiconductor manufacturer so far to establish a front-end operation in Malaysia is Motorola. The Motorola Sarambam line has been operating since midyear 1988 and produces principally discrete devices. Motorola also has a back-end operation located in Petaling Jaya.

Company sources cannot confirm that Hitachi reportedly has plans to build a front-end fab in Malaysia for DRAM fabrication. At present, Dataquest believes that this new fab line in Malaysia is highly unlikely because Hitachi's wafer fab in Landshut, Germany, is slated to come online this fall. The Landshut facility will manufacture DRAMs, and with the current anemic capital spending outlook, the likelihood of a new line in Malaysia appears doubtful.

By Rebecca Burr

1991 Top Ten Wafer Fab Equipment Company Ranking by Region

Q. How many companies in the worldwide top 10 wafer fab equipment company ranking for 1991 also rank as a supplier in the top 10 ranking for all four regional markets?

A. Table 1 identifies the top 10 wafer fab equipment companies in the world and regional markets in 1991. Only four companies (Nikon, Applied Materials, Canon, and Varian) place in the top 10 ranking in each of the four major regional markets. Nikon and Canon achieve this distinction because of their particularly strong presence in the stepper market. Applied Materials and Varian are in each of the top 10 regional rankings because these two companies provide a diverse mix of products designed for leading-edge device manufacturing.

By Peggy Marie Wood

In Future Issues

Look for the following articles in future issues of *Dataquest Perspective:*

- 1991 stepper market in review
- 1991 PVD market in review
- U.S. semiconductor bulk gas market

Table 1
1991 Top Ten Wafer Fab Equipment Company Ranking by Region

Rank	World	($M)	North America	($M)	Japan	($M)
1	Nikon	557.2	Applied Materials	165.0	Nikon	348.2
2	Applied Materials	493.3	Nikon	121.1	Tokyo Electron Ltd.	314.8
3	Tokyo Electron Ltd.	397.3	Silicon Valley Group	108.6	Hitachi	244.0
4	Hitachi	327.6	General Signal	77.8	Applied Materials	203.1
5	Canon	291.5	LAM Research	63.0	Canon	147.2
6	Varian	180.8	Canon	54.4	Ulvac	118.3
7	Silicon Valley Group	180.3	Varian	42.7	Anelva	118.1
8	Anelva	154.6	ASM Lithography	40.7	Dainippon Screen	92.9
9	Kokusai Electric	138.2	ASM International	38.2	Kokusai Electric	76.1
10	Dainippon Screen	138.0	Materials Research Corp.	35.5	Varian	65.8
		2,858.8		747.0		1,728.5
	Total Market	6,039.5	Total Market	1,536.3	Total Market	3,016.7
	Percent Top 10	47	Percent Top 10	49	Percent Top 10	57

Rank	Europe		Asia/Pacific-ROW	
1	Applied Materials	66.2	Tokyo Electron Ltd.	82.5
2	Nikon	39.9	Hitachi	62.3
3	Silicon Valley Group	31.7	Applied Materials	59.0
4	Canon	31.6	Canon	58.3
5	Varian	27.7	Nikon	48.0
6	Varian/TEL	24.6	Varian	44.6
7	ASM International	24.5	Kokusai Electric	43.6
8	E.T. Electrotech	20.8	LAM Research	32.9
9	Eaton	18.4	Silicon Valley Group	26.7
10	General Signal	14.4	ASM Lithography	21.6
		299.8		479.5
	Total Market	634.2	Total Market	852.3
	Percent Top 10	47	Percent Top 10	56

Revenue estimates reflect the major categories of wafer fabrication equipment including lithography, automatic photoresist processing equipment, etch and clean, deposition, diffusion, rapid thermal processing, ion implantation, optical CD and CD SEM tools, and wafer inspection equipment. Revenue associated with service and spares is not included.
Source: Dataquest (April 1992)

CONFERENCE ANNOUNCEMENT

Dataquest's 11th Annual SEMICON/West Seminar: Status 1992

Wafer fab equipment and materials companies had a tough time in 1990 and 1991 as the industry faltered. Dataquest believes that 1992 will also be a difficult year because of the lack of capital investment in semiconductor facilities. Will this dismal scenario continue? We don't think so. This year's SEMICON/West seminar will explore some of the reasons why the equipment and materials industry slowed over the past several years and why we believe that the industry will pick up again to resume a more normal growth path.

Attendees will hear Dataquest speakers discuss the following topics, which will provide a cohesive picture of the wafer fab equipment and materials industry from both supply-side and demand-side perspectives:

- Wafer fab equipment market status and forecast
- Wafer fab equipment company trends
- Semiconductor fab overview
- Capital spending forecast
- Changing strategies for materials companies
- Worldwide semiconductor device forecast
- Is there a future for the 1Gb DRAM?
- Portable PCs: A hot demand-side application

The seminar covers a lot of ground but it is specifically designed to provide the kind of high-level status and trend information that semiconductor equipment and materials industry executives need to support their decision-making. Industry executives have full and hectic schedules during SEMICON/West, but we believe that attendance at our acclaimed annual seminar will be an excellent investment of your time that will pay dividends to you and your company.

Dataquest's Status 1992 Seminar will be held on Wednesday, June 17 at the ANA Hotel (formerly Le Meridien) in San Francisco, just a few minutes' walking distance from Moscone Center, site of the SEMICON/West trade show. The seminar will begin at 8:30 a.m. and conclude by 11:40 a.m. Registration and continental breakfast will commence at 7:30 a.m. The fee for this seminar is $145. Please contact Dataquest's Conference Department at (408) 437-8245 for further information.

For More Information . . .

On the topics in this issue .... Peggy Marie Wood, Director/Principal Analyst (408) 437-8631
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Dataquest Perspective

Semiconductor Equipment, Manufacturing, and Materials

SEMM-SVC-DP-9204 April 13, 1992

In This Issue...

Technology Analysis

Microprocessor Technology Steals the Show at ISSCC/1992

The recent annual International Solid-State Circuits Conference (ISSCC) held in San Francisco provided a glimpse of future device architecture and process technology that will drive the wafer fabrication equipment and materials industry for the next 10 years. Fast-paced advances in microprocessor system-on-chip technology stole the show from the traditional DRAM-driven technology status reports at ISSCC/1992.

Microprocessors Become Semicomputers

Microprocessor architectural advances coupled with the enabling power of submicron process technologies are now enabling computer designers to cram entire systems onto one large chip. In addition to the CPU, leading-edge microprocessors now incorporate the floating-point unit (FPU) and instruction and data cache (8Kb to 36Kb) on board the chip. Factors such as defect densities, yields, and stepper field sizes will constrain the trend toward all-encompassing integration.

The semiconductor revolution is giving way to semicomputer evolution. The design innovation pendulum is swinging away from traditional proprietary, merchant microprocessor houses such as Intel and Motorola toward system-knowledge intensive captive computer companies such as Digital, Hewlett-Packard, IBM, Sun, and Silicon Graphics. The evolution of RISC-based open-architecture computing and access to leading merchant CAD tools and global ASIC foundries has significantly leveled the silicon playing field between traditional merchant microprocessor companies and captive computer/workstation companies.

Table 1 summarizes the key features of advanced microprocessors discussed at ISSCC/1992. All microprocessor papers were presented by computer/workstation companies. Digital's Alpha RISC architecture and MIPS R4000 architecture (not presented at ISSCC/1992) herald the arrival of 64-bit computing. Leading-edge microprocessors are using CMOS technology with minimum lithography design rules in the 0.5- to 0.8-micron range. Extra-wide field stepper lenses and other lithography innovations such as step-and-scan technology will be needed to print increasingly larger microprocessor chips. BiCMOS technology may be needed to implement the ECL-type low-level logic swings of high-speed microprocessors.

Microprocessors continue to drive multilevel interconnect technology. Three-level interconnect technology is rapidly becoming the standard in advanced 32/64-bit microprocessors, with four-level interconnect implementations looming on the horizon. Metal linewidth/space and contact feature sizes in the range of 0.5 to 0.8 microns rival the traditional transistor gate-length as a technology driver. In response, microprocessor manufacturers will increase the proportion of the wafer fab equipment capital budget spent on planarization, plug, interconnect deposition, and etch applications, relative to lithography applications.

Is the DRAM Technology Juggernaut Slowing?

NEC's 64Mb DRAM chip was the lone advanced DRAM entrant in the ISSCC technology horse race. The chip was implemented in 0.4-micron, 3.3V double-metal CMOS technology. NEC used a hemispherical storage-node technique for its stacked capacitor cell scheme to yield a cell size of 1.8 * 0.9 $micron^2$. The prototype chip, which measured 19.48 * 9.55 mm^2, performed with an access time of 30ns. NEC's adoption of built-in self-test (BIST), redundancy, and repair diagnostics logic may signal an emerging advanced DRAM design trend that will contribute to simplified testing and repair at the expense of a slightly larger die size.

A DRAM panel session held at ISSCC/1992 revealed some contradictory opinions on future DRAM generation evolutions. IBM believed that lengthening the historical three-year gap between DRAM generational adoptions was inevitable because of factors such as increasing fab costs that may increase cost per bit, limits to cell-size scaling and lithography, and device reliability issues.

In contrast, Toshiba's outlook was optimistic. Toshiba believed that new cell innovations such as three-dimensional stacked gate transistor (SGT) technology, in which the transfer gate and capacitor node are built in the vertical direction on a silicon pillar island, may allow DRAM technology to evolve at its historical rapid pace. Dataquest believes that new capacitor dielectric materials such as CVD tantalum pentoxide, with its high dielectric constant, may allow DRAM companies to continue scaling cell sizes while maintaining the simplicity and economics of prior-generation processes.

Texas Instruments (TI) believed that future DRAM generations such as a 256Mb DRAM based on 0.25-micron technology and a 1Gb DRAM based on 0.15-micron technology were realistic, achievable long-term targets. TI speculated that DRAMs will become increasingly specialized and segmented to target specific applications such as high-speed workstations and low-power portable computers. Dataquest

Table 1
Key Features of Microprocessor Technology at ISSCC/1992

Company	Architecture	Speed (MHz)	Technology	Design Rule (Microns)	Transistors (Millions)	Chip Size (cm * cm)
DEC	32-Bit/CISC	100	CMOS	0.75	1.30	1.62 * 1.46
DEC	64-Bit/RISC	200	CMOS	0.75	1.68	1.68 * 1.39
Fujitsu	32-Bit/CISC	70	CMOS	0.50	1.50	1.60 * 1.58
Hitachi	32-Bit/CISC	250	BiCMOS	0.30	1.02	0.81 * 0.80
Sun	32-Bit/RISC	40	BiCMOS	0.80	3.10	1.60 * 1.60

Source: Dataquest, ISSCC/1992 (April 1992) believes that application-specific DRAMs such as video DRAMs, wide-word DRAMs, and RAMBUS-based high-performance DRAMs will offer opportunities for differentiation and premium pricing that allow more expensive high-performance process and packaging technologies to be adopted.

Faster and Denser SRAM Technology Mushrooms

Faster and denser SRAM process technologies are mushrooming at an accelerated pace because of the increasing cache-memory needs of high-performance workstations and high-end computers. Table 2 lists the key features of advanced SRAM chips that debuted at ISSCC/1992. Japanese companies such as Fujitsu, Hitachi, NEC, and Toshiba appear to be in the forefront in introducing high-speed, high-density SRAMs such as 1Mb, 4Mb, and 16Mb products. Several SRAM companies continue to pursue BiCMOS technologies because of the high-speed ECL-level I/O requirements. However, pure submicron CMOS technologies that are more cost-effective appear to be catching up rapidly in the speed horse race.

All the advanced SRAMs utilized double-level interconnect technologies. Dataquest believes that advanced SRAM devices present a significant planarization challenge because of their pervasive use of three and four poly/polycide levels coupled with double-level metal technologies. We believe that advanced SRAMs such as 4/16Mb SRAMs will stimulate the growth of the polysilicon CVD equipment market because of the need for multiple, high-quality polysilicon films for BiCMOS emitter, gate, local polycide interconnect, load resistor, and poly thin-film transistor pull-up logic applications.

High-Density, 5V Operation Flash Memory Technology

Toshiba and NEC introduced high-density (4/16Mb) flash memories based on single-voltage (5V operation) EEPROM technology at ISSCC/1992. Flash EEPROM single-voltage technology poses a challenge to the current dominance of EPROM-based dual-voltage flash memory products from market leaders such as Intel.

Toshiba's 4Mb flash EEPROM featured a cell-size of 1.8 * 2.0 micron^2 that resulted in a chip size of 8.11 * 6.95 mm^2 with an access time of 58ns. NEC's 16Mb flash EEPROM design yielded a cell size of 1.7 * 2.0 micron^2; with a chip size of 6.3 * 18.5 mm^2 and an access time of 58ns.

Flash memory technology typically uses double-level metal CMOS processes that rely on multiple poly levels for the gate and floating storage node functions. Dataquest believes that opportunities exist for wafer fabrication equipment companies to develop integrated thin oxide-nitride-oxide (ONO) dielectric and polysilicon CVD cluster tools that allow for enabling, high-quality flash memory structures. The development of production-worthy, high-performance polysilicon CVD equipment modules and rapid thermal processor equipment modules for the ONO dielectric film is a prerequisite for the tunnel dielectric/floating storage electrode integrated application.

Table 2
Key Features of SRAM Technology at ISSCC/1992

Company	SRAM Density	Technology	Design Rule	Gate Oxide (Angstroms)	Poly Levels	Metal Levels	Cell Size (μ * μ)	Chip Size (mm * mm)	Access Time (ns)
Fujitsu	16Mb	CMOS	0.40	110	4	2	2.1 * 4.2	10.4 * 21.5	15
Hitachi	1Mb	CMOS	0.35	100	4	2	2.0 * 3.3	4.0 * 7.4	7
NEC	4Mb	BiCMOS	0.50	120	4	2	3.2 * 5.8	8.8 * 18.9	6
NEC	16Mb	CMOS	0.40	120	4	2	2.0 * 4.0	12.5 * 18.3	12
Toshiba	4Mb	BiCMOS	0.50	110	3	2	3.5 * 5.7	8.7 * 18.8	9

Source: Dataquest, ISSCC/1992 (April 1992)

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The advances in microprocessor and flash memory technology reported at ISSCC/1992 signify the importance of these device families as technology drivers that complement the traditional high-volume DRAM generation advances. The emergence of RISC-based system-on-chip architectures and advanced merchant CAD tools and ASIC foundries is swinging the microprocessor design innovation pendulum away from merchant microprocessor companies toward workstation and computer companies. Wafer fab equipment and materials companies will need to successfully execute their business strategy around the growth prospects of a new breed of semiconductor applications driven by microcomponent and application-specific memory products rather than the traditional commodity DRAM fab customer.

By Krishna Shankar

Semiconductor Manufacturing

How Much Is Too Much?

The semiconductor industry is one of the most capital-intensive in the world. Currently, 18 percent of semiconductor revenue is spent on equipment and facilities. To meet these huge costs, semiconductor companies do what people have always done when the burden gets too heavy: they get help. They are getting help from each other through joint ventures, and from governments in the form of financial incentives and lowered capital costs. The result of all this help is that there may be too much capacity today, particularly in DRAMs.

The semiconductor industry is well on the road to spending $1 billion for a new fab. Intel already has a capital spending budget of more than $900 million per year. Motorola spent more than $600 million on its newest fab at Oak Hill, Texas, which opened in 1991. Sharp reportedly will spend $800 million on a new fab to make flash memory for Intel.

These are staggering sums. On top of this, semiconductor companies also spend about 14 percent of their revenue on R&D. In other words, semiconductor companies each year must spend 33 percent—or one-third—of their revenue on technology development and capital.

No single semiconductor company can carry these costs alone. Intel, one of the industry's most profitable companies, recently announced the formation of a long-term partnership to jointly develop and manufacture future generations of flash memory with Sharp. Why has Intel participated in this partnership? Because it does not have the resources to simultaneously develop and capitalize its flash memory and microprocessor lines.

Even giants such as IBM, Siemens, AT&T, and NEC cannot afford to go it alone. IBM now has partnered with Siemens to produce 16Mb DRAMs, and AT&T and NEC have a joint development/production agreement to develop and produce 0.5-micron ASICs.

In addition to helping each other through joint development and production agreements, semiconductor companies have not been bashful about seeking and getting governmental help to build their fabs. The central government of Italy, as well as the local governments of that country, have provided financial inducements to both Texas Instruments and SGS-Thomson to build fabs in Italy. Ireland has provided Intel with financial incentives to locate its newest fab in Ireland. The Singapore Development Agency is a major backer of Tech Semiconductor, a joint venture involving Canon, Hewlett-Packard, the Singapore Development Agency, and Texas Instruments.

The list goes on and includes many local governments. Most recently, the People's Republic of China (PRC) announced a joint venture with NEC. We believe that both Motorola and VLSI Technology are also negotiating with the PRC to build fabs in China to support its potentially vast market for electronics.

Why are so many players investing so much money in semiconductors? Governments offer financial incentives to attract technology and jobs. Semiconductor companies invest so many millions because, ultimately, they hope to turn a profit.

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But with so many players and so much capacity, how likely is it that a profit will be turned? The answer to that question depends on the balance of supply and demand for individual products.

Currently, we believe that there is an overcapacity of facilities capable of making advanced DRAMs.

Dataquest estimates that demand for 4Mb DRAMs and 16Mb DRAMs in 1992 will be 415 million units and that this demand will rise to 782 million units in 1993. The 415?million units are equivalent to 12 DRAM fabs with a monthly capacity of 20,000 6?inch wafers starts (assuming reasonable, state-of-the-art yields and factory use rates). Currently 50 fabs are capable of producing either 4Mb DRAMs or 16Mb DRAMs—a ratio of actual fabs to needed fabs of 4.2 to 1.

We do note, however, that because some of these fabs are capable of producing SRAMs, ASICs, or other submicron products, the ratio of 4.2 to 1 is somewhat overstated. Still, even assuming that half the capacity of these existing DRAM-capable fabs is devoted to non-DRAM products, the ratio of actual DRAM fab capacity to DRAM fab demand is still 2.1 to 1.

Because of this overcapacity, some DRAM manufacturers have scaled back or delayed DRAM capacity additions. For example, Japanese companies had originally planned to have a total of 11 200mm fabs with a combined monthly capacity of 57,000 wafers online by the end of 1992. However, production start dates have been pushed back, and now only 7 facilities will be online by the end of the year. These facilities will have a monthly combined capacity of 22,000 wafers—a mere 38 percent of what had been originally planned.

However, as Japanese companies cut back their capacity expansion plans, South Korean companies are going ahead with additional 4Mb DRAM and 16Mb?DRAM fabs. South Korean companies will spend $1.5 billion for DRAM capacity in 1992.

Thus, all this help may be too much help. Even with joint ventures and governments sharing the costs of new fabs, the bottom-line question—is it profitable?—will be answered in the negative, at least for the short term. Companies and governments have increased the number of DRAM fabs beyond the current demand for DRAM fabs. DRAM suppliers that also have broad product lines may be able to switch some excess capacity into production for other (and perhaps higher-margin) leading-edge devices. However, companies that do not have broad product lines will have huge investments producing submicron profits in addition to submicron semiconductor devices.

By George Burns

Conferences and Exhibitions

Bad Vibes in Europe

Attendees at this year's SEMICON/Europa show suffered from a collective bout of depression that even a good dose of lithium was unlikely to cure. Equipment manufacturers coming off a difficult 1991 in Europe were expecting further declines in 1992. Likewise, material vendors that had a dismal year last year (European silicon consumption measured in millions of square inches dropped 8 percent in 1991) were estimating a flat 1992.

In addition, the rumors of fab closures or consolidations, especially for IBM and Siemens, were rampant. Only a few companies, mostly non-European, appear to be planning new lines (see Table 1). To heap insult on injury, it was rumored that the German government, strapped with the financial burdens of integrating East Germany, rebuffed Siemens' pleas for tax breaks for a 64Mb line in Germany. Siemens, a quintessential European company, was last heard pitching the Singapore government for similar tax benefits, raising the specter that Europe cannot even compete in attracting its domestic companies to invest in the home market.

The political changes that rocked Eastern Europe last year were evident in the participation of a few companies and individuals from former Eastern Bloc countries. Yet, none of the vendors expected any business to be generated by the "new world order" anytime soon. The more pessimistic attendees believed that the turmoil in some of the Eastern Europe countries was very likely to worsen and drag the already besieged Western economies further into recession.

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It is ironic that the year 1992 may in fact be a bottom for the European semiconductor industry

Table 1
Future European Production and Pilot Lines

Company	Location	Year	Product	Wafer Diameter (Inches)
Hitachi	Landshut, Germany	1992	DRAM/SRAM	8
IBM/Siemens	Corbeil, France	1992	DRAM	8
SGS-Thomson	Grenoble, France	1992	ASIC	8
Fujitsu	Newton, England	1993	DRAM	6
Intel	Kildare, Ireland	1993	MPU	8
Mietec Alcatel	Oudenaarde, Belgium	1993	ASIC	6
Mitsubishi	Alsdorf, Germany	1993	DRAM	6

Source: Dataquest (April 1992)

when just a few years ago 1992 was expected to spur many companies to invest in European fabs because of local content rules. It is evident now that a unified Europe is not a solution to the problems facing the domestic device industry. Eastern Europe, which is partially to blame for the current tough economic times, may be the key to the growth of the European semiconductor industry over the long term. If market forces are allowed to take hold in this region then it is conceivable that a determined and educated engineering work force with its back against the wall could possibly repeat the industrial revolution recently seen in Taiwan, Korea, and Japan.

By Mark FitzGerald

News and Views

Next-Generation Micrascan Soon to Be Unveiled

Much interest and anticipation surround the development of SVG Lithography's advanced Micrascan system, which is slated for introduction at SEMICON/West this June. Designed for the 0.35-micron environment, this second-generation machine achieves improved performance and reliability while offering a substantially smaller footprint than its predecessor. Dataquest understands that a 50 percent reduction in footprint has been achieved through a combination of a new optics system, reconfiguration of the electronics subsystem, and the incorporation of a remote operator station into a stand-up operator console that is part of the main machine housing.

One key feature of the first-generation Micrascan system was its wide field of 20mm x 32.5mm. The new advanced Micrascan slightly extends that field size to 22mm x 32.5mm, which allows three 64Mb DRAM chips to be imaged per exposure. This larger field size translates to a 50 percent improvement in exposure throughput as compared with today's advanced wide-field reduction steppers, which can image only two 64Mb DRAM chips per exposure. Although SVGL must first establish its position in the market with its 22mm x 32.5mm field size, Dataquest understands that the company is well positioned to deal with the larger chip sizes of future device generations. The advanced Micrascan series can be readily reconfigured to accept larger reticles (6 x 9 inches) that correspond to an exposure field of 22mm x 50mm.

In a key strategic move, SVGL will offer i-line capability on the advanced Micrascan tool. The system's deep-UV platform has been designed to accept an i-line source and its corresponding optics. Dataquest believes that this may well prove to be a pivotal marketing decision for SVGL. This strategy allows the company to embrace those customers already attracted to the benefits of the advanced Micrascan technology but that are reluctant to abandon their i-line processing know-how for the unknown realm of deep-UV.

The price point of the new advanced Micrascan as yet has not been made public. Dataquest, however, does not believe that there will be the same level of sticker shock that occurred when the first-generation Micrascan was introduced in 1989. At that time, the Micrascan's price tag of $4 million was in sharp contrast to the average stepper price of $1.3 million. Since that time, there has been a significant shift in the stepper technology product mix away from the older g-line technology to new advanced systems. This in turn has contributed to higher stepper prices. Today's advanced stepper offerings of wide-field i-line and excimer systems are in the range of $2 million to $4 million. Dataquest anticipates a price point of between $4 million and $5 million for the new advanced Micrascan deep-UV system. This price probably seems extremely high for those device manufacturers that grew up on a generation of steppers that cost one-tenth that amount. However, Dataquest believes that the advanced technical capabilities of the new Micrascan system, coupled with a strong emphasis on cost of ownership justification, may well transform SVG Lithography from a captive supplier to IBM to a global player in today's advanced lithography market.

By Peggy Marie Wood

Inquiry Summary

Semiconductor Equipment, Manufacturing, and Materials Inquiry Highlights

Dataquest's response to specific questions from clients frequently can be useful for other clients. In this article we provide a response to one of our inquiries.

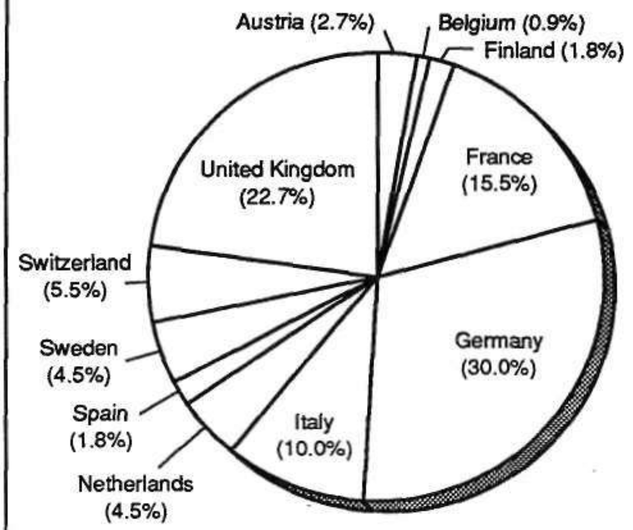
Q. Please provide us with a snapshot of Western European front-end semiconductor fab facilities.

A. Figure 1 presents a distribution of existing production and pilot fab lines in Western Europe by country. Table 1 provides a distribution of theoretical wafer start capacity normalized to 100 percent.

Although Germany now represents a powerful production belt for semiconductor diffusion, Dataquest contends that future growth is likely to be tempered. Germany's high wage structure and prosperous position within the European Community (EC) will mar its ability to attract and maintain semiconductor manufacturing facilities. With the cost of new wafer fab construction becoming more and more exorbitant, Germany will have to pit itself against less affluent EC member nations for an EC hand in underwriting new construction.

By Rebecca Burr

Figure 1
Distribution of Existing Production and Pilot Fab Lines in Western Europe



Note: Segments do not add to 100 percent because of rounding.
Source: Dataquest
G2000582

Table 1
Existing Production and Pilot Fab Lines in Western Europe (in Production or Began Operation during 1991) (Percent Square Inch Capacity)

Country	Percentage Distribution of Theoretical Capacity
Austria	6
Belgium	1
Finland	0
France	20
Germany*	30
Italy*	11
Netherlands*	6
Spain	2
Sweden*	2
Switzerland	2
United Kingdom*	20
Total	100

Note: Totals have been normalized to 100 percent. For some number of fabs in those countries followed by an asterisk (*), Dataquest has incomplete theoretical capacity information. Only facilities with known capacities were incorporated into this analysis.
Source: Dataquest (April 1992)

In Future Issues

Look for the following articles in future issues of *Dataquest Perspective:*

- 1991 wafer fab equipment market by ownership
- U.S. semiconductor gas market
- European photoresist market

Errata

Incorrect Dataquest estimates of market size and company revenue were included in the SEMMS March 2, 1992 issue of *Dataquest Perspective*. In the article entitled "Market Update on Film Thickness Equipment," incorrect estimates were printed in three locations. Please flag page 7 of the March 2, 1992 issue with a note to refer to the corrections in this issue (April 13, 1992) for the correct market size and company revenue estimates. We apologize for any confusion or inconvenience our errors may have caused.

Corrections are as follows:

- On page 7, the first two sentences in "The 1991 Market in Review" section should read: "Dataquest estimates that the 1991 worldwide market for film thickness measurement equipment for the production environment was $43 million. This corresponds to approximately 310 systems reflecting an average selling price of $140,000."
- In the same section, the last sentence on page 7 (which carries onto page 8) should read: "As with other categories of front-end processing equipment, Japan represents the single largest regional market, accounting for $18.9 million, or 44 percent, of the $43 million market in 1991."
- Table 1 on Page 9 incorrectly identifies Dataquest's estimates of 1991 worldwide company revenue and market share. See the new Table 1 for our corrected estimates.

Table 1
1991 Worldwide Film Thickness Measurement Equipment Company Rankings

Company	Revenue ($M)	Market Share (%)
Prometrix	13.5	31
Nanometrics	10.8	25
Dainippon Screen	5.5	13
Tencor	5.3	12
Rudolph Research	2.7	6
Thermawave	0.5	1
Others	4.6	11
Total	43.0	100

Note: Columns may not add to totals shown because of rounding. No offline or lab/R&D ellipsometers are included.
Source: Dataquest (April 1992)

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Semiconductor Equipment, Manufacturing, and Materials

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In This Issue...

The tremendous growth of South Korea's semiconductor industry over the past decade has catapulted the Asia/Pacific region into the limelight. The first three articles in this issue of Dataquest Perspective highlight the strategies and activities pursued by Korean semiconductor manufacturers and provide insight on the emergence of the domestic silicon wafer industry in Korea.

Semiconductor Manufacturing

Is Korea Betting the Farm?

Dataquest believes that the Asia/Pacific region will be the one bright spot in terms of semiconductor capital spending in 1992. The Korean chaebols (conglomerates) will account for the lion's share of that spending. Investment in Korean fabs is expected to climb to U.S.$1.8 billion in 1992. Equipment companies will benefit from the chaebols' spending spree, which will largely target advanced DRAM lines. But over the longer term, equipment opportunities in Korea will depend on whether the chaebols win or lose on their current investments.

These investments are big bets and raise questions about individual company strategies, especially in light of profit losses last year in their semiconductor operations and worldwide DRAM capacity, which currently outstrips demand. Even more puzzling is the timing of these investments. The Western economies—the major export markets for Korea—are in recession and the Korean economy itself is suffering from high inflation rates and spiraling capital costs. Are the executives at these companies gambling or are they taking calculated business risks?

It is unlikely that the companies are shouldering all the risk. Semiconductor technology is a cornerstone of the Korean government's industrial policy. Consequently, these companies will assuredly have access to cheap capital. So, in terms of industrial policy, these investments will certainly move Korea ahead in semiconductor technology faster than would market forces.

Though the Korean government may shield these companies from high capital costs, the government cannot shield them from international market forces. Herein lies the big risk.

With excess worldwide DRAM capacity, the short-term gamble for the Korean companies rests on the strength and timing of the recovery in the U.S. and European economies. If the Western economies have a strong recovery over the next several years, DRAM demand will grow quickly and the Korean companies may exit the recession with more market share than they had prior to the recession. Toshiba pursued a similar strategy in the 1985 recession with the 1Mb and it was very successful. On the other hand, if the Western economies limp out of recession and there is only moderate growth in DRAM demand, then these investments are not expected to pay off financially.

Over the longer term, there is a more fundamental problem for the chaebols. History has shown that the health of a company's semiconductor operations cannot rest on merchant sales of devices alone. A healthy semiconductor operation is increasingly dependent on captive operations using those devices. Yet, Korean electronic products are losing their competitive edge. Wage increases are driving up the price of Korean electronic products whose quality still lags high-end Japanese and U.S. products. On the low end, developing countries such as China and Thailand with their much lower labor costs are grabbing market share.

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The success of the chaebols' current bets on the semiconductor industry will not only rest on how well they execute their device strategies over the short term but also on how quickly they can position their electronic products to compete directly with Japan and the United States. Vertical integration from device to end-user applications will be key to Korea's success.

By Mark FitzGerald

South Korea's Capital Spending and Fab Activities

The worldwide semiconductor industry is entering a period of slow growth because of overcapacity and uncertainty in the end markets. This article presents an update of capital spending trends in the South Korean semiconductor industry. It also provides an analysis of each company's capacity and capabilities in 1992.

Capital Spending: Asia/Pacific Leads World Growth

North American and European capital expenditure has been hit the hardest during the current worldwide semiconductor market slowdown, growing at 0 percent and 8 percent in 1991, respectively. Although Japanese expenditure grew at an impressive 18 percent in 1991, Dataquest expects Japanese spending to decline by 9 percent in 1992. That leaves the Asia/Pacific region as the fastest-expanding spender in 1991 and 1992. The lion's share (72 percent in 1992) of this spending will be by Korean semiconductor companies.

South Korea's Semiconductor Industry: 1992 Outlook

After investigating each fab line planned or under operation in 1992, we have determined that the South Korean semiconductor industry will spend about U.S.$1.8 billion in 1992. We estimate that U.S.$1.5 billion will be spent on equipment and facilities aimed at expanding production primarily of 4Mb and 16Mb DRAMs. The remaining U.S.$260 million will be spent on enhancing equipment and facilities for R&D-related production.

Updates to our South Korean semiconductor manufacturing database are in Table 1. As evidenced by our recent survey, four 4Mb DRAM lines and ten submicron lines will become operational in 1992.

In its drive for 16Mb DRAM production, Samsung is adding an MOS 5 line, which will be a 0.5-micron, 8-inch wafer CMOS facility with a monthly capacity of 10,000 wafers. Total capital spending for Samsung this year will be about U.S.$800 million.

Goldstar will discontinue 256K DRAM production at its Woomyun MOS line, which is a 1.2-micron, 6-inch wafer CMOS facility with a monthly capacity of 10,000 wafers. Goldstar is

Table 1
South Korean Semiconductor Fabs

Company	Fab Name	Process	Est. Min. Linewidth	Wafer Size	Wafer Start Capacity (4 wks.)	Main Products
Samsung	Bip Line	Bipolar	3	4	25,000	Analog
Samsung	MOS Line	CMOS MOS	2	5	20,000	Microcomponents, Consumer ICs
Samsung	MOS 1	CMOS MOS	1.5	4	35,000	64K DRAM
Samsung	MOS 2	CMOS MOS	1.2	6	35,000	256K DRAM
Samsung	MOS 3	CMOS MOS	0.8	6	35,000	1Mb DRAM
Samsung	MOS 4	CMOS MOS	0.6	6	30,000	4Mb DRAM
Samsung	MOS 5	CMOS MOS	0.5	8	10,000	16Mb DRAM
Samsung	R&D	CMOS MOS	0.5	6	10,000	R&D
KEC	Bip Line 1	Bipolar	2.5	4	20,000	Analog
KEC	Bip Line 2	Bipolar	1.5	5	10,000	Custom
Hyundai	Fab I-A	CMOS MOS	1.2	5	15,000	EEPROM, PLD, 16K SRAM
Hyundai	Fab I-B	CMOS MOS	1	5	8,000	256K DRAM, SRAM
Hyundai	Fab II	CMOS MOS	0.8	6	25,000	1Mb DRAM, SRAM
Hyundai	Fab III-1	CMOS MOS	0.8	6	20,000	4Mb DRAM
Hyundai	Fab III-2	CMOS MOS	0.6	6	20,000	4Mb DRAM
Hyundai	R&D	CMOS MOS	0.5	6	5,000	R&D
Goldstar	Phase 1	CMOS MOS	0.8	6	30,000	1Mb, 4Mb DRAM
Goldstar	Phase 2	CMOS MO	0.7	6	30,000	4Mb DRAM
Goldstar	Gumi Bip Line	Bip TTL	3	4	25,000	Linear, Packaging
Goldstar	Gumi MOS Line	CMOS MOS	1.5	5	15,000	SRAM, DRAM, ROM
Dongsung	Bip Line 1	Bipolar	NA	4	NA	Diode, Rectifier
Daewoo	Bip Line	Bipolar	3	4	9,000	Analog
Daewoo	MOS Line	CMOS MOS	1.7	4	9,000	Custom

NA = Not available
Source: Dataquest (March 1992)

expected to spend about U.S.$450 million in equipment upgrades and fab floor space expansion and plans to have two 4Mb DRAM lines ramped up in 1992.

Hyundai is making a U.S.$510 million investment to enhance its production. Hyundai also plans to have two 4Mb DRAM lines ramped in 1992. Samsung will have only one 4Mb DRAM line as it enters the 16Mb DRAM race.

Dataquest Perspective

As demonstrated by our survey results, South Korean semiconductor companies seem to be committed to vigorous participation in the 4Mb DRAM and 16Mb DRAM markets—despite slowdowns in European, Japanese, and North American markets. In response to the slowdown in these major markets, Korean semiconductor companies will increasingly rely on sales of their commodity products to the Asia/Pacific market. Samsung is already the No. 1 supplier to the region, and Hyundai and Goldstar made large gains in market share throughout the region in 1991.

However, the size of these investments require a worldwide market for profitability. We believe that it is an open question whether today's slower-growth worldwide market conditions can support South Korean suppliers' current capacity expansions. South Korean companies may find themselves with abundant high-technology capacity in an oversupplied market. If companies, countries, and regions continue to view high-technology as a game that they cannot afford to stay out of, then the following question arises: Is there enough room at the global table for everyone to play in this high-stakes, high-technology game?

By George Burns, Daniel A. Heyler, and J. H. Son

Company Analysis

Posco-Hüls: The Race for the Asian Silicon Market

Posco-Hüls, the joint venture between Pohang Iron and Steel, MEMC Electronic Materials, and Samsung, is investing U.S.$110 million in a silicon wafer plant south of Seoul, Korea. Dataquest believes that the investment marks a change in strategy for MEMC in its struggle for market share with other major silicon vendors.

In addition, the Posco-Hüls joint venture signals a fundamental change in the global silicon business, which was first dominated by U.S. and European companies through the 1970s. In the 1980s the Japanese companies rose to prominence. For the 1990s the ascent of Asian companies is the theme most likely to dominate. As the industrializing nations in Asia build their semiconductor infrastructures, the region is expected to win a larger share of the new investment in silicon wafer production.

MEMC's Gamble

MEMC's participation in Posco-Hüls is a strategy to stay ahead of the Asia/Pacific silicon growth curve. MEMC is transferring its leading-edge eight- and six-inch wafer technology to the joint venture. The technology transfer includes crystal growing. The big risk for MEMC is that it may lose control of the technology by transferring the process to a joint venture company in which it has a minority position (see Table 1). In the worst-case scenario, MEMC could very well end up putting a competitor into business if the joint venture was to go sour.

MEMC in the mid-1980s was involved in a similar joint venture company in Korea called Korsil. The joint venture was dissolved in 1989 and most of the assets were acquired by Siltron (formerly Lucky Advanced Materials). Little technology was transferred to Korsil because the joint venture was a slicing and polishing operation. But the failure of Korsil points to the potential downside of MEMC's strategy.

On the other hand, the upsides for MEMC are considerable. The Asia/Pacific silicon wafer market is the fastest-growing wafer market in

Table 1
Equity Positions in Posco-Hüls

	Percentage	Type of Investment
MEMC Electronic Materials	40	Capital and Technology
Pohang Iron and Steel	40	Capital
Samsung Electronics	20	Capital

Source: Dataquest (March 1992)

the world and Korea has by far the largest demand within the region. It is unlikely that Korea will relinquish its leadership in semiconductors anytime soon.

In addition, MEMC has a well-matched partner in Pohang. From a business point of view, Pohang is expected to bring valuable relations critical in doing business throughout the Pacific Rim. (Parenthetically, 35 percent of Pohang is owned by the Korean government. The government's equity position is a key point, considering the Korean style of doing business at senior levels.)

Pohang is also a source of highly educated and motivated metallurgists. If the company's rapid ascent in steel is any kind of barometer, then the joint venture could easily push the current MEMC technology further and faster than MEMC could by itself.

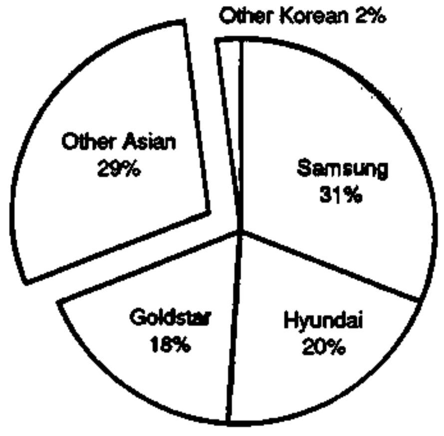
On its face, Samsung's involvement in the joint venture is as an end user. It is the largest user of silicon in Korea. It is also one of MEMC's largest customers, accounting for an estimated 13 percent of MEMC's 1991 sales. But from a business point of view Samsung's involvement is probably more important in providing balance to the joint venture. In fact, it is unlikely that MEMC, after its experience with Korsil, would have agreed to a joint venture where Pohang held majority ownership.

Korean Semiconductor Industry

Korean capital investment in front-end semiconductor facilities will defy economic gravity in 1992. Though Dataquest is forecasting worldwide capital spending to decrease 2 percent in 1992, we believe that Asia/Pacific capital spending will buck the trend and increase 22 percent. Korean companies will account for the lion's share of that spending, U.S.$1.8 billion out of a total U.S.$2.5 billion (see Figure 1). Within Korea, the chaebols (conglomerates) Samsung, Goldstar, and Hyundai will account for more than 95 percent of the semiconductor capital spending. The three top companies are investing U.S.$1.76 billion in 1992 as they push ahead with plans for advanced DRAM lines.

Samsung is adding an MOS 5 line that will be a 0.5-micron, 8-inch CMOS fab with a monthly capacity of 10,000 wafers. Goldstar and Hyundai are late to the 4Mb DRAM game but are determined to get a piece of the action. Both companies will add two 4Mb DRAM lines. These

Figure 1
1992 Asia/Pacific Semiconductor Capital Spending



Source: Dataquest (March 1992) G2000013

investments will rapidly increase the demand for silicon.

Because the semiconductor industry is a cornerstone of the Korean government's industrial policy, Dataquest expects the pace of investment in new semiconductor technology to remain strong. Domestic silicon wafer production is not only a natural extension of the government's vertically integrated semiconductor strategy but also is especially critical in light of the country's mounting trade deficit. In 1991, Korea imported 78 percent of its wafers, accounting for about U.S.$140 million of its U.S.$9.5 billion trade deficit.

The Korean Silicon Market

As a result of growth in domestic demand for silicon, investment in silicon wafer plants has increased rapidly in the last several years. In addition to the Posco-Hüls investment, two local companies are expanding their production. Siltron is expanding its domestic crystal growing capacity, and Oriental Electronic Metals, a newly formed company, is also building a silicon wafer plant for slicing and polishing. All three plants will begin ramping production (see Table 2) within the next 12 months.

Local production will come online just in time to take advantage of the next upturn in the silicon cycle. Dataquest forecasts the demand for silicon in Korea to grow at an 11.3 percent compound annual growth rate from 1991 to 1996 (see Table 3). Though prime, test, and monitor wafer demand showed only moderate growth in 1991 and is forecast to grow only 8.2 percent in 1992, we expect demand to pick up in 1993 because of stronger Western economies and a ramping of new DRAM lines. All three of the new plant expansions will be in place to take advantage of this growth.

An important point to note is that Dataquest has increased its estimate of the overall size of the Korean silicon market based on information we collected during a recent visit to South Korea. Conversations with suppliers and users lead us to believe that we underestimated the market by 35 million square inches (msi) in 1990. Table 3 shows the current adjusted totals for silicon consumption from 1987 through 1991. These adjustments mean that silicon consumption data for the Asia/Pacific region were understated in earlier publications. All future regional data will reflect the new information.

Domestic production of silicon will increase over the next several years. We expect local production to total 150 msi by 1996. Even so, we estimate that Korea will still import 125 msi to meet local demand. Imports will still be required because the current investments in capacity are not expected to meet the growth in demand. Also, device manufacturers will still second source from vendors overseas in case domestic production is interrupted.

SEH and Wacker are the two foreign-based vendors that stand to lose the most because of Posco-Hüls' move. By installing leading-edge crystal-pulling technology in Korea, MEMC hopes to grab significant share of the Asian market and to keep SEH and Wacker, the other market share leaders in the region, on the

Table 2
Korean Silicon Wafer Production, by Plant (Millions of Square Inches)

Plant	Capacity/Year	1988	1989	1990	1991	1992	1993	1994	1995	1996
Siltron	60 msi/1991	32	29	31	32	33	43	45	50	50
Posco-Hüls	90 msi/1993	NA	NA	NA	NA	NA	16	27	45	59
Oriental Electronic Metals	60 msi/1992	NA	NA	NA	NA	5	26	36	41	41
Total		32	29	31	32	38	86	108	136	150

NA = Not applicable
Source: Dataquest (March 1992)

Table 3
Korean Silicon Consumption (Millions of Square Inches)

	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
Total	56	80	100	120	131	142	163	187	206	223	11.2
Prime, Test	53	77	95	116	126	137	157	180	199	216	11.3
and Monitor		26.4	23.9	21.7	8.9	8.2	15.1	14.6	10.2	8.7	
Merchant Epi	2.7	3.3	4.2	4.4	4.7	4.9	5.8	6.8	7.4	7.3	9.4
Local Production		32	29	31	32	38	86	108	136	150	
Imports		50	72	92	102	112	111	125	122	125	
Exports		1	1	3	3	8	33	46	51	51	
Local Consumption		80	100	120	131	142	163	187	206	223	

Source: Dataquest (March 1992)

defensive. The two domestic competitors—Siltron and Oriental Electronic Metals—are not currently focused on the high-end markets and are not expected to compete directly with Posco-Hüls in the immediate future.

However, it is unlikely that SEH or Wacker will abdicate market share without some spirited defense. There probably will be additional investment in Asian wafer lines as foreign competitors move to secure a position in the Asia/Pacific market. These potential investments may not necessarily be made in Korea. Even now there are rumors that China Steel—a Taiwan-based company—has plans to enter the silicon business in Taiwan.

Dataquest Perspective

The challenge for established silicon companies is to win a piece of the Asian market. The days when a silicon vendor could simply ship wafers into these countries are waning. Future investment in world-class Asian plants will most certainly be necessary. The Posco-Hüls joint venture marks the first of these investments.

Though Korea is the largest consumer of silicon in the Asian market today, the really big opportunity over the long term is China. So, investments made today may prove to be more strategic than tactical by paving the way for participation in a much larger Asian market.

By Mark FitzGerald

Market Analysis

Semiconductor Equipment—The High-Risk, High-Reward Metal CVD Equipment Market

The worldwide metal chemical vapor deposition (CVD) equipment market represents a high-risk, high-reward market that will grow from $83 million in 1990 to $247 million by 1995. The risks from the equipment vendor viewpoint include high process R&D investment, above-average customer support costs because of the challenging process field support involved, and stunted market growth because of alternative solutions such as poly plugs, planarized/collimated sputtered aluminum films, and optimized tapered contact/via profiles that obviate the need for plugs. The rewards for the metal CVD equipment vendor include participation in a high-growth profitable market, a migration path to integrated metal CVD/PVD equipment solutions, and the ability to build up good company core competency to address future CVD markets. Table 1 shows the growth of the major segments of the worldwide metal CVD equipment market. Blanket tungsten CVD for plugs and global interconnect applications is rapidly becoming the largest segment of the market, surpassing the traditional silane-based tungsten silicide film market for polycide gate/local interconnect applications. Dataquest believes that the blanket tungsten CVD equipment market stands poised at a crucial threshold of transition from pilot line to full-scale production at a number of global semiconductor companies. The blanket tungsten process technology issues have largely been solved. Cost per wafer and equipment performance issues are being addressed currently. The associated tungsten plug etchback equipment market will also grow concurrently in synergy with the blanket tungsten CVD market. The downside to the growth of the blanket tungsten market lies in the ability of PVD companies to offer cost-effective, reliable, enhanced step-coverage barrier metal/sputtered aluminum solutions.

Growth in the tungsten silicide film market will be driven by the emergence of dichlorosilane (DCS) high-temperature processes for enhanced step-coverage and low fluorine content in thin oxide dielectrics. Dataquest believes that the DCS silicide equipment market is still in its infancy with regard to process reproducibility and equipment reliability issues. Unless a production-worthy DCS silicide process emerges, the tungsten silicide market will shrink dramatically as DRAM companies design CVD silicides out of local interconnect applications.

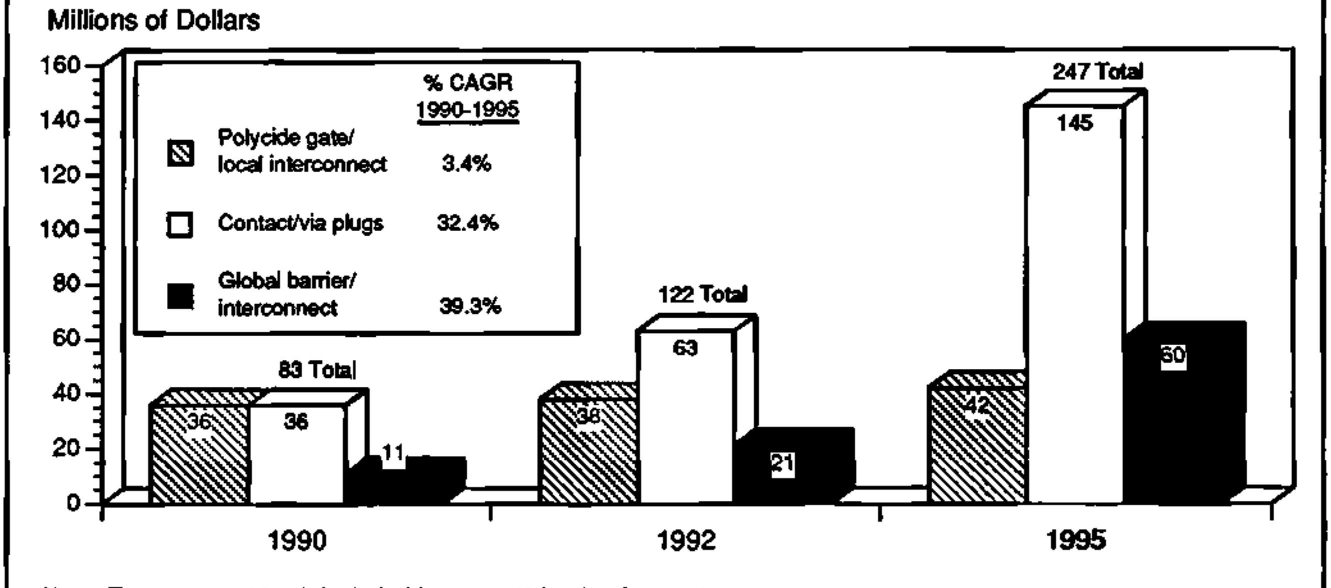
Growth in the selective tungsten CVD equipment market will be driven by the market success of companies in packaging together reproducible in situ precleans and CVD processes in cluster tools. Success in this high-risk market segment will depend on the ability of the equipment company to forge close cooperative development efforts with large semiconductor companies. Similarly, other long-term metal CVD equipment markets such as CVD titanium nitride and CVD copper will depend upon early joint-development efforts with key semiconductor partners.

Table 1
Worldwide Metal CVD Equipment Market Forecast, by Film Application (Millions of Dollars)

Calendar Year	1990	1991	1992	1993	1994	1995	CAGR (%) 1990-1995
Tungsten Silicide	36	37	38	39	44	42	3.4
Blanket Tungsten	30	36	53	73	100	114	30.8
Tungsten Plug Etchback	11	13	18	23	29	32	24.5
Selective Tungsten	4	6	7	11	15	22	40.0
Titanium Nitride	1	1	2	6	15	27	101.1
Aluminum	1	1	1	2	2	2	24.5
Copper	1	1	1	2	4	7	55.1
World Metal CVD Market	83	96	122	155	209	247	24.5

Source: Dataquest (March 1992)

Figure 1
Worldwide Metal CVD Equipment Market, by Process Application



Note: Tungsten etchback included in contact/via plug forecast.

Source: Dataquest (March 1992) G2000014

Dataquest Perspective

Figure 1 illustrates the worldwide metal CVD equipment market segmented by process applications such as polycide gate/local interconnect, contact/via plugs, and global barrier/interconnect applications. Clearly, the contact/via plug application market (including plug etchback) represents the largest market opportunity, growing from $36 million in 1990 to $145 million by 1995. Metal CVD equipment companies can plug the short-term void left by PVD films in the interconnect equipment. As in all technology markets, timing is everything!

By Krishna Shankar

News and Views

NEC Announces I-Line Intent for 64Mb DRAM Production

The host of lithography alternatives for the 64Mb DRAM generation facing semiconductor manufacturers include i-line with or without phase shift masks, excimer/deep-UV, e-beam, and X-ray lithography. NEC, the first company to announce its lithography tool choice for volume production of 64Mb DRAMs, has opted to go i-line without phase shift masks.

One key reason NEC chose i-line lithography is because of the significant experience the company already has with this technology. In addition, the choice of i-line tools will help the company reduce its lithography capital expenditure, compared with other alternatives. For example, today's advanced i-line steppers range in price from $1.8 million to $2.5 million, compared with excimer/deep-UV tools with a $3.5 million to $4.0 million price tag.

Dataquest believes that the major factor behind NEC's decision to forgo excimer/deep-UV for 64Mb DRAM production is still the lack of production-worthy resists. The interesting aspect of the company's choice to go i-line was its decision not to use phase shift masks. Dataquest believes that the difficulty of phase shift mask production and inspection coupled with the lack of repair tools prompted NEC's decision. Both Canon and Nikon recently announced new illumination filtering techniques that allow them to extend conventional i-line lithography down to the 0.35-micron regime, which will allow semiconductor manufacturers to forgo the additional costs and problems associated with phase shift masks, at least for the 64Mb DRAM generation.

By Peggy Marie Wood

New Marketing Agreement for Advanced Surface Topography Tool

Tencor Instruments and Park Scientific Instruments recently announced a five-year agreement under which they will introduce a scanning force microscope (SFM) designed specifically for use in a semiconductor manufacturing environment. The product will be developed and manufactured by Park Scientific and marketed exclusively by Tencor to the worldwide semiconductor industry. Targeted introduction for this new 200mm system is summer 1992.

Scanning force microscopy provides three-dimensional imaging and measurement of surface topography on an atomic scale. The SFM technique is based on the technology of scanning tunneling microscopy, for which IBM Zurich researchers were awarded the 1986 Nobel Prize in Physics. Although scanning tunneling microscopy is limited to conducting and semiconducting surfaces, SFM is also effective in evaluation of surfaces of nonconducting materials such as photoresist.

SFM produces images using a microfabricated cantilever and tip placed in contact with, or a few nanometers above, a surface. While the cantilever and tip are translated across a surface, a sensor detects deflections in the cantilever as the tip rides over changes in surface topography. SFM provides a nondestructive measurement technique and in some special applications, technique can even resolve individual atoms. Unlike optical metrology, resolution for a scanning force microscope is not governed by the wavelength of light but rather by the size of the tip. Reasearch is currently under way in the SFM field to fabricate smaller, sharper tips suitable for accurate measurements of critical features on the wafer such as linewidth and sidewall profiles. Such smaller and sharper tips are essential before SFM can be extended to CD measurement.

Dataquest believes that this marketing agreement represents a sound strategy for both Tencor and Park Scientific. Park Scientific is a relatively small company focused on developing leading-edge products for advanced R&D applications. Tencor is a major player in the process control equipment arena for the semiconductor industry and has a well-established service and support network in all major manufacturing regions of the world. This new SFM provides Tencor with an advanced system that is a logical extension of its current product offerings in wafer profilometry. Dataquest believes that, with further development in tip fabrication and characterization, the SFM technique will be extended to CD measurement applications. This agreement with Park Scientific may eventually evolve into a new market opportunity for Tencor in the realm of advanced CD metrology.

By Peggy Marie Wood

In Situ Chemical Generation at Intel

Intel is developing in situ chemical generation technology for pregate clean sequences. The typical pregate clean sequences involves four steps, as follows:

- Piranha (sulfuric acid:hydrogen peroxide)
- Dilute hydrofluoric acid
- SC1 (ammonium hydroxide:hydrogen peroxide:water)
- SC2 (hydrochloric acid:hydrogen peroxide:water)

Intel has found that the SC1 process introduces metals contaminants even when semiconductor grade aqueous chemicals with a maximum metal impurities level of 20 parts per billion is used. As a result, Intel is evaluating replacing chemicals used in SC1 and SC2 with in situ-generated chemicals. SC1 and SC2 mixtures are generated by bubbling anhydrous hydrochloric acid and ammonia gas into ultrapure water. Ozone gas is used as a substitute for hydrogen peroxide.

The purity of the in situ-generated chemicals surpasses commercially available semiconductor chemicals (see Table 1). In addition, particle counts for in situ-generated chemicals are significantly lower (see Table 2).

By Mark FitzGerald

Table 1
Impurity Levels of Chemical Solutions (Parts per Billion)

	Commercially Available High-Purity Aqueous Chemicals	In Situ-Generated Chemicals 1st Sample	After 1 Week
Ammonium Hydroxide	25.9	14.5	1.2
Hydrochloric Acid	31.8	8.4	5.3
Hydrogen Peroxide	7.96	NA	NA
Ozonated Ultrapure Water*	NA	0	NA

NA = Not applicable
*Ozone gas is used as a substitute for hydrogen peroxide.
Source: Intel Corporation

Table 2
Average Liquid Particle Counts

Particle Size Ranges (Microns)	0.1-0.2	0.2-0.5	>0.5
In situ-generated NH_4OH	250	24	8
Commercial aqueous NH_4OH	2,333	67	18
In situ-generated HCl	322	61	11
Commercial aqueous HCl	5,138	88	7

Source: Intel Corporation

Inquiry Summary

Semiconductor Equipment, Manufacturing, and Materials Inquiry Highlights

Dataquest's response to specific questions from clients frequently can be useful for other clients. In this article we provide a response to one of our inquiries.

Q. What relationship, if any, exists between U.S. semiconductor equipment vendors' market share and the market share of U.S. semiconductor companies?

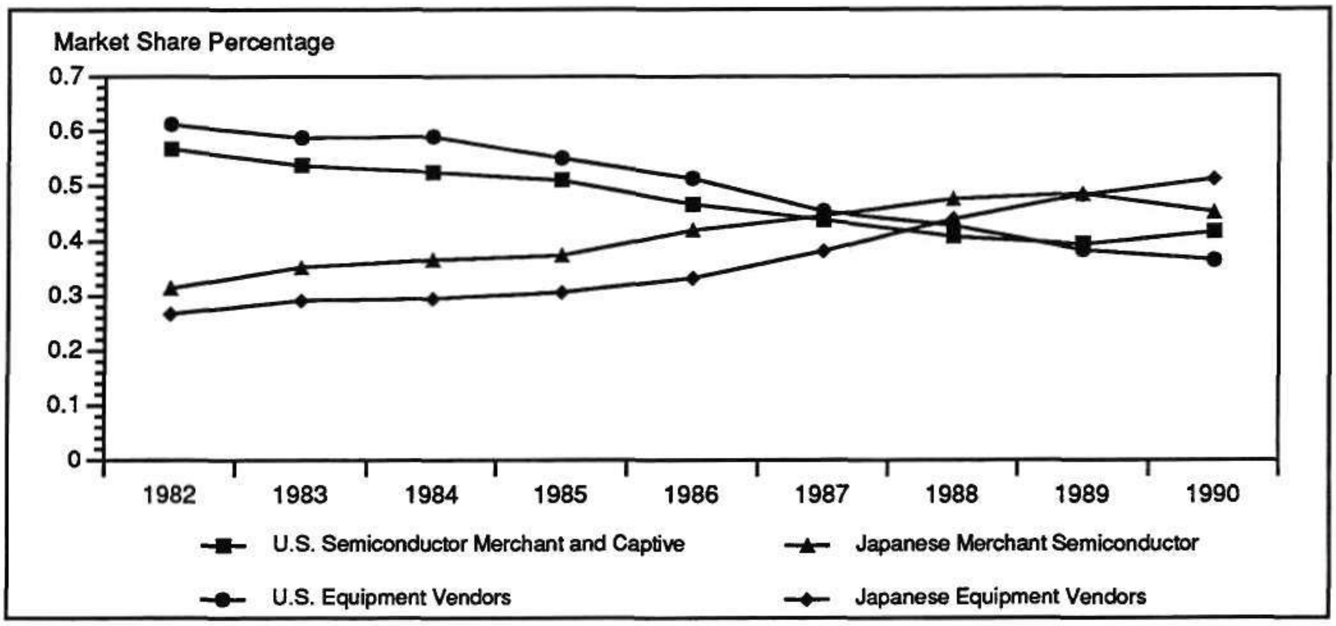
A. See Figure 1. From the period 1982 to 1990, U.S. semiconductor equipment company market share decreased from 61 percent of the worldwide market to 36 percent. The worldwide share of U.S. semiconductor companies (including captives) also declined during this period, from 57 percent of the worldwide market to 42 percent.

The story for Japanese semiconductor companies and equipment vendors is almost the mirror opposite: The market share of Japanese semiconductor equipment companies grew during this period from 27 percent of the worldwide market to 51 percent. Japanese semiconductor companies also saw their share of the worldwide market grow during this period from 31 percent to 45 percent.

There is a strong tendency on the part of U.S. and Japanese semiconductor manufacturers to buy equipment from semiconductor equipment vendors that are a part of a locally developed support infrastructure. However, we note that this tendency does not necessarily lock out overseas vendors from either the Japanese or U.S. semiconductor industry. For example, because of advanced technology, excellent service, and strong local support from Japanese companies, U.S. semiconductor companies buy a significant portion of their lithography equipment from Japanese vendors; and, for the same reasons, Japanese semiconductor companies buy a significant portion of their CVD equipment from U.S. equipment vendors.

By George Burns

Figure 1
Semiconductor and Semiconductor Equipment Market Share



Source: Dataquest (March 1992)

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In Future Issues

Look for the following articles in future issues of *Dataquest Perspective:*

- 1991 wafer fab equipment market, by region
- 1991 stepper market
- 1991 CVD market
- U.S. semiconductor gas market

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Dataquest Perspective

Semiconductor Equipment, Manufacturing, and Materials

SEMM-SVC-DP-9202 March 2, 1992

In This Issue...

Market Analysis

Market Analysis

U.S. Photoresist Market in 1992—How Much Does a Dead Cat Bounce?

Photoresist consumption in the United States decreased on a unit basis in 1991 for the first time since 1986. The prospects for 1992 are not much brighter. Dataquest believes that volume consumption of negative and positive resist will grow a mere 3.3 percent in 1992 (see Table 1), much lower than the double-digit growth the resist industry experienced for most of the last five years.

Dataquest estimates that 265,200 gallons of positive resist were used in the United States in 1991 (see Table 2). Positive resist consumption decreased 0.5 percent from 1990 levels. We had forecast positive resist consumption to grow 2 percent in 1991; actual resist consumption fell short of our forecast because the U.S. semiconductor industry did not pick up in the second half of 1991. In fact, the fourth quarter was the weakest quarter of the year in terms of U.S. wafer starts and resist consumption.

Negative resist consumption is much smaller than is positive resist consumption, totaling about 75,100 gallons in 1991 (see Table 3), a decline of 3.7 percent from 1990. Negative resist is largely used in less-critical applications such as discrete devices and as a result is not expected to grow.

Technological Trends

A bright spot is the forecast growth for i-line resists; consumption is expected to grow threefold in 1992. Volumes for the period 1991 to 1996 are forecast to grow at a 66.8 percent compound annual growth rate (CAGR). Leading-edge devices will be the primary application, especially the next generations of DRAM and microprocessor devices.

Table 1
U.S. Optical Photoresist Consumption by Technology (Thousands of Gallons)

	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
U.S. Total	345	340	351	381	410	421	440	5.3
Percent Change (%)	8.0	-1.2	3.3	8.5	7.5	2.6	4.5	
Type								
Positive	267	265	277	304	337	351	372	7.0
Annual Growth (%)	12.0	-0.5	4.3	9.8	11.0	4.0	6.0	
Negative	78	75	75	78	73	70	68	-2.0
Annual Growth (%)	-3.7	-3.7	-0.4	3.9	-6.0	-4.1	-3.1	
Technology								
G-line	341.8	334.1	333.7	349.5	373.0	370.2	369.6	2.0
Annual Growth (%)	7.7	-2.3	-0.1	4.7	6.7	-0.7	-0.2	
I-line	2.1	5.1	16.3	30.4	35.6	48.3	66.0	66.7
Annual Growth (%)	59.7	140.7	217.8	86.4	17.2	35.7	36.5	
Deep-UV	0.7	1.1	1.4	1.5	1.6	2.1	4.0	29.3
Annual Growth (%)	114.8	56.8	27.7	9.5	2.2	35.6	87.0	

Source: Dataquest (March 1992)

Table 2
1991 U.S. Optical Photoresist Market (Positive Resist in Thousands of Gallons)

Company	Gallons	Share of Volume (%)	Sales ($M)
Merchant			
Shipley	85.7	32.3	28.3
OCG	50.5	19.0	16.7
Hoechst (AZ Photoresist)	44.0	16.6	14.5
Tokyo Ohka	28.3	10.7	9.3
Dynachem	26.5	10.0	8.7
KTI Chemical	14.2	5.4	4.7
Sumitomo Kagaku	2.5	0.9	0.8
J.T. Baker	1.5	0.6	0.5
UCB-JSR	0.4	0.2	0.1
Mitsubishi Kasei	0.4	0.1	0.1
Captive			
IBM	11.2	4.2	-
Total	265.2	100.0	83.7

Source: Dataquest (March 1992)

Table 3
1991 U.S. Optical Photoresist Market (Negative Resist in Thousands of Gallons)

Company	Gallons	Share of Volume (%)	Sales ($M)
Merchant			
OCG	43.0	57.3	3.9
KTI Chemical	23.0	30.6	2.1
Dynachem	9.0	12.0	0.8
Tokyo Ohka	0.1	0.1	0
Total	75.1	100.0	6.8

Source: Dataquest (March 1992)

The largest U.S. end users of i-line resist in 1991 were IBM and Micron Technology. Dataquest believes that DRAM manufacturers' 4Mb shrink uses i-line resist for some critical layers and that the 16Mb, which will reach production quantities in 1992, will use i-line resist almost exclusively. In addition, Intel's next generation of microprocessor, the 8486, will use i-line technology.

The rapid growth of i-line resist volumes assumes that mix-and-match strategies will not be widely adopted by device makers. Mix-and-match is a lithographic strategy where the less-critical layers of a device employ g-line technology and the more-critical layers use i-line or another advanced technology. The primary benefit of a mix-and-match strategy is the need for fewer advanced steppers, which are selling for more than $2 million each.

Deep-UV technology is assumed to have little effect on the growth of the U.S. resist market over the forecast period. SVG Lithography is working to commercialize the Micrascan tool, which uses an excimer laser source. Dataquest believes that even if SVG solves the technical hurdles, the adoption of this tool, beyond its use at IBM, will be delayed until device makers move to 0.3-micron geometries. Devices with this type of resolution will not begin to impact the market for photoresist until the end of our current forecast.

Moreover, the adoption of deep-UV technology is hampered by the fact that that there is no good positive resist commercially available today. Positive deep-UV resist is required for contact, trench, and via applications—negative resist will not work. In general, resist vendors have been cautious about aggressively investing in advanced deep-UV resist technology because they believed that their efforts would lose out to phase shift technology or other strategies to extend the life of i-line technology. Their caution is probably well founded, considering how long the industry has extended the life of g-line technology.

Market Share

Most companies' resist shipments were flat to down in 1991, reflecting the weak semiconductor market. However, Tokyo Ohka (TOK) bucked this trend largely because of its strong position at Intel and the Sony fab in San Antonio, Texas. Intel sales shot ahead last year because of its microprocessor product line, and Sony began to ramp up production in the San Antonio fab.

TOK's 1991 shipments into the United States climbed 40 percent from a year earlier. Dataquest estimates that TOK sold 28,300 gallons of positive resist in 1991, giving it a market share of 10.7 percent (see Table 2). The company's sales in the United States are reaching a level such that the company can now justify local production and has announced plans to build a plant in the Portland, Oregon, area that will be completed in 1993.

OCG Microelectronics (OCG), a joint venture formed in 1991, dominated the negative resist market share because the electronics operations of the two companies forming the joint venture, Olin Hunt and Ciba Geigy, had significant positions in this market. On the other hand, the formation of OCG had little effect on positive resist market share because Ciba Geigy was such a small player in the U.S. positive resist market. As a result, OCG's U.S. positive resist market share reflects Olin Hunt's previous share.

Finally, though Sumitomo is still a small vendor in the U.S. market, Dataquest believes that Sumitomo is a company to watch for two reasons. First, it has a very successful i-line resist as measured by its acceptance in the Japanese market. Second, it is expected to benefit, probably even more so than will TOK, as Japanese fab lines locate in the United States.

Specifically, Sumitomo is expected to benefit the most from the ramp up of NEC's M-line in Roseville, California, one of the largest merchant fabs in the world. The M-line will run 10,000 wafer starts per month in 1992 and eventually will increase to 30,000 by 1994. Consequently, we expect Sumitomo's resist market share to grow very quickly over the next several years.

Dataquest Perspective

Although Dataquest expects slower growth over the next five years for the U.S. photoresist market, the challenges for vendors selling into this marketplace are expected to escalate. Mounting competitive pressures as Japanese vendors scramble for business in an already crowded market and shifts in resist technology ensure that the next several years will be a dynamic period for the U.S. resist industry.

By Mark FitzGerald

Sputtering Equipment Market Forecast, by Film Application

The high-growth sputtering equipment market will have a compound annual growth rate (CAGR) of 10.1 percent from $359 million in 1990 to $581 million by 1995 (see Table 1). Much of the growth will be driven by average selling price (ASP) increases attributed to the increasingly stringent requirements imposed on sputtering chambers because of process trends such as module isolation, staged ultrahigh-vacuum requirements, damage-free preclean procedures, and low particles. System ASPs will also increase because of the integration of related interconnect modules such as rapid thermal processing (RTP) and metal chemical vapor deposition (CVD). This article presents a forecast for the sputtering equipment market by film application and the trends underlying our forecast.

Table 1
Worldwide Sputtering Equipment Market Forecast, by Film Application (Millions of Dollars)

Sputtered Film	1990	1991	1992	1993	1994	1995	CAGR (%) 1990-1995
Aluminum Alloys	244	262	243	272	327	372	8.8
TiW	18	16	15	17	15	17	-1.1
TiN	32	39	41	50	67	76	18.9
Titanium	43	51	52	63	82	93	16.7
MoSix	14	16	11	8	10	11	-4.7
WSix	8	8	7	8	10	12	8.4
Worldwide Sputtering Equipment Market Total	359	392	369	418	511	581	10.1

Source: Dataquest (March 1992)

Worldwide Revenue and Shipments Units Forecast

The worldwide sputtering equipment market comprises almost 90 percent of the $435 million 1991 physical vapor deposition (PVD) market. Evaporation equipment accounts for the remaining 10 percent. Figure 1 shows the worldwide revenue and shipments forecast for the sputtering equipment market from 1990 to 1995. Even though system unit shipments are expected to remain relatively flat, increases in modules per system and module ASPs will drive the growth of the market. Worldwide sputtering process module shipments will increase from about 1,500 modules in 1990 to 1,700 modules by 1995.

For example, the average number of modules per system is expected to increase from four in 1990 (module ASP: $243,000) to five in 1995 (module ASP: $342,000). A typical configuration today consists of a preheat/soft sputter-etch module and process modules for titanium, TiN, and aluminum sputtering. By 1995, the standard configuration will extend to include metal CVD chambers for CVD TiN, blanket/selective tungsten, plug etchback, and RTP anneal. In effect, the standalone sputtering, RTP, metal CVD, and plug etchback systems of today will converge toward a complete hybrid systems solution for multilevel interconnection.

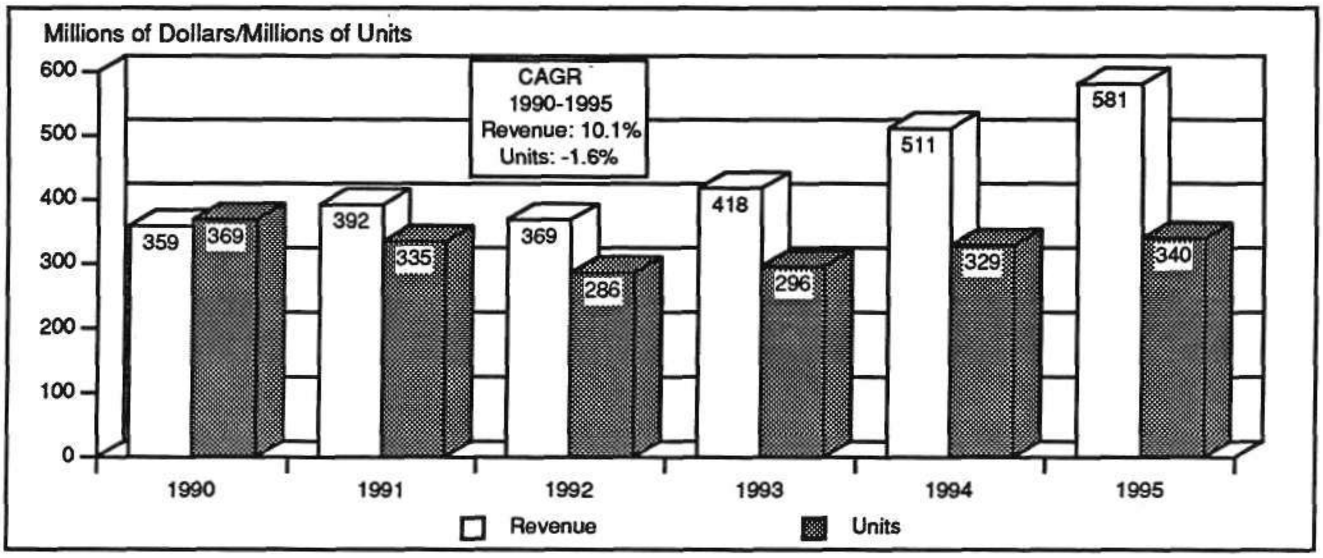
Process reliability, reproducibility, cost-of-ownership, cross-contamination, and integration issues need to be completely resolved before device manufacturers plunge into adoption of a hybrid interconnect solution. Interconnect integration offers the maximum leverage in stimulating the migration toward cluster tools from standalone systems. Interconnect processes may fundamentally force the transition to mix-and-match multivendor, open-architecture SEMI/MESC cluster tools because of the twin factors of equipment-vendor-process specialization and device manufacturers' need for interconnect customization. Dataquest believes that global, multiproduct equipment companies may eventually become one-stop systems integrators offering a complete interconnect product and service solution.

Sputtered Film Market Trends

Table 1 shows the detailed breakdown of the sputtering equipment market into the mainstream film applications. The forecast is based on our understanding of current process technology trends and the relative adoption of single-level, double-level, and triple-level metal architectures by key semiconductor device families such as memories, ASICs, and microcomponents.

We believe that sputtered aluminum/silicon/copper alloys will continue to be the global interconnect material of choice through 1995. Improvements in aluminum step-coverage and electromigration reliability due to process advances such as DC bias/heated substrate sputtering, partial laser planarization, and advanced source design will sustain the momentum of the aluminum sputtering application market. In addition, tungsten contact and via plugs will relax the step coverage requirements of sputtered aluminum for submicron geometry aspect ratios. Dataquest also predicts that CVD aluminum and CVD copper will not encroach upon the sputtered aluminum market until 1996.

Figure 1
Worldwide Sputtering Equipment Market Forecast



Source: Dataquest (February 1992)

Sputtered aluminum will continue to be the dominant portion of the PVD market, growing at a CAGR of 8.8 percent from $244 million in 1990 to $372 million by 1995.

The sputtered TiW barrier film market will remain flat between 1990 and 1995 because of the conversion to the superior TiN barrier for submicron processes. Also, the bipolar LSI market, which traditionally has used the platinum silicide/TiW Schottky barrier scheme, is shrinking and being replaced by CMOS technology.

The sputtered TiN barrier film market will experience the greatest growth: a CAGR of 18.9 percent from $32 million in 1990 to $76 million in 1995. TiN films are the barrier of choice in submicron CMOS processes because of their superior barrier characteristics, high temperature resistance, ease of patterning, and compatibility with tungsten plug processes. TiN is also commonly used as a thin antireflective coating on sputtered aluminum for interconnect patterning purposes. Beyond 1995, however, sputtered TiN may be replaced by CVD TiN because of the superior step coverage of CVD TiN in high-aspect ratio contacts and vias.

Sputtered titanium is used in a variety of applications such as barrier adhesion layer, source-drain silicide straps, salicide local interconnect, and contact resistance promoter. All these applications, however, use relatively thin films ranging from 200 to 1,000 angstroms in thickness. Hence the throughput and chamber requirements are smaller for sputtered titanium compared with the aluminum and TiN thickness and throughput requirements. Dataquest expects the sputtered titanium film equipment market to grow at a CAGR of 16.7 percent from $43 million in 1990 to $93 million by 1995.

Sputtered silicide films such as molybdenum silicide (MoSix) and tungsten silicide (WSix) are extensively used in 1Mb DRAM and 4Mb DRAM applications for polycide gate, local interconnect, and bitline contact applications. Many DRAM companies have converted to CVD tungsten silicide because of its superior step coverage in local interconnect and bitline contact applications. The advent of high-temperature dichlorosilane-based CVD tungsten silicide (DCS WSix), with its superior step coverage and low fluorine contaminant content, is expected to accelerate the conversion from sputtered silicides to CVD silicides in 16Mb and 64Mb DRAM applications. Hence the sputtered silicide film market will grow principally because of capacity expansion and replacement buys for 1Mb and 4Mb DRAM fabs.

Dataquest Perspective

Growth in the sputtered film application market will continue to outpace the growth of the overall wafer fab equipment market between 1990 and 1995 because of factors such as increased system ASPs, increased interconnect levels, and increased use of multilayer barrier and aluminum interconnect films. We expect sputtered aluminum to continue as the global interconnect material of choice through the 64Mb DRAM generation. Sputtered titanium and TiN films will be high-growth segments between 1990 and 1995 because of their design-ins at multiple levels in submicron processes. Beyond 1995, we expect a convergence of the sputtered films and metal CVD films markets as equipment companies offer completely integrated hybrid interconnect solutions.

By Krishna Shankar

Market Update on Film Thickness Equipment

Semiconductor device structures are becoming increasingly complex. In particular, multilevel metalization schemes for advanced logic and ASIC devices are driving growth in the dielectric and metal deposition equipment segments. One of the process control equipment segments directly impacted by the move to multilevel metalization is film thickness equipment, which is used to measure such films as photoresist, oxide, nitride, polysilicon, and other dielectric film combinations. This article examines the 1991 thin film measurement equipment market and highlights several of the technical challenges that face companies in this market segment.

Film Thickness Measurement Equipment

Film thickness measurements historically have been divided into two segments: ellipsometers, used primarily in off-line and lab/R&D applications, and spectrophotometers for use in the production environment. Ellipsometers measure film thickness based on changes in the polarization of light due to the presence of thin films. These tools are considered to be the de facto reference for film thickness measurement because of their high degree of measurement accuracy and their ability to measure film thickness and refractive index simultaneously. Historically, ellipsometers have not made the transition to the production environment because of their relatively large spot size and lack of automation. Spectrophotometers, traditionally based on microscope stations, measure the interference patterns created by the reflections between the top of a film and the film-substrate or film-film interface. These tools measure film thickness under the conditions that the refractive index of the film is known. Spectrophotometers have a significantly smaller spot size, several microns, in relation to the 50-micron spot size of a traditional ellipsometer. The smaller spot size is necessary for measuring film thickness on patterned wafers with device structures. In addition to smaller spot size, spectrophotometers provide a high degree of equipment automation. Many product offerings today now include pattern recognition to eliminate initial operator alignment procedures.

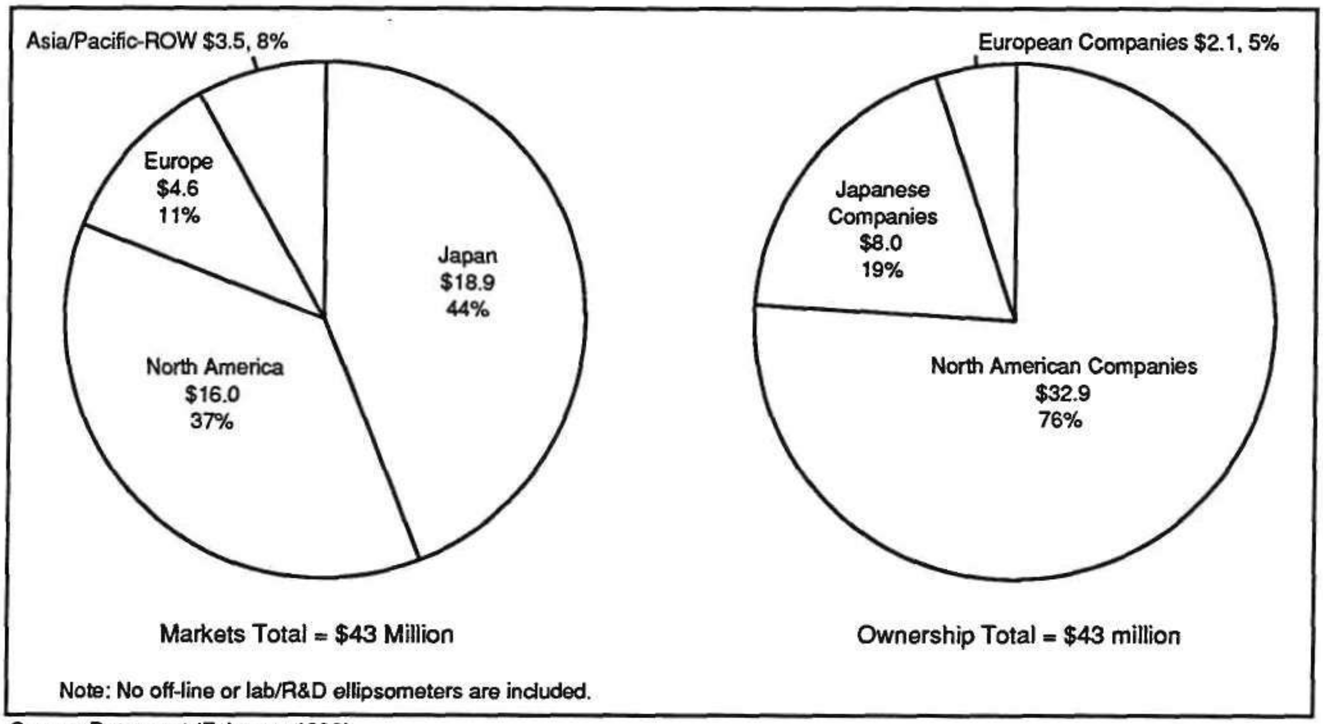
In addition to semiconductor applications, film thickness measurement equipment is used in areas including thin film magnetic head manufacturing, multichip modules, and flat panels. Our market estimates presented in this article reflect film thickness measurement equipment used only in the semiconductor wafer fab production environment.

The 1991 Market in Review

Dataquest estimates that the 1991 worldwide market for film thickness measurement equipment for the production environment was $39 million. This corresponds to approximately 285 systems reflecting an average selling price of $137,000. The price range for film thickness measurement tools for the production environment ranges from just under $100,000 to almost $300,000. In contrast, we estimate that the traditional (off-line and lab applications) market for ellipsometers that same year was significantly smaller—somewhere between $6 million and $8 million worldwide. At an approximate average selling price of $50,000, this 1991 market estimate for ellipsometers corresponds to about 140 units. Although the ratio of spectrophotometers to ellipsometers in 1991 is approximately 2:1, Dataquest understands that in some facilities this tool ratio can be as high as 5:1 or 6:1, or even higher, in favor of spectrophotometers.

Figure 1 shows the size of the regional markets for the film thickness equipment market. As with other categories of front-end processing equipment, Japan represents the single largest

Figure 1
1991 Film Thickness Equipment Regional Markets and Ownership (Millions of Dollars)



Source: Dataquest (February 1992)

regional market, accounting for $18.9 million, or 44 percent, of the $39 million market in 1991. However, as Figure 1 also illustrates, U.S. companies dominate this market by supplying 76 percent of the world's film thickness equipment needs in 1991. This dominance by U.S. companies is due to several factors: the historical strong role that Nanometrics has played in the market since it began, the successful product offerings of Prometrix and Tencor at the high end of the product mix, and the entry of two new companies offering film thickness measurement systems for the production environment.

Companies

Table 1 identifies the 1991 film thickness measurement equipment company revenue rankings. The top four players together account for 80 percent of the market. Newcomers Rudolph Research and Thermawave account for an additional 8 percent share, and other companies including Canon, Leica, Olympus, and Zeiss account for the remaining 12 percent share.

Rudolph Research is actually not a newcomer to the film thickness market. Rudolph and Gaertner Scientific have been leaders in the field of ellipsometers for many years. What is new, however, is Rudolph's decision to develop and market an ellipsometer for the production environment to compete head-to-head with spectrophotometers. At SEMICON/West in May 1991, Rudolph introduced its new FE III ellipsometer system. This automated system has pattern recognition and a spot size about one-half that of the traditional ellipsometers. The company has done very well in its first year of shipping systems for production applications. It is interesting to note that at the same SEMICON show, Leica announced its intention to provide an ellipsometer module to be used in conjunction with its spectrophotometer system.

Thermawave was a new entrant to the film thickness market in 1991 with its Opti-Probe system. The company believes that its optical technology is particularly well suited for eliminating edge-effect errors in film thickness measurement because its system utilizes a beam with a small spot size from a coherent light source in conjunction with the company's proprietary optical subsystem. Film thickness

Table 1
1991 Worldwide Film Thickness Measurement Equipment Company Rankings (Millions of Dollars)

Company	Revenue	Market Share (%)
Prometrix	11.0	28
Nanometrics	9.5	24
Dainippon Screen	5.5	14
Tencor	5.3	14
Rudolph Research	2.7	7
Thermawave	0.3	1
Others	4.8	12
Total	39.1	100

Notes: Columns may not add to totals shown because of rounding. No off-line or lab/R&D ellipsometers are included.
Source: Dataquest (March 1992)

measurement is a new market for Thermawave. Prior to this new equipment offering, the company has focused much of its attention on developing advanced ion monitoring and subsurface defect detection equipment based on thermal wave measurement technology. At the end of 1991, it was announced that Thermawave would be acquired by Toray Industries and Shimazu of Japan for an estimated $70 million.

Technical Challenges

The increasingly complex device structures of advanced semiconductors continue to provide technical challenges for film thickness measurement. Traditionally, film thickness equipment was used to measure a single top layer, but there is now a need to measure two and three levels of films simultaneously. Today's film thickness equipment companies are developing increasingly sophisticated software algorithms to interpret the signals from thin multilayer film stacks. Other key technical issues involve the measurement of ultrathin films as well as film combinations with proprietary stoichiometry.

One of the challenges that face film thickness measurement is measuring a transparent film on another transparent film. One of the innovative approaches that film thickness measurement companies have taken to deal with this problem in measuring oxide on poly is to utilize UV sources. Polysilicon is opaque in the UV range, so this measurement procedure can be reduced to a single-layer system rather than a double-layer film.

Finally, one of the interesting issues facing the film thickness measurement equipment companies is how the adoption of integrated deposition cluster tools will impact the use of their equipment. The primary advantage of cluster tool processing is the tools' ability to sequentially deposit a series of thin films without having to return wafers to the ambient environment between processing steps. Semiconductor manufacturers, however, will want to be able to monitor that the deposition process steps are in control, and thus arises the potential need for an in situ film thickness measurement system. Film thickness measurement data would be sent ahead via feed-forward controls to establish etchback time in integrated CVD, PVD, and dry etch cluster tools.

Dataquest Perspective

To manufacture the increasingly complex device structures of advanced integrated circuits in the 1990s, film thickness measurement equipment companies must continue to improve their equipment performance and capability. This presents a series of technical challenges. Challenges, however, translate to opportunities for companies with strong technical ability and innovative technology. Dataquest believes that the film thickness equipment market will keep pace with or even exceed the overall growth of the CVD and PVD market to reach a level of approximately $65 million by 1995.

By Peggy Marie Wood

Semiconductor Manufacturing

A Response to the Growing Burden of R&D: Joint Development

Dataquest has just completed its analysis of U.S. merchant and captive semiconductor company-funded R&D spending. This article will highlight results of that analysis and examine one consequence of ever-growing R&D budgets: the joint development project.

Survey Results

Semiconductor R&D spending for U.S. merchant and captive semiconductor companies rose by 10 percent to $4.1 billion in 1991 (see Table 1). We expect R&D spending to increase by 8 percent in 1992 to $4.4 billion. This total includes only company-funded spending and not R&D funding from noncompany sources. Total R&D spending for U.S. merchant and captive R&D represented 14 percent of revenue in 1991 (see Table 2). By way of comparison, U.S. merchant and captive capital spending in the same year was $4.8 billion and 17 percent of revenue. In other words, R&D spending and capital spending together totaled 31 percent of U.S. merchant and captive semiconductor revenue in 1991.

Of the merchant semiconductor companies' company-funded expenditure, we estimate that Intel's $585 million was the most spent in 1991. Dataquest estimates that Intel will increase this amount to $720 million in 1992.

Sharing the Burden: Joint Development Projects

Expected growth in 1992 U.S. merchant and captive R&D spending will take place even though the current economic climate is clouded by uncertainty and patches of gloom. R&D spending will grow because it is investment in tomorrow's processes and products—investment deferred only at a company's peril. Indeed, because R&D has been so central in the advance of new technology and products, U.S. R&D spending has increased every year since 1976.

As semiconductor technology has become ever more complex and sophisticated, R&D spending has grown in absolute terms and as a percentage of total semiconductor revenue. For example, in 1980, the ratio of U.S. merchant R&D spending to revenue was 8 percent; in 1990, it had grown to 14 percent. (For a more complete discussion of the necessity of R&D for new products and the increasing R&D "intensity" of the industry, please see "Investing in Tomorrow: Steady Growth for U.S. Semiconductor R&D," in the Semiconductor Equipment, Manufacturing, and Materials *Dataquest Perspective,* Vol. 1, No. 1.)

As R&D budgets take an ever-increasing share of the industry's revenue, the industry has

Table 1
U.S. Semiconductor R&D Expenditure (Millions of Dollars)

	1990	1991	1992
Merchant Companies			
Advanced Micro Devices	204	215	225
Altera	11	14	17
Analog Devices	73	81	81
California Micro Devices	3	3	3
Chips & Technologies	49	58	45
Cypress	55	72	83
Harris	76	74	69
IDT	44	49	51
IMP	13	10	11
Intel	465	585	720
LSI Logic	60	81	85
Linear Technology	9	11	14
Micron Technology	41	37	40
Motorola	330	370	420
National Semiconductor	251	200	200
Seeq	19	8	9
Siliconix	17	19	2
Texas Instruments	357	348	348
VLSI Technology	54	54	62
Xicor	20	23	18
Others	783	848	913
Total Merchant	2,920	3,159	3,436
Percent Change	16	8	9
Total Captive	793	921	981
Percent Change	12	16	7
Total Merchant and Captive	3,713	4,080	4,417
Percent Change	15	10	8

Source: Dataquest (March 1992)

Table 2
U.S. Semiconductor R&D Expenditure
(Percentage of Revenue)

	1990	1991
Merchant Companies		
Advanced Micro Devices	19	18
Altera	14	13
Analog Devices	19	17
California Micro Devices	10	23
Chips & Technologies	19	33
Cypress	25	26
Harris	10	11
IDT	22	24
IMP	23	22
Intel	15	14
LSI Logic	10	12
Linear Technology	11	11
Micron Technology	14	8
Motorola	9	9
National Semiconductor	15	12
Seeq	19	17
Siliconix	14	15
Texas Instruments	14	13
VLSI Technology	17	15
Xicor	28	32
Others	14	15
Total Merchant	14	14
Total Captive	17	17
Total Merchant and Captive	14	14

Source: Dataquest (March 1992)

responded by searching for ways to lighten the burden of R&D spending. One promising method of easing the burden of R&D spending is joint development of processes and products. Typically, a joint development project involves two companies agreeing to share financial and technical resources in order to jointly develop new processes or products. Recent examples of joint development projects are shown in Table 3.

Dataquest Perspective

Because R&D is so crucial to the semiconductor industry, and at the same time so expensive, we believe that joint R&D projects will gain in popularity. These projects may not be confined to just the efforts of two individual companies. Consortia such as Sematech, JESSI, or Taiwan's submicron research project will also gain in popularity as vehicles to develop advanced processes. These consortia will involve governments, universities (for example, Tohoku University or Stanford University's Center for Integrated Systems), vendors to the industry, and semiconductor companies.

A natural consequence of joint development is joint production by joint development partners. It is a natural consequence not only because of the obvious financial benefits, but also because the integration of product and process development with volume production is now an integral part of advanced semiconductor manufacturing. Joint production agreements have already arisen from the IBM/Siemens and AT&T/NEC joint development projects listed in Table 3.

In the past, semiconductor companies have invented and shaped the technology. Now, the technology is affecting the shape of the individual company: Where one semiconductor company begins and where another ends is becoming difficult to pinpoint. This identity crisis does not only confront joint venture partners as they try to integrate a different culture into their own culture. More pointedly, this

Table 3
Recent Joint Development Agreements

Companies	Development Project
Hitachi/Texas Instruments	64Mb DRAM
IBM/Siemens	64Mb DRAM
AT&T/NEC	0.5-micron SRAM
Philips/SGS-Thomson	Submicron logic
Analog Devices/Hewlett-Packard	Submicron mixed-signal

Source: Dataquest (March 1992)

identity crisis also has to be faced by governmental agencies that have a charter to develop a national technology base in an industry in which boundaries between international companies are becoming ever more permeable.

By George Burns

News and Views

Materials Notes

Semiconductor Gases: Shortage Improves

- The shortage of Freon-116 (C_2F_6), a semiconductor specialty gas used in the plasma etching process, should improve. The supply has been very tight since the U.S. military placed orders carrying priority ratings during the war in the Middle East. Du Pont, the primary manufacturer of Freon-116, is bringing online additional capacity that will increase the company's production by 50 percent.
- Union Gas company, the Korean joint venture company of Union Carbide's Linde division, has won two pieces of business in the Korean market. Union Gas will supply bulk gases to the new Posco-Huls silicon wafer plant in Korea. Union Gas has also won the contract to supply nitrogen to Samsung's new 200mm fab, which will produce 16Mb DRAMS. The Samsung facility will be supplied by a stainless steel pipeline.

Silicon Wafers: 200mm Wafer Demand to Grow

- Dataquest expects the demand for 200mm silicon wafers in the United States to increase in 1992 even though the demand for 200mm wafers at IBM, the largest U.S. user, has been down over the last six months. The decline in demand at IBM will more than be replaced by use at Intel and Motorola. Intel's D2 facility in Santa Clara, California, will convert completely to 200mm wafers in 1992. Previously the facility ran 150mm wafers. In addition, Intel's D1A facility in Portland, Oregon, will begin ramping up this year, adding demand for 200mm wafers. And finally, Motorola's MOS 11 facility in Arizona is ramping up.

Photoresist: Further Industry Consolidation

- OCG Microelectronics has finalized the purchase of KTI Chemicals. OCG is a joint venture company formed when Olin Hunt's Electronic Chemicals group and Ciba Geigy's Electronics Materials group were merged in March 1991. The acquisition of KTI will add resist product lines to the OCG portfolio and provide OCG more mass to sustain the capital spending required to develop and commercialize advanced resist technology.

Chemicals: New Thin Film Material

- Advanced Technology Materials has received two contracts from the Strategic Defense Initiative Office to develop barium titanate thin films using chemical vapor deposition. The source materials are organometallic compounds. Barium titanate and other advanced dielectric thin films such as tantalum pentoxide are targeted at the high-volume production of 256Mb DRAMS. Barium titanate is also being evaluated for a variety of high-precision, low-intensity laser applications.

By Mark FitzGerald

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Dataquest Perspective

Semiconductor Equipment, Manufacturing, and Materials

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In This Issue...

Market Analysis

Semiconductor Materials—Market Trends Conspire against Epi Film Growth

We provided a regional forecast for silicon wafer consumption through 1995 in Vol. 1, No. 14 of the Semiconductor Equipment, Manufacturing, and Materials *Dataquest Perspective* (see Table 1). This forecast was compiled from separate forecasts for merchant epitaxial wafers (see Table 2) and for silicon wafers—prime, test, and monitor—including merchant and captive production (see Table 3). The breakout of epi wafers reveals some interesting trends.

Regional Analysis

Dataquest forecasts an 8.4 percent compound annual growth rate (CAGR) through 1995 for epi wafers in the United States, the largest market for epi wafers. U.S. consumption is growing twice as fast as the prime test and monitor products, which have a forecast 3.8 percent CAGR. Although the forecast growth in epi wafers is strong, it is down from the double-digit growth they enjoyed in the previous five years.

CMOS epi wafers have historically accounted for the lion's share of merchant epi wafer sales in the United States. IBM and Intel are the two largest customers for CMOS epi wafers. The PC boom in the 1980s fueled the growth of both companies' semiconductor operations and accounted for much of the growth of the U.S. epi wafer market. IBM's DRAM product line and Intel's microprocessor product line are fabricated on epi wafers.

However, Dataquest believes that several market trends will slow the growth of epi wafer demand in the United States. First, the overall growth of silicon consumption is expected to decelerate because of slower growth in capital spending for new fab capacity. Epi wafers will not escape this slow growth environment. Second, IBM and Intel will move more of their

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File inside the *Dataquest Perspective* binder labeled Semiconductor Equipment, Manufacturing, and Materials

Table 1
Forecast of Silicon and Merchant Epitaxial Wafer Consumption by Region (December 1991)
(Units—Millions of Square Inches)

	1991	1992	1993	1994	1995	CAGR (%) 1991-1995
United States	645	665	705	769	810	4.6
Percent Growth	-0.5	3.1	6.0	9.1	5.3	
Japan	1,102	1,175	1,258	1,367	1,480	7.8
Percent Growth	8.4	6.6	7.1	8.7	8.3	
Europe	218	212	225	257	292	5.1
Percent Growth	-4.0	-2.8	6.1	14.2	13.6	
Asia/Pacific	168	185	213	247	281	14.2
Percent Growth	16.1	10.1	15.1	16.0	13.8	
Total	2,133	2,237	2,401	2,640	2,863	17.0
	4.7	4.9	7.3	10.0	8.4	

Source: Dataquest (February 1992)

Table 2
Forecast of Merchant Epitaxial Wafer Consumption by Region (December 1991)
(Units—Millions of Square Inches)

	1991	1992	1993	1994	1995	CAGR (%) 1991-1995
United States	105	110	123	137	145	8.4
Percent Growth	8.2	4.8	11.8	11.4	5.8	
Japan	97	104	116	122	125	6.1
Percent Growth	4.3	7.2	11.5	5.2	2.5	
Europe	18	18	22	26	26	6.2
Percent Growth	-3.2	-1.6	21.5	16.4	0.4	
Asia/Pacific	6	7	8	9	11	17.1
Percent Growth	12.0	17.9	16.7	11.7	27.9	
Total	226	239	269	293	307	7.5
	5.6	5.6	12.6	9.1	4.6	

Source: Dataquest (February 1992)

Table 3
Forecast of Silicon (Prime, Test, and Monitor) Wafer Consumption by Region (December 1991)
(Units—Millions of Square Inches)

	1991	1992	1993	1994	1995	CAGR (%) 1991-1995
United States	540	555	582	632	665	3.8
Percent Growth	-2.1	2.8	4.9	8.6	5.2	
Japan	1,005	1,071	1,142	1,245	1,355	8.0
Percent Growth	8.8	6.6	6.6	9.0	8.8	
Europe	200	194	203	231	266	5.0
Percent Growth	-4.1	-2.9	4.7	14.0	15.1	
Asia/Pacific	162	178	205	238	270	14.1
Percent Growth	16.2	9.9	15.1	16.1	13.3	
Total	1,907	1,998	2,132	2,347	2,556	7.0
	4.6	4.8	6.7	10.1	8.9	

Source: Dataquest (February 1992)

production overseas, largely benefiting epi consumption in Europe at the expense of U.S. epi consumption. Finally, IBM is expected to cut back the use of epi wafers, which are expensive when compared with prime wafers. Mounting competitive pressure and a more merchant-focused IBM semiconductor operation is forcing Big Blue to address costs more closely.

Japanese semiconductor companies have traditionally avoided epi wafers wherever possible. Consequently, CMOS epi consumption in Japan is small relative to the discrete and analog applications. Dataquest expects a moderate 6.1 percent CAGR for epi wafer consumption in Japan. Consumer applications using discrete and analog devices will be the main driver. An important trend for the Japanese epi market is a move away from float zone wafers to thick epi films in power device applications.

Prime wafer consumption in Japan is forecast to have an 8.0 CAGR, outpacing epi wafer growth. Prime wafer consumption will benefit from the growth of high-volume DRAM production and the growth of the microcontroller market.

European epi wafer consumption in 1992 is forecast to decline as a result of weak economic conditions and the retrenchment of several large Europe-based device makers. Consumption of epi wafers in Europe is forecast to begin growing in the 1993 time frame as Intel's fab line in Ireland and the IBM-Siemens line in France begin ramping production. Both fabs will use CMOS epi wafers.

Asia/Pacific, led by Korea and Taiwan, is the fastest growing region for silicon consumption. Prime, test, and monitor wafers will grow at 14.1 percent CAGR through 1995 and epi wafers at 17.1 percent CAGR. Even with this aggressive growth rate, the unit consumption of merchant epi wafers in the Asia/Pacific region will remain small. Captive production accounts for the bulk of the epi films deposited.

However, Dataquest is optimistic that Asian device makers will slowly be weaned away from captive epi production to merchant supply as silicon wafer plants with advanced epi lines are built in the region. But over the forecast period this trend will have minimal impact on the unit growth of merchant epi wafers.

Dataquest Perspective

Dataquest forecasts a worldwide epi unit CAGR of 7.5 percent through 1995, a rate considerably lower than the 16.6 percent growth from 1986 to 1991. Some deceleration can be attributed to the slower growth of the total silicon wafer market. But more important is the search by device makers for lower-cost alternatives because the competitive edge among device makers is increasingly being won on the manufacturing floor. In this environment, an epi wafer that costs three times the price of a prime wafer is not a viable alternative.

By Mark FitzGerald

Semiconductor Manufacturing

Spending on Semiconductor Facilities Expected to Take a Dive in 1992

Spending on semiconductor facilities is a major component of total semiconductor capital spending. Facilities expenditure is important not only because of its magnitude ($2.3 billion in 1991), but also because of the sophisticated level of technology that goes into providing an ultraclean, vibration-free environment for the manufacture of semiconductor devices.

Dataquest believes that spending on semiconductor facilities will fall 15 percent in 1992 to $2.0 billion. However, we expect to see the beginnings of a recovery in spending on clean room facilities beginning in mid-1992, and our forecast calls for growth in the range of 9 to 11 percent per year from 1993 to 1995 (see Table 1).

Methodology

Dataquest defines facilities expenditure to include capital spending for new fabrication facilities, retrofits of existing fabs, and assembly and test facilities. The aggregate regional company data included in Table 1 are derived from a facility-by-facility analysis of actual expenditure for 1990 to 1991 and from a facility-by-facility analysis of planned expenditure for 1992.

The data for the forecast period 1993 to 1995 are not categorized by regional companies and are

Table 1
Semiconductor Facilities Expenditure Forecast (Millions of Dollars)

	1990	1991	1992	1993	1994	1995	CAGR (%) 1990-1995
Facilities Expenditure							
U.S. (Including Captive) Companies	625	820	640				
Japanese Companies	791	838	789				
European Companies	140	327	153				
Asian/Pacific Companies	239	343	384				
Total	1,795	2,328	1,967	2,152	2,357	2,608	7.8
Percent Change	-7	30	-15	9	10	11	

Source: Dataquest (February 1992)

derived from an analysis of facilities expenditure and technology trends in relation to worldwide semiconductor capital spending and device production trends. (See the Semiconductor Equipment, Manufacturing, and Materials *Dataquest Perspective,* Vol. 1, No. 14 for analyses of these trends.)

Company Facilities Expenditure

Facilities expenditure for European, Japanese, and U.S. companies is expected to be down in 1992, although the level of spending by Japanese and U.S. companies is expected to remain high. Spending by European companies, including expenditure by Siemens for its 16Mb DRAM joint production venture with IBM at Corbeilles, France, will fall sharply from $327 million in 1991 to $153 million in 1992.

Semiconductor facilities expenditure is down for European, Japanese, and U.S. companies because of current overcapacity in the semiconductor industry—particularly in DRAMs—and also because of uncertainty about the length of the current recession. For example, Japanese manufacturers had originally planned to have 11 200mm fab lines online by the end of 1992. Japanese manufacturers now plan to have only seven facilities online by the end of the year. (See SEMMS Blast-O-Fax, "Delays and Downsizing of 200mm Fab Lines in Japan," December 13, 1991, for more details).

Pacific Rim-based companies, on the other hand, are adding new capacity in a continuing drive to participate in high-technology industries and to gain market share in semiconductors. Indeed, Pacific Rim-based semiconductor companies are the one bright spot for clean room and facilities spending in 1992. Dataquest expects spending by Asia/Pacific companies to increase 12 percent in 1992 from $343 million to $384 million. This increase will be led by Korean companies, particularly Goldstar and Hyundai, as they build new fabs for the production of 16Mb DRAMs.

Recovery Will Begin This Year

Although new facilities activity by European, Japanese, and U.S. companies is in the doldrums, planning is now under way for new capacity additions and upgrades that will come online after the current period of uncertainty is past. Dataquest is aware of at least four new fabs, as yet unannounced, that U.S. companies plan to build in 1992. We expect this recovery, starting about midyear, to last throughout the remainder of our forecast period and that total clean room expenditure will reach $2.6 billion in 1995.

The 1990-to-1995 compound annual growth rate (CAGR) of clean room expenditure will be 7.8 percent, which is much lower than the 10.0 percent CAGR for the previous five-year period ending in 1990. Two long-term trends are responsible for this slowdown in the CAGR of clean room spending. The first reason is that the class of semiconductor fabs is now about as clean as it needs to be. The current state-of-the-art fab is now Class 1 or Class 0.1. Because air is no longer the major source of device contamination, the necessity to spend increasing amounts of capital on air-handling systems is no longer compelling. Indeed, because of advances in microenvironment technology, it is even possible that less will be spent on air-handling in the future.

The other major reason for the slow growth of clean room expenditure is that semiconductor companies, particularly those in the United States, are becoming more efficient. Many U.S. companies have realized that their yields did not compare well with those of their international competitors. As a result, many have instituted quality programs to increase fab and probe yield and reduce cycle time. One benefit of these programs is increased yields and faster cycle times. These efficiencies allow semiconductor manufacturers to achieve increased output from a given facility without additional capital outlays for that facility.

Dataquest Perspective

Dataquest has noted that the semiconductor industry is undergoing a significant structural change, the result of which will be a lower long-term growth rate for capital spending (see "The 'Go For Broke' Boom Fades," in the Semiconductor Equipment, Manufacturing, and Materials *Dataquest Perspective*, Vol. 1, No. 14). Clean room expenditure will be negatively impacted by the macro issues affecting capital spending in general and also will be dampened by increased manufacturing efficiencies as a result of the widespread institution of wide-ranging quality improvement programs.

Additionally, the growth rate of facilities spending will decelerate because of the shifting emphasis of contamination control efforts: The focus of contamination control will continue to shift from air and people toward equipment and materials as the major sources.

Although the clean room industry can still look forward to healthy growth, these trends will result in growth slower than that of the past. Consequently, competition will be tougher than in the past. The companies that will do well in this tightened market will be those able to offer a wide range of high-quality services on a worldwide basis and position themselves as a key partner of the semiconductor companies in their quest for improved quality and efficiency.

By George Burns

Conferences and Exhibitions

Wafer Fab Equipment Market Trends at SEMICON/Japan 1991

SEMICON/Japan 1991 presented an unusual picture of strong technology product introductions in the midst of a weakening business environment that universally drew responses of caution and concern (see Table 1). Wafer fab equipment companies were beginning to feel the pinch of delayed or reduced capital equipment orders as Japanese semiconductor companies delayed their wafer fab investments. Many wafer fab equipment companies concurred with our forecast of a tough year ahead in 1992 (down 8 percent compared with 1991) because of the combination of several market forces: weakening global economies; severe DRAM price competition; and overcapacity due to sluggish demand, maturing PC industry, and lack of barn-burner end-user consumer electronics drivers in the near term.

Japan, with about 50 percent of the worldwide wafer fab equipment market, is emerging from a capital spending binge on leading-edge capacity fueled by cheap money, exponentially growing 1Mb DRAM demand, and a drive for market share dominance in high-volume, leading-edge commodity products. However, times have changed. Japanese bank interest rates have jumped, the equity capital markets are woefully depressed, and there is growing competition from Korea and Taiwan in the commodity memory and logic business.

Dataquest believes that Japanese semiconductor companies are redefining their manufacturing strategies. We believe that Japanese semiconductor companies will minimize their focus on the commodity memory business and diversify into value-added, high-margin products such as microprocessors, system-on-a-chip microcontrollers, high-end ASICs, and high-performance memories. Korea, Taiwan, and other relatively lower-cost manufacturing regions will pick up the high-volume DRAM manufacturing baton. Japanese semiconductor companies will continue to expand their presence in North America and Europe in order to be closer to end-user markets and to avoid trade friction.

Table 1
Key Wafer Fabrication Equipment on Display at SEMICON/Japan 1991

Company	Equipment Segment	Model	ASP ¥M	Comments
Amaya	APCVD reactor	ATO-6000	200	TEOS/Ozone, 320-450 C, ILD/IMD applications
Anelva	LPCVD reactor	ILC-1060M	240	Blanket or selective tungsten
Applied Materials	Integrated process	Endura 5500	400	Integrated PVD Ti/TiN/Al with CVD tungsten plugs
ASM International	Integrated tube process	Advance 600/2	350	Loadlocked furnace cluster/in situ HF clean
ASM International	LPCVD reactor	P-1/R-1	170	Doped poly, RTP applications, single-wafer
ASM International	PECVD reactor	Eagle-10	180	200mm, single-wafer, two-chamber, TEOS oxide
Canon	Dry etch	APS-3800	200	PMT Helicon source, electrostatic chuck, 16/64Mb DRAM
Canon	Stepper	FPA2000i1	300	200mm, wide-field (20 × 20 sq. mm.), i-line
Canon	Stepper	FPA2000i2	NA	200mm, wide-field (22 × 22 sq. mm.), i-line
Dainippon Screen	Integrated wet stations	WSW-8200	170	Carrierless wet processing
Fuji Electric	Integrated wet stations	NA	100	Carrierless wet processing
Genus	High-energy implant	1510	280	Higher throughput, 40 KeV-3 MeV, DRAM retrograde wells, CCD
Hitachi	CD SEM measurement	S-6280	150	Field emission beam technology
Hitachi	Dedicated overlay	LA-2000	80	High-speed automatic overlay measurement
Hitachi	Direct-write e-beam	EB-H	NA	Cell-projection scheme, silicon substrate mask, 20 wph (150mm)
Hitachi	Dry etch	M-328SX	200	Microwave/ECR source, oxide etch
Hitachi	Dry etch	DM-421P	100	Noncritical nitride, poly plasma etch technology
Hitachi	High current implant	IP-2500	460	Wide-energy range, 2-250 KeV
Hitachi	Maskmaking e-beam	HL 700 M III	400	0.2-0.3um applications, 64Mb/256Mb DRAM, vector-scan
Hitachi	Reticle inspection	PD-3000	250	16MB DRAM reticle inspection
Hitachi	Steppers	LD-5015iDS	250	200mm, wide-field (22 × 22 sq. mm.), i-line, 16Mb DRAM
Hitachi	Wafer inspection	WI-870	150	Automatic wafer inspection
Kokusai Electric	Vertical tube	Vertex-V	120	Enhanced automation, process control
Lam Research	Dry etch	Rainbow 4720	125	Dedicated tungsten etchback/plug applications
Nikon	Stepper	NSR 2005i8A	260	200mm, wide-field (20 × 20 sq. mm.), i-line, 16Mb DRAM

(Continued)

Table 1 (Continued)
Key Wafer Fabrication Equipment on Display at SEMICON/Japan 1991

Company	Equipment Segment	Model	ASP ¥M	Comments
Nikon	Stepper	NSR 2005EX8A	NA	200mm, wide-field (20 × 20 sq. mm.), excimer stepper
Nissin Electric	High current	Exceed-8000	325	Low contamination, low charge-up
Nissin Electric	High voltage	NT-1000P	NA	
Nissin Electric	Medium current	NH-20P	150	
Novellus	Integrated process	Concept-Two	400	Integrated PVD Ti/TiN/Al and CVD tungsten plugs
Plasma System	Dry strip	DES-220/ 456AVL	100	Batch, RF plasma
Plasma System	Dry strip	DES-A110L	40	Single-wafer, RF downstream plasma
Ramco	Dry strip	RAM-8500	60	Batch, RF plasma
Shimada	Integrated wet stations	NA	150	Carrierless wet processing
Shinko Seiki	Dry strip	Dream	70	Two-step strip, single-wafer, RF and Microwave
Sugai	Integrated wet stations	NA	150	Carrierless wet processing
Sumitomo Eaton Nova	High current	NV-GSD-A	250	Enhanced NV-GSD system
Sumitomo Eaton Nova	High voltage	NV-1002	430	
Sumitomo Eaton Nova	Medium current	NV-8200P	160	
Sumitomo Metals	Dry strip	Helios	35	Single-wafer, microwave downstream plasma
Sumitomo Metals	ECR CVD	CN5000	200	CVD TiN barrier with soft preclean
Sumitomo Metals	ECR/Microwave etch	OZ 3000	200	Poly/polycide gate etch, 16Mb/64Mb DRAM
Tokyo Electron	Dry etch	TEL 7000/8000	175	MERIE technology, 200mm, 16/64Mb DRAMs
Tokyo Electron	Integrated wet stations	NA	150	Carrierless wet processing
Tokyo Electron	Vertical tube	IW-6	90	Nitrogen laminar flow load area
Tokyo Ohka	Dry strip	TCA-2802	70	Single-wafer, RF plasma
Tokyo Ohka	Dry strip	OPM-2811	30	Batch, RF plasma
Ultratech Stepper	Stepper	M2244i	NA	1x wide-field (22 × 44 sq. mm.), i-line stepper
Ulvac	Dry etch	Euclid 8000	200	Magnetron RIE, 16Mb/64Mb DRAM gate etch
Ulvac	Integrated process	Ceraus Z-2000	375	Soft preclean, Ti/TiN PVD, selective tungsten CVD integration
Ulvac	Medium current implant	IPZ-9000	260	Multielectrostatic scanning, parallel scan
Varian	High current	Extrion 500	300	Double-charge implants
Varian	Medium current	200U	150	Enhanced E-220 system, double-charge implants
Watkins Johnson	APCVD reactor	WJ-TEOS999	130	APCVD TEOS/Ozone, ILD/IMD applications

NA = Not available
Source: Dataquest (February 1992)

Japanese semiconductor companies will always nurture leading-edge process technologies in order to add custom value and differentiation to their endless array of electronics products. Hence, the Japanese wafer fab equipment market is only pausing as it consolidates, changes course, and begins to pick up momentum for the next boom. Table 1 lists key wafer fab equipment systems on display at SEMICON/Japan 1991, which was held in Makuhari near Tokyo in December. The diversity and advanced technology content of this equipment clearly illustrates the crucial, test-bed nature of the Japanese equipment market for global companies. The Japanese market is clearly a tough and competitive market in which global equipment companies fiercely compete for market leadership.

By Kunio Achiwa (Tokyo) and Krishna Shankar (San Jose)

News and Views

Phase Shift Masks: The Fever Begins to Break

Phase shift masks have been the hottest "hot topic" of interest in lithography during the last two years. Their ability to generate patterns with increased resolution and depth of focus using conventional lithography tools and resist chemistry has made phase shift masks seem almost too good to be true.

A significant problem, however, has plagued phase shift mask technology: mask repair. Research has shown more types of defects are on phase shift masks and the defects print larger and are more damaging than chrome metal defects. A major concern of device manufacturers is that repair tool technology is still only at the R&D stage. Recently, both equipment and device manufacturers announced new innovative approaches toward 64Mb DRAM i-line lithography that do not incorporate phase shift masks. Dataquest believes that these developments are an early sign that the phase shift mask fever that has taken hold of the industry for the 64Mb DRAM has finally begun to break.

At SEMICON/Japan in December 1991, Canon announced an improved precision alignment technique for 64Mb DRAM lithography. The new technique relies on improved beam processing to allow for better use of the i-line wavelength characteristics. Canon believes that it will be able to use the technique dubbed "QUEST" to achieve 0.4-micron processing with a conventional i-line stepper system and, by pushing the resist, manufacture 0.35-micron geometries without the use of phase shift masks.

In a similar vein, Nikon has developed a new technique for improving i-line stepper resolution. The name of the Nikon system is SHRINC (Super High Resolution by Illumination Control). Nikon believes that the new technique can be used to produce 0.3-micron geometries, like Canon, on a conventional i-line stepper without the use of phase shift masks. The company plans to commercialize a new stepper incorporating this technology for 64Mb DRAM production.

In another innovative approach to get around the problems of phase shift masks, Sharp has developed a phase shift technique that eliminates the requirement for the phase shift mask all together. In Sharp's technique, a phase shifter is created directly in the resist that coats the wafer. The company claims that a 0.2-micron pattern can be achieved.

Dataquest Perspective

Stepper manufacturers Nikon and Canon have a vested interest to continue to push the limits of their i-line stepper technology. If phase shift masks become a significant portion of the 64Mb DRAM lithography strategies, both companies would suffer some reduced level of stepper shipments than if phase shift masks were not adopted. These new systems that provide improved resolution without phase shift masks allow Canon and Nikon the opportunity to offer a new stepper alternative to the semiconductor manufacturer. Sharp's new development, while still relying on the fundamental principles of phase shift technology, eliminates one major problem with phase shift masks, the mask itself. With DRAM manufacturers eager to settle on their 64Mb DRAM lithography strategies and phase shift mask repair technology still in development, Dataquest believes that these alternative strategies will be given serious consideration.

By Peggy Marie Wood

Nippon Sanso Purchases Tri-gas

Nippon Sanso, the largest supplier of industrial and specialty gases to the Japanese semiconductor industry, on January 7 completed the purchase of Tri-gas Inc., a regional U.S. supplier of industrial gases located in Irving, Texas. The purchase marks Nippon Sanso's entry into the U.S. bulk gas market.

Tri-gas is primarily a bulk gas supplier with air separation plants in Albuquerque, New Mexico; West Palm Beach, Florida; and Houston and west Texas. Its fiscal year 1991 sales are estimated to be $70 million. Nippon Sanso is one of the five largest industrial gas companies in the world, with forecast 1992 revenue of ¥200 billion (unconsolidated with foreign subsidiaries).

The purchase price for Tri-gas is reported to be ¥11 billion ($90 million dollars). Tri-gas' long-term debt prior to the sale totaled $76.5 million, with the majority of the debt collateralized by specified assets. Dataquest believes that the company was struggling under this mountain of debt. The sale will free the company from the burden of paying down debt and permit Tri-gas management to pursue a more aggressive growth strategy.

Nippon Sanso has acquired about 80 percent of the equity of Tri-gas that had been owned by First Boston, a New York investment bank, and Metropolitan Life. The remaining 20 percent will continue to be owned by Edward Johnson, president of Tri-gas, and Timothy Page, vice president of Tri-gas.

The board of Tri-gas will consist of five Nippon Sanso executives, Edward Johnson, and Timothy Page. Two Nippon Sanso board members will be Jiro Nozaki, the current president of Nippon Sanso, and Seigo Ishii, the executive vice president.

Tri-gas was formed in 1987 as a result of the purchase of Big Three Industries by Liquid Air. For Liquid Air's acquisition to conform to antitrust rules, certain assets of Big Three were spun off to form Tri-gas.

Dataquest Perspective

Nippon Sanso is pursuing an aggressive overseas strategy with investment primarily focused in Europe, the Pacific Rim, and the United States. The Tri-gas acquisition fits Nippon Sanso's strategy of being a full line supplier of bulk and specialty gases in the North American market. The purchase complements its earlier acquisition of Matheson Gas Products, a U.S. specialty gas supplier, and Semigas, a manufacturer of gas handling equipment. Tri-gas will mark Nippon Sanso's entry into the North American bulk gas market.

Nippon Sanso's purchase of Semigas, completed in April 1991, was widely challenged on both national security and antitrust bases. The careful review of the Semigas acquisition was due largely to the vocal opposition to the sale by SEMATECH. Dataquest believes that the Tri-gas acquisition did not receive the same scrutiny because Tri-gas is a small player in the bulk gas market with little exposure to the semiconductor business.

Nippon Sanso has been the slowest among the big five industrial gas companies (Air Products, BOC, L'Air Liquide, Linde, and Nippon Sanso) to expand overseas. It only entered the U.S. industrial gas business in 1983 with the purchase of a 50 percent equity position in Matheson Gases (see Table 1). In 1989, Nippon Sanso purchased the remaining shares of Matheson Gases.

Table 1
U.S. Acquisitions Made by Nippon Sanso

Company	Product
Ansutech	Air separation plant designer/contractor
ISOTEC	Manufacturer of stable isotopes
Matheson Gas Products	Speciality gases
Semi-gas	Gas handling equipment
The Thermos Group	Vacuum bottles and leisure products
Tri-gas	Industrial gases

Source: Dataquest (February 1992)

Dataquest expects Nippon Sanso to continue to build its U.S. position in industrial gases. Dataquest believes that possible future targets are Liquid Carbonic, Sokatronics, Scott Speciality Gases, and assets from the Linde division of Union Carbide.

By Mark FitzGerald

NEC Completes M-Line in Roseville

NEC has completed construction of its M-Line fab in Roseville, California. The site now contains two fab lines, the K-Line completed in 1984 and the M-Line. The new 456,000-square-foot M-Line expansion began in 1989. Dataquest estimates that a total of $400 million ($200 million equipment and $200 million facility) has been invested in the fab to date, with an additional $200 million earmarked for future equipment expenditure. About 70 percent of the installed equipment is of Japanese origin and 30 percent is of U.S. origin. This is significant because the U.S. equipment suppliers that make it into NEC Roseville are also qualified for other NEC manufacturing facilities. Also, all silicon wafers and gases used at Roseville are manufactured in the United States, along with 50 percent of the wet chemicals. Dataquest believes that Roseville is buying silicon wafers manufactured in the United States by a Japanese company.

This is one of the largest merchant fabs in the world. A total of 111,000 square feet of Class 1 clean room space will eventually be capable of 30,000 6-inch wafer starts per month. NEC plans to ramp the fab with 10,000 wafer starts per month in 1992. Business conditions permitting, NEC will ramp the fab at 20,000 wafer starts per month in 1993, and 30,000 wafer starts per month in 1994. The fab is heavily automated with a silent overhead track system for transit between equipment and a musical AGV for transport from WIP stations to process equipment.

All equipment is under control of the host computer and all in-line data gathering is logged in real time by the host. NEC's M-Line will initially manufacture 4Mb DRAMs. However, ASICs and MCUs will also be manufactured in Roseville. The fab was designed to also manufacture 16Mb DRAMs. NEC plans to supply 50 percent of its North American demand from this fab.

By George Burns, Rebecca E. Burr, Jeff Seerley, and Krishna Shankar

Electronic Goods Inventory Increases for Japanese Companies

Inventory levels held by Japanese companies climbed, according to November electronic production and inventory data released on December 31 by Japan's Ministry of International Trade and Industry (MITI). The data covered about 1,800 different products. The increase in inventory is largely attributable to weakening export markets and will most likely result in large write-offs at the end of the Japanese fiscal year (March 1992), further squeezing profit margins for these companies.

Dataquest has forecast weak earnings in 1992 for the large Japanese electronic companies. In "The 'Go For Broke' Boom Fades," Vol. 1, No. 14 of the Semiconductor Equipment, Manufacturing, and Materials *Dataquest Perspective,* we cited profit pressures at Japanese companies as one main factor supporting our forecast decrease in semiconductor capital spending in 1992. MITI's inventory data certainly support our weaker earnings assumption and soft capital spending forecast.

Semiconductor End-Use Markets

Japanese computer production is flat. November production was up only 4 percent year to year. Large mainframes showed 20 percent gains in November; however, production of midrange computers and PCs shrank. IBM Japan has already reported a decline in sales and earnings this year. It is probably safe to assume that NEC's and Fujitsu's computer business will show similar performance.

PC production in Japan declined 12 percent in November year to year. NEC is bucking the trend in the PC market because of new product offerings and aggressive marketing. I/O equipment was flat year to year but down month to month. External memories were down 6 percent year to year and external equipment production was off 18 percent for the same period.

Telecommunications equipment data showed electronic exchanges off 13 percent over the previous November. Cellular car telephones showed gains of 20 percent year to year.

Consumer electronics showed mix results. Camcorder unit inventories were up 44 percent while sales and shipments were up only 20 percent and 15 percent, respectively. Disk and CD player data showed a more positive trend. Unit volume inventories were down from both the same time last year and last month. Production and shipment of videodisk players were down as inventories were brought down from unrealistic levels. CD players recorded respective 30 percent and 44 percent gains in unit volume production and shipments.

Dataquest Perspective

Electronic equipment production in Japan is showing mixed signals at best as we enter the new year. Segments important to the semiconductor industry, such as PC production, are off significantly. Dataquest believes that this will result in weak earnings for the large Japanese electronic companies through most of 1992. Consequently, we expect these companies to begin announcing fiscal 1992 (ending March 1993) capital spending plans that are lower than for fiscal year 1991. Capital spending on semiconductor operations is not expected to escape these cuts. Dataquest is forecasting semiconductor capital spending in Japan to decline 9 percent in calendar 1992.

By Mark FitzGerald

LSI Logic and Micron Leave SEMATECH

In January, LSI Logic Corporation announced that it had resigned its membership in the semiconductor consortium, SEMATECH, but that the decision was not made recently. SEMATECH membership requires a two-year resignation notice, which LSI said it gave. The company said that the technology value SEMATECH offered did not meet LSI's needs and that it did not want to be part of the funding agency for the semiconductor equipment industry. LSI said it had hoped to gain an integrated manufacturing system and processes that would be applicable to short or long production runs, but believed that SEMATECH had changed its focus more toward R&D for equipment to achieve very fine geometries such as that needed for microprocessors and DRAMs.

Micron Technology's announced resignation will not become effective until July 1992. A spokesperson for the company said that the timing for the announcement was prompted by direct questions from the press about whether Micron had given notice to SEMATECH. Micron expected to receive integrated process technology, and it believes that SEMATECH is more focused on working with U.S. chip production equipment manufacturers to develop hardware. Micron readily acknowledges that it has benefited from its membership in SEMATECH because of the equipment development, but has not realized its principal need from the relationship—obtaining advanced process technology. Micron's SEMATECH contribution has been about $2.4 million per year. Upon resignation, this amount will be turned to internal process technology R&D. Micron said that it is well on track with the processes for its 64Mb DRAM and sees light at the end of the tunnel for its future 256Mb DRAMs.

When LSI made its decision to drop out of SEMATECH, it was not experiencing the financial constraints it currently faces. However, the company has not been highly profitable for some time. LSI is a talented design house with short production runs; it does not have the high-volume production levels of commodity chips. SEMATECH focused on equipment development for fine-geometry, high-volume, mass production fabrication, such as DRAMs or MPUs, where it has spent about 60 percent of its budget.

The fledgling consortium U.S. Memories was about to officially disband when LSI Logic gave its notice to SEMATECH at the end of 1989. Its demise had been anticipated from October 1989 when it appeared that there would not be enough member/investors to get the would-be producer of the most popular commodity chip (DRAMs) off the ground. This had to be a clear signal to LSI, which had little chance to break into the commodity memory market from scratch, should it have chosen to enter the market.

LSI could have canceled its resignation at any time during the two-year period, but there has been little incentive to do so. Its fabs have been underused (LSI closed its fab in England), resulting in higher manufacturing costs, a situation that the company had hoped to solve with mass-produced devices. LSI was also entering the chip set market. However, chip set market competition developed too rapidly for LSI to gain the volume of production for full fab use. The declining economy of the past year also provided incentive to resign.

LSI does not have a partner for process technology development and, not finding it through SEMATECH, the company has had to broaden its internal R&D efforts. The cancellation of its SEMATECH contribution will ease this expenditure by an estimated $5.5 million per year.

It is certain that SEMATECH does not want to see LSI or Micron leave, but Dataquest believes that the loss of this revenue will not jeopardize the consortium's existence. The large semiconductor producers involved in high-volume production will continue to participate in SEMATECH. What is perhaps more worrisome to SEMATECH is that some other members have concerns similar to those of LSI and Micron. Harris Semiconductor, now under financial strain, reluctantly gave notice that it may resign at the end of the year, as has one other unidentified company. SEMATECH also faces a possible reduction in the $100 million government participation. The embarrassment of losing many members could make it harder to achieve the same level of government funding. But SEMATECH has stated that it has three strong prospects for new memberships.

Dataquest does not believe that SEMATECH will fold even if a few more of the smaller participants opt out, or if the government does cut some of the funding. However, under these economic constraints, it may be necessary for SEMATECH to limit the number or extent of its research projects.

By Marc Elliot, Bryan Lewis, and Jeff Seerley

In Future Issues

Look for the following articles in future issues of *Dataquest Perspective:*

- Computer-integrated manufacturing
- Film thickness equipment
- IEDM/ISSCC device trends

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Dataquest Perspective

Semiconductor Equipment, Manufacturing, and Materials

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How to Use This Index

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Dataquest Perspective

Special Edition

December 30, 1991

Market Analysis

Preliminary 1991 Worldwide Semiconductor Market Share Estimates: Microcomponents Lead the Way

Dataquest has completed its preliminary 1991 semiconductor market share survey analysis. Once again the growth of MOS microcomponents outpaced all other categories. MOS memories recovered from 1990's dismal showing. However, this category still experienced the lowest growth of all products in the MOS category.

By Gerald J. Banks and Ken Dalle-Molle

Market Analysis

Preliminary 1991 Worldwide Semiconductor Market Share Estimates: Microcomponents Lead the Way

Dataquest has completed its preliminary 1991 semiconductor market share survey and analysis. We sent out a detailed survey to more than 150 semiconductor vendors in early November. The respondents then provided us with a detailed breakout of their revenue based upon a combination of their actual year-to-date revenue and a company-generated forecast for the balance of the year. These data were then processed using Dataquest's own research and analysis. The results of this process are published in this article. We will continue to refine and update the data until our final market share data documents are published on May 31, 1992.

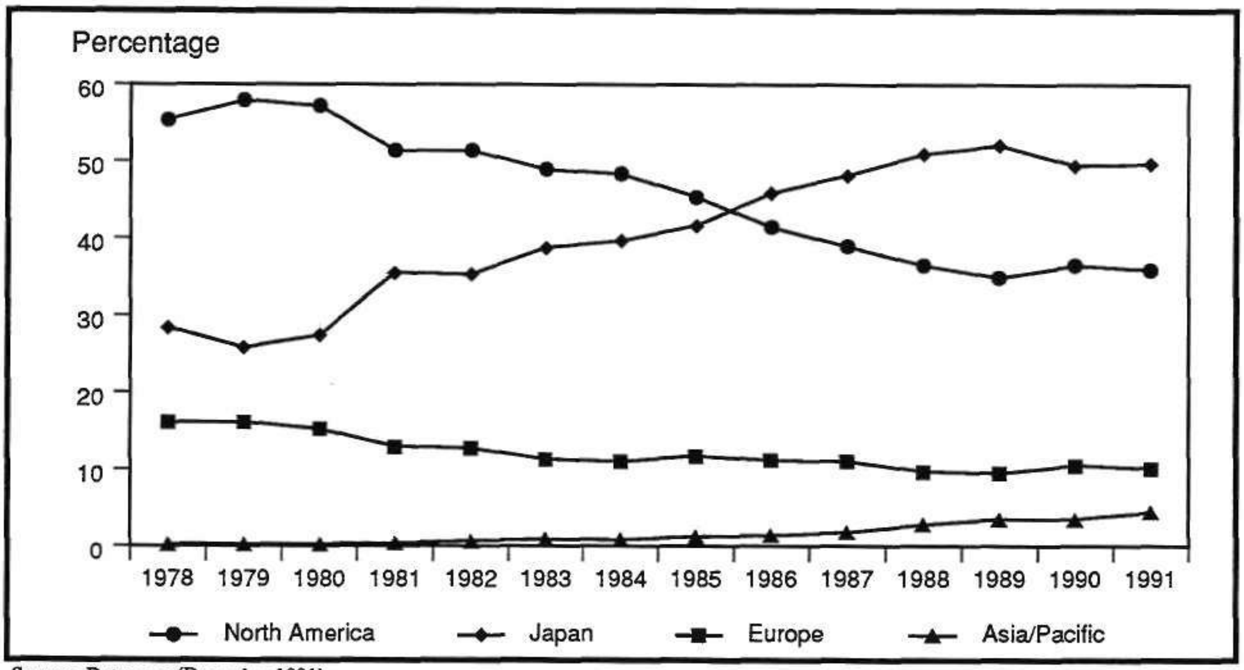
Market Share Highlights

The preliminary results indicate the following:

- Preliminary data indicate that the worldwide semiconductor market grew 11.5 percent over 1990, driven by portable, consumer, and telecommunications applications.
- Microcomponents were the primary growth contributor in the product arena and outperformed all others, growing at 22 percent.
- Bipolar digital was the big loser, dropping by 9 percent.
- North American companies' 1991 market share dropped slightly to 35.9 percent, compared with the prior year's 36.5 percent. Also, Intel Corporation surpassed Motorola Incorporated to become the No. 1 North American semiconductor vendor.
- Japanese market share grew slightly to 49.6 percent, compared with last year's 48.7 percent. NEC Corporation maintained its No. 1 position in the worldwide ranking.
- European companies' market share remained basically flat, moving from 10.7 percent in 1990 to 10.1 percent in 1991.
- Asian companies grew slightly, 4.4 percent in 1991 versus 3.6 percent in 1990.

Figure 1 shows the historical worldwide market share held by each regional company base.

Figure 1
Worldwide Semiconductor Market Share



Source: Dataquest (December 1991)

Semiconductor Rankings

Tables 1 through 9 list the top 20 suppliers for total semiconductors, total integrated circuits, total bipolar digital, and for the individual product categories: MOS microcomponents, MOS logic, analog, MOS memory, discrete, and optoelectronics.

NEC retained its No. 1 ranking, and in fact extended its lead over No. 2 Toshiba by virtue of its strong position in microcomponents. Intel, with its overwhelming strength in microprocessors, was able to overtake Motorola to claim bragging rights as the No. 1 North American semiconductor manufacturer. By virtue of its 28 percent growth in 1991, Intel outpaced the growth of every other company in the top 10. In fact, it isn't until the No. 20 position that a semiconductor vendor can be found with a higher growth rate than Intel's (see Table 1).

Product Rankings

Bipolar logic continues its precipitous slide, declining in 1991 by 9 percent. Texas Instruments Inc. (TI) suffered a 12 percent setback in this product area but was still able to regain the No. 1 position, overtaking Fujitsu, which experienced an even more severe 18 percent decline (see Table 3).

MOS microcomponents was the star performer in 1991 growing 22 percent in revenue over 1990. The top 8 vendors, led by Intel's 29.3 percent market share, remain the same as in 1990. However, a significant newcomer to the top 10 has arrived: Advanced Micro Devices Inc. (AMD). Based upon 386 microprocessor revenue, AMD jumped to the No. 9 position from last year's No. 13 (see Table 4).

MOS logic experienced strong revenue growth of 17.6 percent. The top five players, led by NEC with an 11.7 percent market share, remained the same as in 1990. Matsushita Electric Industrial Company Ltd. shot up from No. 10 last year to the No. 6 position. Sony moved up five places to No. 18 (see Table 5).

Analog grew at a 12 percent rate, which proves once again that where you find electronics you will find analog. This category experienced the greatest shakeup in regards to market share rankings. No vendor within analog's top 10 players maintained last year's position (see Table 6).

Table 1
Preliminary Estimated Market Share Ranking: Worldwide Total Semiconductor (Millions of Dollars)

1991 Rank	1990 Rank		1990 Revenue	1991 Revenue	Percent Change	1991 Market Share (%)
1	1	NEC	4,898	5,547	13	8.5
2	2	Toshiba	4,843	5,337	10	8.2
3	3	Hitachi	3,893	4,351	12	6.7
4	5	Intel	3,171	4,059	28	6.3
5	4	Motorola	3,694	3,915	6	6.0
6	6	Fujitsu	2,880	3,111	8	4.8
7	7	Texas Instruments	2,574	2,753	7	4.2
8	8	Mitsubishi	2,319	2,568	1	4.0
9	10	Matsushita	1,942	2,421	25	3.7
10	9	Philips	2,011	2,072	3	3.2
11	11	National Semiconductor	1,719	1,697	-1	2.6
12	13	Sanyo	1,381	1,612	17	2.5
13	15	Samsung	1,315	1,592	21	2.5
14	14	Sharp	1,325	1,562	18	2.4
15	12	SGS-Thomson	1,463	1,490	2	2.3
16	17	Sony	1,146	1,426	24	2.2
17	16	Siemens	1,224	1,250	2	1.9
18	19	Advanced Micro Devices	1,053	1,185	13	1.8
19	18	Oki	1,074	1,157	8	1.8
20	22	Rohm	774	1,029	33	1.6

Source: Dataquest (December 1991)

Table 2
Preliminary Estimated Market Share Ranking: Worldwide Total Integrated Circuit (Millions of Dollars)

1991 Rank	1990 Rank		1990 Revenue	1991 Revenue	Percent Change	1991 Market Share (%)
1	1	NEC	4,207	4,742	13	9.0
2	4	Intel	3,171	4,059	28	7.7
3	2	Toshiba	3,628	3,910	8	7.4
4	3	Hitachi	3,182	3,587	13	6.8
5	5	Motorola	2,860	3,096	8	5.9
6	6	Fujitsu	2,639	2,802	6	5.3
7	7	Texas Instruments	2,488	2,667	7	5.0
8	8	Mitsubishi	1,940	2,121	9	4.0
9	9	National Semiconductor	1,649	1,637	-1	3.1
10	11	Matsushita	1,243	1,585	28	3.0
11	10	Philips	1,473	1,504	2	2.8
12	12	Samsung	1,238	1,489	20	2.8
13	14	Advanced Micro Devices	1,053	1,185	13	2.2
14	13	SGS-Thomson	1,148	1,172	2	2.2
15	16	Sharp	986	1,130	15	2.1
16	15	Oki	1,031	1,109	8	2.1
17	17	Sanyo	979	1,075	10	2.0
18	19	Sony	791	984	24	1.9
19	18	Siemens	835	820	-2	1.6
20	20	AT&T	717	780	9	1.5

Source: Dataquest (December 1991)

Table 3
Preliminary Estimated Market Share Ranking: Worldwide Bipolar Digital (Millions of Dollars)

1991 Rank	1990 Rank		1990 Revenue	1991 Revenue	Percent Change	1991 Market Share (%)
1	2	Texas Instruments	663	583	-12	14.5
2	1	Fujitsu	690	564	-18	14.0
3	3	Hitachi	510	555	9	13.8
4	6	Motorola	406	391	-4	9.7
5	4	National Semiconductor	423	344	-19	8.6
6	5	Advanced Micro Devices	407	319	-22	7.9
7	7	NEC	295	311	5	7.7
8	8	Philips	280	286	2	7.1
9	9	Toshiba	113	122	8	3.0
10	10	Mitsubishi	105	113	8	2.8
11	13	Harris	60	53	-12	1.3
12	14	AT&T	59	53	-10	1.3
13	15	Raytheon	54	53	-2	1.3
14	16	Oki	47	48	2	1.2
15	12	GEC Plessey	66	41	-38	1.0
16	17	Siemens	45	38	-16	0.9
17	20	Applied Micro Circuits	24	32	33	0.8
18	18	Goldstar	26	22	-15	0.5
19	19	Chips & Technologies	25	19	-24	0.5
20	21	Matsushita	14	15	7	0.4

Source: Dataquest (December 1991)

Table 4
Preliminary Estimated Market Share Ranking: Worldwide MOS Microcomponent (Millions of Dollars)

1991 Rank	1990 Rank		1990 Revenue	1991 Revenue	Percent Change	1991 Market Share (%)
1	1	Intel	2,726	3,590	32	29.3
2	2	NEC	1,083	1,318	22	10.7
3	3	Motorola	1,009	1,175	16	9.6
4	4	Hitachi	607	678	12	5.5
5	5	Mitsubishi	464	571	23	4.7
6	6	Toshiba	441	559	27	4.6
7	7	Texas Instruments	320	419	31	3.4
8	8	Matsushita	250	338	35	2.8
9	13	Advanced Micro Devices	178	315	77	2.6
10	9	National Semiconductor	248	293	18	2.4
11	11	Fujitsu	239	260	9	2.1
12	12	Philips	192	205	7	1.7
13	16	Oki	147	169	15	1.4
14	14	SGS-Thomson	175	166	-5	1.4
15	22	VLSI Technology	105	165	57	1.3
16	10	Chips & Technologies	240	158	-34	1.3
17	18	Sharp	138	156	13	1.3
18	19	Cirrus Logic	129	155	20	1.3
19	17	AT&T	145	134	-8	1.1
20	15	Western Digital	148	133	-10	1.1

Source: Dataquest (December 1991)

Table 5
Preliminary Estimated Market Share Ranking: Worldwide MOS Logic (Millions of Dollars)

1991 Rank	1990 Rank		1990 Revenue	1991 Revenue	Percent Change	1991 Market Share (%)
1	1	NEC	1,036	1,255	21	11.7
2	2	Toshiba	838	980	17	9.1
3	3	Motorola	559	645	15	6.0
4	4	Fujitsu	540	634	17	5.9
5	5	LSI Logic	503	567	13	5.3
6	10	Matsushita	285	478	68	4.4
7	8	Texas Instruments	306	469	53	4.4
8	6	Oki	410	432	5	4.0
9	7	Hitachi	352	404	15	3.8
10	1	Sharp	278	339	22	3.2
11	9	AT&T	303	333	10	3.1
12	12	Philips	252	290	15	2.7
13	13	Hewlett Packard	230	239	4	2.2
14	15	VLSI Technology	211	203	-4	1.9
15	14	National Semiconductor	216	201	-7	1.9
16	17	Sanyo	194	200	3	1.9
17	19	Samsung	153	196	28	1.8
18	23	Sony	116	187	61	1.7
19	21	Advanced Micro Devices	139	184	32	1.7
20	20	Yamaha	145	178	23	1.7

Source: Dataquest (December 1991)

Table 6
Preliminary Estimated Market Share Ranking: Worldwide Analog
(Millions of Dollars)

1991 Rank	1990 Rank		1990 Revenue	1991 Revenue	Percent Change	1991 Market Share (%)
1	3	Toshiba	610	720	18	6.1
2	5	Sanyo	541	707	31	6.0
3	2	National Semiconductor	619	680	10	5.7
4	1	Philips	653	650	0	5.5
5	4	SGS-Thomson	554	601	8	5.1
6	8	Mitsubishi	441	518	17	4.4
7	9	NEC	417	514	23	4.3
8	6	Motorola	491	496	1	4.2
9	10	Matsushita	410	485	18	4.1
10	12	Analog Devices	360	460	28	3.9
11	11	Sony	399	459	15	3.9
12	7	Texas Instruments	458	446	-3	3.8
13	13	Hitachi	347	412	19	3.5
14	14	Rohm	282	380	35	3.2
15	15	Harris	260	267	3	2.3
16	16	AT&T	197	244	24	2.1
17	21	Fujitsu	164	208	27	1.8
18	18	GEC Plessey	173	185	7	1.6
19	19	Silicon Systems	165	184	12	1.6
20	20	Sanken	164	179	9	1.5

Source: Dataquest (December 1991)

Table 7
Preliminary Estimated Market Share Ranking: Worldwide MOS Memory
(Millions of Dollars)

1991 Rank	1990 Rank		1990 Revenue	1991 Revenue	Percent Change	1991 Market Share (%)
1	3	Hitachi	1,366	1,538	13	11.0
2	1	Toshiba	1,626	1,529	-6	11.0
3	2	NEC	1,376	1,344	-2	9.7
4	4	Fujitsu	1,006	1,136	13	8.2
5	5	Samsung	971	1,135	17	8.2
6	6	Mitsubishi	853	826	-3	5.9
7	7	Texas Instruments	741	750	1	5.4
8	8	Sharp	497	557	12	4.0
9	14	Micron Technology	286	453	58	3.3
10	10	Oki	392	421	7	3.0
11	11	Intel	371	395	6	2.8
12	9	Motorola	395	389	-2	2.8
13	12	Siemens	320	301	-6	2.2
14	13	SGS-Thomson	299	280	-6	2.0
15	16	Advanced Micro Devices	253	272	8	2.0
16	15	Matsushita	284	269	-5	1.9
17	22	Hyundai	115	248	116	1.8
18	17	Sony	227	234	3	1.7
19	25	Goldstar	96	225	134	1.6
20	19	Cypress Semiconductor	166	185	11	1.3

Source: Dataquest (December 1991)

Table 8
Preliminary Estimated Market Share Ranking: Worldwide Total Discrete (Millions of Dollars)

1991 Rank	1990 Rank		1990 Revenue	1991 Revenue	Percent Change	1991 Market Share (%)
1	1	Toshiba	904	1,070	18	12.0
2	2	Motorola	808	792	-2	8.9
3	3	Hitachi	641	688	7	7.7
4	4	NEC	567	655	16	7.4
5	5	Philips	507	531	5	6.0
6	6	Matsushita	374	438	17	4.9
7	8	Rohm	321	411	28	4.6
8	7	Mitsubishi	348	408	17	4.6
9	10	Fuji Electric	304	342	13	3.9
10	9	SGS-Thomson	315	318	1	3.6
11	12	Sanyo	232	301	30	3.4
12	13	Sanken	224	264	18	3.0
13	11	Siemens	258	243	-6	2.7
14	14	International Rectifier	224	228	2	2.6
15	15	General Instrument	214	208	-3	2.3
16	16	Shindengen Electric	176	180	2	2.0
17	20	Fujitsu	117	166	42	1.9
18	17	ITT	161	110	-32	1.2
19	23	Eupec	96	109	14	1.2
20	22	Semikron	106	108	2	1.2

Source: Dataquest (December 1991)

Table 9
Preliminary Estimated Market Share Ranking: Worldwide Total Optoelectronic (Millions of Dollars)

1991 Rank	1990 Rank		1990 Revenue	1991 Revenue	Percent Change	1991 Market Share (%)
1	1	Sharp	339	432	27	13.4
2	2	Matsushita	325	398	22	12.4
3	3	Toshiba	311	357	15	11.1
4	4	Sony	270	336	24	10.4
5	6	Sanyo	170	236	39	7.3
6	5	Hewlett Packard	223	230	3	7.1
7	7	Siemens	131	187	43	5.8
8	8	NEC	124	150	21	4.7
9	9	Fujitsu	124	143	15	4.4
10	10	Rohm	105	130	24	4.0
11	11	Telefunken Electronic	78	83	6	2.6
12	12	Hitachi	70	76	9	2.4
13	15	Texas Instruments	33	58	76	1.8
14	13	Optek	66	52	-21	1.6
15	18	Mitsubishi	31	39	26	1.2
16	17	Philips	31	37	19	1.1
17	16	Oki	33	36	9	1.1
18	14	Quality Technologies	34	35	3	1.1
19	19	Motorola	26	27	4	0.8
20	20	Honeywell	25	25	0	0.8

Source: Dataquest (December 1991)

MOS memory last year grew at a relatively moderate 6 percent versus 1990's disastrous 17 percent decline. Observed in this light, however, MOS memory has made a rather impressive recovery, especially considering the fact that the 4Mb DRAM has not taken off as quickly as some had hoped. Hitachi jumped from the No. 3 position in 1990 to No. 1 in 1991, just barely surpassing last year's leader Toshiba, which was pushed to the No. 2 position. The balance of the top 10 remained essentially the same, with the exception of Micron Technology Inc., which shot from No. 14 to No. 9 via a 58 percent growth rate (see Table 7).

Dataquest Perspective

This past year was a prime example of positioning paying off. Those companies with strong positions in consumer, communications, and portable applications had the greatest opportunities for growth in 1991. With the exception of portable applications, the segments of data processing, industrial, automotive, and mil/aero all experienced moderate growth.

However, as in every broad sweeping conclusion, there are exceptions to the rule. Intel, with its dominant position in microcomponents and its near monopoly in the X86 microprocessor family, has been able to consistently outperform the market even though its revenue is very strongly dependent upon the data processing market. Additionally, AMD has been able to piggyback upon Intel's dominance by developing its own Intel-compatible 386 microprocessor family.

This market share report reflects revenue growth but does not address the more pressing issue of profitability. Although some companies are experiencing strong revenue growth, it is rare indeed to find companies achieving satisfactory profit margins. This area requires the most focus. Weak revenue growth is more acceptable if profitability is achieved. With this in mind, the wisest course of action for companies still is to focus on value-added products that generate higher margins.

By Gerald J. Banks
Ken Dalle-Molle

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Dataquest Perspective

Semiconductor Equipment, Manufacturing, and Materials

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Semiconductor Manufacturing

The "Go for Broke" Boom Fades

The unprecedented global expansion of the semiconductor industry over the last five years is on the wane. Between 1986 and 1991, semiconductor plant and equipment capital spending grew from $5.1 billion to $14.1 billion. The incredible surge in capital spending is largely attributed to an exceptionally strong semiconductor capital investment boom in Japan, fueled by cheap money and double-digit growth in the global PC market.

The "go for broke" character of this boom has left excess capacity hanging over the market, and that capacity will take time to work off. Consequently, we do not expect the current level of capital spending to be maintained. Dataquest forecasts that global capital spending will shrink 2 percent and that wafer fab equipment sales will decline 8 percent in 1992.

We also believe that the end of the boom marks a major turning point for the global semiconductor industry. Worldwide five-year growth rates in capital spending, wafer fab equipment purchases, and silicon wafer consumption will decelerate from the historical double-digit growth to a single-digit level.

The Overcapacity Issue

Since 1986, semiconductor companies have dramatically increased their level of investment in new plant and equipment. The level of investment in 1991 is almost three times the investment level in 1986. The lion's share of the spending has gone into submicron facilities, which by 1991 accounted for about one-fourth of the total installed capacity.

Dataquest does not believe that this level of capital spending is sustainable in 1992, given the semiconductor market dynamics today. The capital spending binge has left several segments of the semiconductor industry with excess wafer fab capacity. With excess capacity hanging over the market, there is little opportunity to raise chip prices; this situation results in downward pressure on semiconductor company profits. Dataquest expects the squeeze on profits to continue for several quarters. Poor profits in conjunction with a weak global economy will increasingly force many companies to rethink their spending plans.

The first signs of this capacity problem can be seen in the poor reception of the 4Mb DRAM. The slow ramp of the 4Mb DRAM will mean low utilization for the fabs running this product. Furthermore, there is uncertainty as to whether the 16Mb DRAM will receive any better reception in the marketplace than the 4Mb.

Several other signs indicate an overcapacity problem. The rate of fab closures is picking up pace, and a number of companies have recently announced the closure of several older lines running 4-inch wafers. Also, increased levels of foundry activity suggest that companies are scrambling to sell excess fab capacity to attain higher utilization rates.

A Turning Point

The end of the Japan-led boom signals a major turning point in the worldwide semiconductor industry. Perhaps the single most significant structural change will be the lower rate of investment. Japanese semiconductor companies' capital investment is expected to slow. Many of their planned fabs in Japan, the United States, and Europe will be delayed or put on hold.

The migration from Japan of equipment and material suppliers that followed Japanese semiconductor companies overseas is also expected to slow. As a result, Dataquest expects fewer acquisitions of or investments in local vendors by Japanese companies entering foreign markets. Ironically, U.S. companies and entrepreneurs will be the biggest losers, considering the important part that Japanese capital has played in funding start-ups.

Japanese semiconductor companies will increasingly move away from commodity products toward higher-value-added products. Consequently, chip design and manufacturing flexibility will grow in importance.

Where Is the Engine of Recovery?

The difficult question is: How quickly will the end-use markets soak up the excess capacity? The PC boom was the main driver of the recovery following the 1985 recession, but growth rates in this market are falling off. Today, there simply is not any single product on the horizon that will boost IC demand as the PC did after the last recession.

Perhaps even more problematic is the general economic malaise today. The 1985 semiconductor recession hit in the middle of an unprecedented global economic expansion; it was an isolated downturn amid a healthy economic expansion. Device makers had simply built up too much inventory. Today, the major industrialized nations are in recession or their economies are decelerating. The global economic problems suggest that semiconductor capital spending will not snap back as it did following the 1985 recession.

United States

The speculative bubbles in the real estate and capital markets have burst. For the United States, there is no quick fix. Dataquest expects the U.S. economy to experience several years of slow growth in gross national product (GNP). The United States is forecast to achieve modest growth rates in GNP for 1994 and 1995.

The U.S. consumer, who accounts for two-thirds of the GNP, is battered and in retreat. Falling prices in real estate—the biggest component of a consumer's net worth—are eroding the consumer's confidence to increase spending, a necessary condition for reigniting the domestic economy.

A heavy debt load is also weighing down the U.S. economy. The federal government has used fiscal policy, tax cuts, or increased spending effectively in the past to stimulate the economy. But a $340 billion deficit makes fiscal policy intervention very risky.

The US Federal Reserve is driving down interest rates; the discount rate in November was at 4.5 percent—the lowest in almost 20 years. Yet even low short-term rates are having only a muted stimulus affect. A large share of the blame falls on U.S. businesses and consumers, already carrying a high debt burden and unable to borrow more. Some of the blame can also be laid at the doorsteps of U.S. banks, which are not passing on the benefits of short-term rates because of their weak balance sheets.

Dataquest expects the U.S. economy to eke out a small level of growth in GNP through 1993. Growth will average in the 1 to 2 percent range per year. By 1994, the country will be in a stronger position to increase spending, having paid down its debts for several years and worked through a large share of its real estate problems. The U.S. economy is expected to pick up pace in 1994 and 1995, with GNP growing moderately in the 4 percent range.

Japan

The problems in Japan are quite different. During the second half of the 1980s, very strong growth in the money supply fueled an unprecedented capital spending binge and led to spiraling price appreciations in the domestic equity and real estate markets. In 1991, the Bank of Japan applied a brake to monetary policy in an effort to curtail inflation and wring the speculative excesses out of the economy.

With a tighter monetary policy and rising interest rates, the Japanese stock market has tumbled. This decline in the stockmarket—roughly 35 percent from its high in January 1990—has eroded the capital base of Japanese banks, limiting their ability to lend.

The liquidity crunch has broad implications. Japanese companies are weighing more carefully each new investment. Capital investments that could be justified when interest rates were at 5 percent are more difficult when rates are bumping 7 percent.

The excess capacity will provide little opportunity for Japanese companies to raise prices, resulting in downward pressure on Japanese corporate profits over the next year. Poor profits in conjunction with weak sales to western export markets are forcing many companies to cut back their spending.

However, the general trend in global interest rates is permitting the Bank of Japan to loosen the reins. Interest rates are expected to decrease through most of 1992 as the Japanese economy decelerates. This interest rate trend should set the stage for a recovery in 1993, and Dataquest believes that the upturn is sustainable through 1995. The recovery in Japan will depend on strong domestic consumption because there will be little opportunity to increase exports to the United States.

Europe

The European economic problems are more tractable because the European countries did not suffer the excesses of the U.S. and Japanese economies. Europe's banking system is perhaps the most solid in the world today. Moreover, real estate appreciation in Europe never reached the overheated levels of the United States and Japan. Prices have come down and are expected to go lower under our global disinflation assumption, but the market retreat will be orderly with few casualties. The trends in real estate are expected to dampen consumer demand.

A slow recovery from the recession in the United Kingdom and the reunification-induced drag on the German economy are expected to lower European GNP growth in 1992. GNP growth is expected to pick up in 1993 as domestic consumption improves and as projects to rebuild eastern Europe gain steam.

Asia/Pacific

The Asia/Pacific region will continue to see strong growth relative to the other regions of the world. Growth in the newly industrialized nations of Southeast Asia will benefit as these nations build their industrial infrastructure. Dataquest believes that individual country GNPs will grow in the 5 to 9 percent range through 1995.

However, in 1992 growth rates will fall toward the lower end of this range. Industries relying on exports like the semiconductor industry will feel the drag of weak export markets.

Dataquest Perspective

The semiconductor industry is passing from adolescence to a more mature stage. Spurts in growth such as the industry experienced over the last six years are less likely to occur without new products or markets to fuel the growth. Even so, the pervasiveness of semiconductors suggests that the prospects for industry are still very bright. ■

By Mark FitzGerald

Overcapacity and Uncertainty: Capital Spending Takes a Downward Turn

Semiconductor capital spending will be down by 2 percent in 1992 from its 1991 level. This decrease in capital spending will occur in spite of a 14 percent increase in production (see Table 1 for Dataquest's five-year forecast).

This decrease in 1992's capital spending level while production is increasing is because of overcapacity, particularly in DRAMs. Dataquest estimates that submicron capacity has increased threefold since 1989. Because of this large expansion of submicron capacity, we believe

Table 1
Semiconductor Regional Capital Spending and Worldwide Production Forecast (Millions of Dollars)

	1990	1991	1992	1993	1994	1995	CAGR (%) 1990-1995
Capital Spending in North America	4,088	4,097	3,821	4,352	4,787	5,217	5
Percent Change	6	0	-7	14	10	9	
Capital Spending in Japan	5,425	6,382	5,828	6,586	7,442	7,744	7
Percent Change	-1	18	-9	13	13	-22	
Capital Spending in Europe	1,512	1,631	1,688	1,984	2,322	2,554	11
Percent Change	25	8	3	18	17	10	
Capital Spending in Asia/Pacific-ROW	1,495	2,084	2,543	2,825	3,248	3,573	19
Percent Change	-22	39	22	11	15	10	
Total Capital Spending	12,519	14,194	13,879	15,747	17,799	19,090	9
Percent Change	0	13	-2	13	13	7	
Worldwide Production	62,772	69,231	78,769	91,056	102,194	110,352	12
Percent Change	2	10	14	16	12	8	

Source: Dataquest (December 1991)

that there is currently enough capacity in place to grow production in 1992 without any growth in capital investment.

By the end of 1992, if production grows as forecast, capital spending will rebound and reach $19 billion by 1995. However, this rebound in the 1993 to 1995 time period will have much less "snap" than previous rebounds. The five-year compound annual growth rate (CAGR) for 1990 to 1995 is only 9 percent.

In addition to overcapacity, there is another reason for the low growth rate in capital spending: There is a great deal of uncertainty about the end-use markets for very high density DRAMs. Where are the PCs of yesteryear? Where is a strong market driver that will spur growth in application areas that will use up large quantities of 16Mb and 64Mb DRAMs?

Capital Spending in Japan

We believe that in 1992, Japanese semiconductor companies as a whole will cut their worldwide capital spending budgets by 10 to 15 percent from 1991's levels. Most of Japanese company capital spending occurs in Japan (92 percent of the spending in Japan is by Japanese companies) and, therefore, spending in Japan will be down significantly (9 percent).

Japanese manufacturers have recently postponed or scaled back several major projects in Japan. For example, Fujitsu has postponed its new 8-inch line at Iwate. Hitachi at Naka and Sharp at Fukuyama have both scaled back the start-up capacity of their new 8-inch fabs scheduled to begin production in 1992. Toshiba has scaled back and postponed start of its new 8-inch DRAM line at Yokkaichi.

Because of profit pressure, overcapacity, and end-market uncertainty, we believe that Japanese manufacturers are currently re-evaluating their product and manufacturing strategies. The result of this re-evaluation will be a shift of some capacity from DRAMs to design-intensive, high value-added products such as microprocessors.

Currently, each of the major DRAM manufacturers has a large number of facilities capable of producing 4Mb DRAMs. Given overcapacity, uncertainty about end markets for high-density devices, and a price tag of $500 million for a 16Mb fab, we believe that the number of 16Mb DRAM fabs per major manufacturer will shrink dramatically. If this occurs, it will represent a major shift in manufacturing strategy for DRAM manufacturers—and it will dampen the long-term growth rate of capital spending.

Capital Spending in North America

Capital spending in North America will decline by 7 percent in 1992. The largest falloff will be experienced by Japanese companies spending in North America—from over $400 million in 1991 to less than $200 million in 1992. This rather precipitous drop in Japanese capital spending in North America is due to the completion of some major projects by Japanese companies, such as Fujitsu and NEC. Further expansion by other Japanese companies awaits the working off of excess capacity.

Spending by U.S. companies in the United States will be down slightly in 1992; Intel and Texas Instruments are planning to spend at their 1991 levels and Motorola, which completed its MOS-11 facility in 1991, will probably see a slight decline in its capital spending.

However, there will still be some new fab activity in the United States in 1992. Intel is currently building a new development line (D1A) in Aloha, Oregon, and in 1992 it will begin conversion of its current development line D1 (also in Aloha) to a production line.

Other new fab activity expected to be begin in 1992 includes National Semiconductor's new line in its Arlington, Texas, facility and AT&T's new line in Orlando, Florida.

Capital Spending in Europe

Capital spending in Europe will be up 4 percent in 1992. This small increase will be led by European companies spending in Europe. We expect spending increases by both Siemens and SGS-Thomson to offset a decline in spending by Philips. Siemens will be spending on its joint venture to manufacture 16Mb DRAMs with IBM at Corbeilles, France. SGS-Thomson will be facilitizing and equipping its new developmental fab at Grenoble, France. In addition to increases by Siemens and SGS-Thomson, there will also be substantial spending increases by Matra and Mietec for new fabs in 1992.

Spending by U.S. and Japanese semiconductor manufacturers in Europe will decline by about 10 percent in 1992. Major activities by Japanese and U.S. manufacturers in 1991 included the addition of substantial new DRAM capacity: Texas Instruments completed its 4Mb DRAM Avezzano fab and NEC added new DRAM capacity at its Livingston, Scotland, fab. Fujitsu's new DRAM fab at Newton-Aycliffe in the United Kingdom was just officially opened by Queen Elizabeth II in November. Dataquest believes that these new DRAM fabs will contribute to industry overcapacity.

Hitachi's 4Mb DRAM fab at Landshut, Germany, is now in the process of being equipped, but at a much slower rate than called for in its original plans. Mitsubishi's DRAM fab in Alsdorf, Germany, is another example of a DRAM fab that has had its original spending plan pushed back. This facility was originally slated to begin construction in the summer of 1991. Construction has now been delayed until 1992.

Capital Spending in Asia/ Pacific-ROW

Capital spending in Asia/Pacific-ROW increased by 39 percent in 1991 to $2.1 billion. This spending increase in percentage terms was strongest in Taiwan, where capital spending more than doubled in 1991. However, Dataquest expects capital spending in Taiwan to decrease in 1992 as major expansions by Macronix, TI/Acer, and TSMC are completed.

Major new sources of capital spending in Asia/ Pacific-ROW in 1992 will be Goldstar, Hyundai, possibly Samsung, and TECH Semiconductor (the joint venture of Cannon, Hewlett-Packard, the Singapore Economic Development Board, and TI).

The economies of the Pacific Rim countries are some of the world's fastest-growing economies. Because of this rapid economic growth, semiconductor consumption and semiconductor production are growing faster in Asia/Pacific-ROW than in any other region of the world. The five-year CAGR (1990 to 1995) of capital spending will also increase faster in Asia/Pacific-ROW than in any other region of the world. Capital spending will reach $3.5 billion in Asia/ Pacific-ROW by 1995.

Dataquest Perspective

We have been forecasting an overcapacity of DRAMs since our Dataquest Semiconductor Conference in Monterey, California, in October of 1990. Unfortunately, that forecast has come to pass. Most major DRAM manufacturers are delaying adding capacity or seriously downsizing capacity additions. The result in the short term will be a modest downturn in capital spending in 1992.

Overcapacity will have an additional effect: It will force DRAM manufacturers to ask themselves the question, "Is there really a market for all these DRAMs?" In answer, we believe that many manufacturers will hedge their bets. They will build fewer DRAM fabs and they will re-evaluate their production/manufacturing strategy. A result of this re-evaluation will be movement into new products and the building of fabs that have the flexibility to produce DRAMs and other products that the market may demand, such as advanced logic or ASICs.

In the long term, the effect of this re-evaluation will be a much slower CAGR than in the past—unless a new application or perhaps several application markets emerge with the capability of lifting the industry to higher growth rates, such as the PC did in the mid-1980s. ■

By George Burns

Market Analysis

Wafer Fab Equipment Forecast: Slower Five-Year Growth Pattern Sets In

The tremendous growth in the wafer fab equipment industry in the latter half of the 1980s has come to a faltering halt in the early 1990s. The "go for broke" character of this boom has left excess capacity hanging over the market that will take time to work off. The wafer fab equipment market, expected to experience only modest growth of 4 percent in 1991, is forecast to decline 8 percent in 1992.

Assumptions behind Our Forecast

The following assumptions constitute the foundation of Dataquest's five-year wafer fabrication equipment forecast:

- Macroeconomic assumptions—Dataquest assumes that the global economy in 1992 will be weaker than in 1991. The Japanese and German economies are decelerating and the U.S. and U.K. economies are having difficulties shaking off their recessions. Both the Japanese and European economies are expected to pick up in 1993, but recovery for the U.S. economy is expected to be weak. All major regions of the world are forecast to return to healthy GNP growth by the 1994 to 1995 time frame.

- Shifts in the semiconductor device product mix—Dataquest is forecasting that the combined share of MOS micro and MOS logic categories in the device revenue product mix will increase from 40 to 47 percent between 1990 and 1995. These two market segments will increase their share at the expense of traditional high-volume analog building blocks and high-volume, low-end bipolar TTL glue logic. MOS micro, the fastest-growing segment of the worldwide IC market, is being driven increasingly by system-on-a-chip ultralarge-scale integration (ULSI) trends and the adoption of application-specific standard product chip set solutions for many end-use markets. The high value-added, design-intensive nature of certain MOS micro segments, such as microprocessors and microperipherals, translates to higher average selling prices (ASPs) and lower unit volumes relative to the DRAM market. Programmable logic devices, a subset of MOS logic, are similar to microcomponents in that they also represent high value-added, low-volume manufacturing, which requires proportionately less wafer fab equipment than DRAMs. Shifts in the semiconductor device product mix toward MOS micro and MOS logic segments characterized by high value-added, low-volume manufacturing will contribute to lower fabrication equipment unit demand and thus deceleration in the long-term growth rate for the wafer fab equipment market.

- Escalating cost of process development and advanced manufacturing—The rising cost of advanced technology means that fewer semiconductor companies can afford to go it alone. Dataquest anticipates that a number of the larger semiconductor companies will continue to pursue joint-development and/or manufacturing pacts as a strategy to control both the costs and risks associated with advanced device technology such as DRAMs. Device companies will focus on market applications and sales/distribution channels to distinguish their products in the marketplace from those of their development partner/competitor. Joint-development/manufacturing strategies and shared foundry facilities between semiconductor manufacturers will contribute to a smaller number of megafabs being built in the future.

- Increased wafer fab equipment productivity—The ASP of wafer fab equipment will continue to increase in order to achieve the technical requirements of advanced submicron manufacturing. In response to demands from semiconductor manufacturers for increased equipment productivity to offset higher equipment prices, wafer fab equipment companies will aggressively compete on equipment cost of ownership. Increased equipment productivity will contribute to lower equipment unit demand.

Dataquest believes that the end of the 1980s boom marks a major turning point for the global semiconductor industry. For the reasons cited above, worldwide five-year growth rates in capital spending and wafer fab equipment purchases will decelerate from historical double-digit growth to a single-digit regime. Revenue growth in the wafer fabrication equipment market primarily will reflect escalating ASPs of advanced equipment technology. For a number of wafer fab equipment categories, unit shipments in 1995 will be essentially flat or decline slightly, relative to shipment levels in 1990.

Wafer Fabrication Equipment Markets

Table 1 presents Dataquest's five-year forecast for wafer fabrication equipment by segment. As the semiconductor industry pushes into the submicron era, process complexity and fabrication technology requirements continue to increase dramatically. Lithography, deposition, and etch/clean equipment continue to be the technology drivers that fuel the wafer fabrication equipment industry's growth. A key factor driving growth in the stepper market over the five-year time period is the significant shift in the product mix away from g-line tools to advanced i-line and excimer/deep-UV steppers with wide-field capability.

The adoption of double-level metal technology for the 16Mb DRAM generation, together with the rapid move toward triple and even four-level metal for MOS microprocessor and ASIC devices, will continue to push the CVD, PVD, and dry etch thin-films market to outperform the overall wafer fab equipment market. The dry etch equipment market will experience healthy growth because of the triple factors of increased dry etch process steps, complex new plasma source technologies, and rapid ASP increase due to the need for tighter process control at sub-0.5 micron geometries.

In addition to the well-established low temperature, plasma-enhanced CVD reactor market, the thermal CVD market (including metal CVD and thermally driven atmospheric and low-pressure

Table 1
Worldwide Wafer Fab Equipment Market Forecast, 1990-1995
(Millions of Dollars)

	1990	1991	1992	1993	1994	1995	CAGR (%) 1990-1995
World Fab Equipment Market	5,818	6,026	5,568	6,450	7,885	8,833	8.7
Lithography							
Contact/Proximity	19	17	17	16	16	15	-4.2
Projection Aligners	89	76	65	69	76	78	-2.6
Steppers	1,067	1,042	955	1,113	1,404	1,610	8.6
Direct-Write Lithography	50	55	63	75	85	88	11.9
Maskmaking Lithography	71	72	76	89	112	126	12.3
X-Ray	2	8	12	25	38	55	102.7
Total	1,297	1,270	1,188	1,387	1,730	1,972	8.7
Automatic Photoresist Processing Equipment	338	350	315	356	428	483	7.4
Etch and Clean							
Wet Process	350	370	361	408	477	525	8.4
Dry Strip	125	130	120	145	180	200	9.8
Dry Etch	683	715	650	775	950	1,050	9.0
Ion Milling	13	15	12	15	18	20	9.0
Total	1,172	1,230	1,143	1,343	1,625	1,795	8.9
Deposition							
Chemical Vapor Deposition	689	735	675	775	950	1,075	9.3
Physical Vapor Deposition	408	435	400	450	550	625	8.9
Silicon Epitaxy	68	75	58	53	71	61	-2.2
Metalorganic CVD	42	44	42	49	61	66	9.2
Molecular Beam Epitaxy	55	53	50	57	66	71	5.5
Total	1,262	1,342	1,225	1,384	1,698	1,898	8.5
Diffusion	322	325	270	330	400	475	8.1
Rapid Thermal Processing	33	40	45	65	80	100	24.9
Ion Implantation							
Medium Current	116	123	106	116	144	153	5.6
High Current	250	266	238	272	338	373	8.4
High Voltage	5	15	18	30	38	42	53.4
Total	371	405	362	418	520	568	8.9
Process Control							
CD (Optical & SEM)	151	160	150	175	210	241	9.9
Wafer Inspection	99	71	74	87	103	116	3.2
Other Process Control	368	398	380	432	520	567	9.0
Total	618	629	603	694	833	924	8.4
Factory Automation	216	232	234	266	319	335	9.2
Other Equipment	189	204	183	206	252	282	8.3
Total World Fab Equipment	5,818	6,026	5,568	6,450	7,885	8,833	8.7
Percentage Change	-3	4	-8	16	22	12	

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (December 1991)

CVD) will experience healthy growth over the next five years because of the continuing need for planarized device topology. New organic CVD precursor sources will lead to precisely tailored metal and dielectric CVD films that exactly satisfy specific device topology requirements. Concurrently, new advances in PVD technology such as advanced barrier metallization, laser reflow, and planarization of sputtered aluminum will lend impetus to growth in the PVD market.

Potential DRAM Doldrums

In a recent survey of business expectations for the wafer fabrication equipment industry, the majority of equipment companies indicated that they expected an upturn in their sales activities sometime in the latter half of 1992. For a number of companies, the anticipated upturn will be predicated upon a resurgence in DRAM fab activity. Dataquest anticipates that the return to growth for wafer fab equipment industry in 1993 will be driven in part by demand for 0.5-micron equipment for the 16Mb production ramp. Although we believe that our forecast of 16 percent growth in 1993 is reasonable, there is a potential downside if 16Mb DRAM applications do not materialize as anticipated. Along with high-performance workstations, notebook and palmtop PCs are expected to be major consumers of 16Mb chips. However, for the high-volume notebook and palmtop PC markets to take off as forecast, the cost of component technologies such as flash memory and liquid crystal displays must come down. If the application end-use markets for 16Mb DRAMs are weak, Dataquest's forecast for wafer fabrication equipment in 1993 would need to be moderated downward.

Dataquest Perspective

Dataquest does not expect growth rates in semiconductor investment to return to the levels reached in the late 1980s until a major new product driver, like high-definition TV, is commercialized or until a new regional market such as China, India, Eastern Europe, or the Soviet Union is developed. These regions, however, are characterized by fragile, infant market economies, and it will take years to develop the hard currency capital structure needed to fuel their domestic semiconductor industries.

Dataquest, however, believes that there is a silver lining to this looming, dark cloud of industry slowdown. Semiconductor pervasiveness and content in the entire spectrum of electronics markets such as data processing, communication, automotive, consumer, and military/aerospace continues its steady increase. Several emerging end-use application markets have the potential to kick the semiconductor industry back into high gear within the next several years. These applications include high-bandwidth/high-speed data communication, personal wireless communications networks, portable computer/communicator devices that incorporate pen-based input and fax/modem/voice communication, optical CD-ROM based consumer multimedia systems, filmless electronic still photography, consumer video telephones, and electronic automotive controls. All of these new product applications promise to extend the scope of the semiconductor industry well beyond the restricted office-automation PC market into the mass-consumer market.

We believe that a new wave of time-to-market-oriented, flexible, low-volume semiconductor manufacturing technologies that diverge from traditional high-volume DRAM manufacturing technologies will emerge within the next five years. Small, medium-size, captive, and fabless semiconductor companies will explore radically different methods of flexible semiconductor manufacturing that seek to overcome the tyranny of the billion-dollar megafab entry barrier. Opportunities exist for wafer fab equipment and materials companies that can successfully address the changing needs and demands of an increasingly flexible semiconductor industry. ■

By Krishna Shankar
Peggy Marie Wood

CVD and Dry Etch Applications Forecast

This article presents Dataquest's chemical vapor deposition (CVD) and dry etch thin films forecast by application and the key factors behind the growth of individual segments.

CVD Equipment Forecast

Table 1 presents Dataquest's forecast for the worldwide CVD equipment market by thin-film segment for the five-year period between 1990 and 1995. Metal CVD, which includes tungsten-based films, titanium nitride, aluminum, and copper, is projected to be the fastest-growing segment overall. Our metal CVD forecast assumes that tungsten plugs will be used in contact and via applications for 0.5-micron 16Mb DRAMs, 32-bit microprocessors, and

Table 1
Worldwide CVD Equipment Market Forecast by Film Application, 1990-1995
(Millions of Dollars)

	1990	1991	1992	1993	1994	1995	CAGR (%) 1990-1995
Total CVD	689	735	675	775	950	1,075	9.3
Plasma Oxide	208	221	198	223	272	307	8.1
Thermal Oxide	150	154	132	149	174	188	4.6
Plasma Nitride	138	140	108	124	143	151	1.8
Thermal Nitride	34	37	34	31	38	43	4.8
Poly Silicon	76	88	81	93	114	140	13.0
Metal	83	96	122	155	209	247	24.4

Source: Dataquest (December 1991)

ASICs. Tungsten plugs offer the benefits of high reliability, planarization, and easy scaling to three-level and four-level interconnect processes. However, competitive developments in other plug technologies such as laser-planarized physical vapor disposition aluminum or poly plugs could slow the growth of the metal CVD market.

The trend toward multiple poly applications in stacked DRAM capacitors, BiCMOS SRAMs, and poly-emitter-based very large scale integration bipolar logic will kick the poly CVD equipment market into healthy growth over the next five years. An intense market battle will develop between the large-batch vertical tube market and the rapid thermal processing RTP/RTCVD market for integrated gate-stack applications.

Low-temperature TEOS CVD and other new organic sources will continue to drive the plasma oxide market for intermetal dielectric applications. However, the development of recent TEOS/ozone-based thermal subatmospheric CVD and atmospheric CVD processes has the potential to drive the thermal oxide market on an accelerated growth path over the next five years. Thermal and plasma-oxide processes will increasingly be combined into integrated planarization solutions at the expense of the traditional PECVD oxide/spin-on-glass and resist-etchback planarization schemes. The thermal oxide market may also be augmented by the adoption of tantalum oxide as a capacitor dielectric for 64Mb DRAM or 256Mb DRAM applications.

Table 2
Worldwide Dry Etch Equipment Market Forecast by Film Application, 1990-1995
(Millions of Dollars)

	1990	1991	1992	1993	1994	1995	CAGR (%) 1990-1995
Total Dry Etch	683	715	650	775	950	1,050	9.0
Oxide	287	300	260	310	380	420	7.9
Poly/Polycide	157	164	150	178	219	242	9.0
Metal	171	186	176	209	257	284	10.7
Plasma Nitride	21	14	13	16	19	21	0
Thermal Nitride	27	21	20	23	29	32	3.5
Silicon/Trench	21	29	33	39	48	53	20.3

Source: Dataquest (December 1991)

Dry Etch Equipment Forecast

Table 2 presents Dataquest's forecast for the worldwide dry etch equipment market by thin-film segment for the five-year period between 1990 and 1995. The oxide etch market will continue to be the largest segment of the dry etch market due to the pervasiveness of thermally grown oxides, thermal and plasma CVD oxides in submicron, and multilevel interconnect processes. The metal etch market segment will grow concomitantly as device manufacturers migrate to multiple-level, sandwich-metal films composed of barrier films, aluminum interconnect, and refractory caps. The average selling price of metal etch systems will increase due to the addition of post-etch passivation and dry strip modules.

The poly/polycide etch market growth will be driven by the need for precise sub-0.5-micron gate definition, high selectivity to gate oxide, and low ion bombardment damage. Other applications such as poly capacitor fin etch, poly LDD spacers, and poly plugs will increase the unit demand for poly etch equipment. In general, the trend toward multichamber dry etch/dry strip applications and more complex plasma sources will drive up equipment ASPs sharply.

Dataquest Perspective

An understanding of the thin-film applications trends and their relative growth rates is an essential component in developing a worldwide forecast of growth in the CVD and dry etch equipment markets, the second- and third-largest segments of the wafer fab equipment market. These two segments of equipment will account for a combined share of 24 percent of the 1995 wafer fab equipment market of $8,833 million. Semiconductor manufacturers will increasingly emphasize low cost-of-ownership CVD and dry etch solutions that provide enabling technologies on production-worthy platforms. ■

By Krishna Shankar

Semiconductor Materials

Slower Growth for Silicon Wafer Market

The demand for silicon wafers (prime, epitaxial, test, and monitor) deteriorated in the fourth quarter of 1991. Dataquest believes that the fourth-quarter data are a harbinger of weak growth in 1992. We now forecast 1992 demand to grow only 4.9 percent worldwide (see Table 1); our previous estimate was for 10.1 percent growth (see Table 2). Dataquest is also lowering its preliminary estimate of 1991 worldwide growth from 7.1 percent to 4.7 percent.

We are cutting back on the near-term growth in silicon demand for two reasons. First, our previous assumptions concerning the major industrialized economies has changed. We are less optimistic about the economies of the seven industrialized countries that consume the major portion of global semiconductor production.

Table 1
Forecast Silicon and Epitaxial Wafer Consumption by Region (December 1991), 1990-1995 (Millions of Square Inches)

	1990	1991	1992	1993	1994	1995	CAGR (%) 1990-1995
United States	648	645	665	705	769	810	4.6
Percent Growth	11.4	-0.5	3.1	6.0	9.1	5.3	
Japan	1,017	1,102	1,175	1,258	1,367	1,480	7.8
Percent Growth	10.1	8.4	6.6	7.1	8.7	8.3	
Europe	227	218	212	225	257	292	5.1
Percent Growth	-1.7	-4.0	-2.8	6.1	14.2	13.6	
Asia/Pacific	145	168	185	213	247	281	14.2
Percent Growth	27.0	16.1	10.1	15.1	16.0	13.8	
Worldwide	2,037	2,133	2,237	2,401	2,640	2,863	7.0
Percent Growth	10.1	4.7	4.9	7.3	10.0	8.4	

Source: Dataquest (December 1991)

Table 2
Forecast Silicon and Epitaxial Wafer Consumption by Region (July 1991), 1990-1995
(Millions of Square Inches)

	1990	1991	1992	1993	1994	1995	CAGR (%) 1990-1995
United States	648	687	731	807	894	921	7.3
Percent Growth	11.4	6.0	6.4	10.4	10.8	3.0	
Japan	1,017	1,102	1,230	1,389	1,498	1,572	9.1
Percent Growth	10.1	8.4	11.6	12.9	7.8	4.9	
Europe	227	224	244	272	312	343	8.6
Percent Growth	-1.7	-1.4	8.9	11.5	14.7	9.9	
Asia/Pacific	145	168	196	231	271	295	15.3
Percent Growth	27.0	16.1	16.7	17.9	17.3	8.9	
Worldwide	2,037	2,181	2,401	2,699	2,975	3,131	9.0
Percent Growth	10.1	7.1	10.1	12.4	10.2	5.2	

Source: Dataquest (December 1991)

Second, the capital investment climate for the semiconductor industry is deteriorating and Dataquest expects many semiconductor companies to delay fab investments.

Regional Analysis

Japan

The Japanese economy is decelerating as the investment boom begun in 1986 winds down. Dataquest believes that the investment in new semiconductor plants will not escape this trend. Already, several of the larger device makers in Japan have announced capital spending cuts, resulting in delays or cancellation of new fabs.

Since our earlier forecast published in July 1991 Hitachi has announced that it will freeze fiscal year 1991 capital spending (the Japanese fiscal year ends March 1992). As a result, Hitachi decided not to proceed with plans to construct a new 4Mb DRAM facility. Toshiba also reduced its 1991 capital spending from ¥125 billion to ¥100 billion and the company will postpone the completion of its new 200mm line at Yokkaichi for half a year. Mitsubishi will postpone and scale back its Saijo plant. Fujitsu will delay its 200mm line at Iwati. In addition, many other semiconductor companies have announced delays and cutbacks.

Dataquest believes that the Japanese semiconductor companies at best will keep capital spending flat in fiscal 1992, causing additional delays in fabs planned for calendar 1992 and 1993. Consequently, the five-year compound annual growth rate (CAGR) for silicon consumption in Japan has been reduced from 9.1 percent to 7.8 percent. We also expect silicon wafer demand to grow only 6.6 percent in 1992 versus our previous forecast of 11.6 percent because of the weakening Japanese economy and sluggish export markets.

United States

The short- and long-term silicon consumption forecast for the United States also has been revised downward. The previous U.S. forecast of 6.0 percent growth in 1991 appears optimistic. Demand in the fourth quarter has fallen off and we now expect annual consumption to shrink by 0.5 percent. Our previous forecast was based on an economic recovery in the second half of 1991 that was more aggressive than actually happened.

We are also lowering the forecast 1992 growth rate of U.S. silicon demand. Dataquest now expects silicon to grow only 3.1 percent; our previous forecast was 6.4 percent. The impact of the recession will linger well into 1992, dragging down the end-use markets for semiconductors. Growth in data processing and consumer applications appears particularly vulnerable.

The weak market for semiconductors and the overcapacity problem is prompting many companies to close marginal fabs. AMD, Intel, SEEQ, and Western Digital have announced fab closings in 1991. We expect National to continue this trend into 1992 and announce the closure of three California lines. The new forecast reflects this decrease in wafer start capacity.

Europe

Our estimate of European silicon wafer demand in 1991 has changed little from our previous estimate. We continue to expect demand for silicon wafers to shrink this year. The production of discrete devices appears to be holding its own; however, IC production is expected to be down. Demand is very weak among the Europe-based IC producers.

We are more cautious on the outlook for 1992. Previously, we had expected silicon demand to grow 8.9 percent in 1992 but we are less sanguine about the market now. The German economy is grappling with higher interest rates and is expected to decelerate. The British economy is having difficulties shaking off the recession. Two of the other major European economies, France and Italy, are on the edge of a recession. Consequently, the end-use markets for semiconductors are expect to be weak in 1992.

European silicon wafer demand is also expected to suffer as Japanese and U.S. companies scale back their capital spending plans in Europe. Dataquest does not believe that Mitsubishi's planned fab line in Germany will be put into production in 1992 as originally planned. In addition, we expect Texas Instruments to cut back the ramp of its Avezzano, Italy, facility and Hitachi to delay the equipping of its Landshut, Germany, facility because of the weak demand for 4Mb DRAMS.

We now forecast the European silicon market to begin growing in 1993, when we assume that an improved economic climate will result in increased demand for semiconductors. However, growth of silicon wafer demand in Europe still hinges on planned investments by Japanese and U.S. companies.

Asia/Pacific

Nothing on the horizon has caused us to change our long-term forecast for the Asia/Pacific region, which still remains the fastest-growing region of the world. A potential problem is the weak end-use market for 4Mb DRAMs and the uncertainty surrounding the 16Mb market. This problem could delay the fab plans of device makers such as Hyundai and Samsung. However, at this writing the Korean companies are pushing ahead with their new fabs so we remain optimistic on our aggressive silicon wafer forecast for the Asia/Pacific region. We have lowered the growth rate for the 1992 market because of the weak export markets and the slow ramp of the 4Mb DRAM. Our forecast now projects silicon wafer demand to grow 10.1 percent in 1992 verses our previous estimate of 16.7 percent.

Dataquest Perspective

The demand for silicon wafers is expected to grow marginally in 1992 because of the weak global economy and the decline in capital spending on new semiconductor fabs. Pricing for silicon wafers is expected to come under pressure in this environment. Pricing pressures will be further exacerbated by the new wafer plants being built in Japan and Korea. Dataquest believes that it will take several years for the profitability picture to improve for silicon wafer suppliers. ■

By Mark FitzGerald

Technology Analysis

Sensor-Based Manufacturing: A Technology Whose Time Has Come

Sensor-based manufacturing (SBM) is a method of extending the useful life of semiconductor equipment. SBM schemes also improve wafer-to-wafer process repeatability as well as die-to-die repeatability on a single wafer, reducing the need for expensive and time-consuming in-line metrology. The result is greater process control, improved cycle time, and reduced capital expenditures for metrology equipment. The payback for semiconductor manufacturers that implement SBM can be measured in terms of reduced wafer misprocessing, which implies higher manufacturing yields.

SBM History

The addition of sensors to the fabrication process has long been a goal of semiconductor manufacturers. Vacuum and plasma-based processes are excellent candidates for SBM because of semiconductor manufacturers' increasing demand for dry processing. However, implementation problems have hampered this effort. For example, one difficulty was the inability to identify and obtain statistically significant product-correlated signals. Recent efforts by the SEMATECH Parametric Response Surface Control (PRSC) project has defined a strategy for establishing and implementing SBM in new and existing fabrication environments.

Implementation Strategy

The initial task of the SBM implementation strategy is to define the user's needs. Even within a specific user's fab this task is very process-dependent (not all processes require the same level of control). For example, a 16Mb DRAM design incorporates 0.5-micron gate lengths and 1.0-micron metal pitch with process specifications of ±10 percent. In this case, the linewidth control requirements alone mandate improved process capability available with SBM techniques. Improved process capability is required to increase yields and reduce the need for in-line metrology. SBM implementation techniques are designed to improve process capability through the application of sensors and the proper interpretation of their statistically significant signals.

In order to achieve the benefits of SBM discussed later in this article, a plan encompassing both the goals and the problems of improved process performance must be developed and executed. The SEMATECH PRSC project strategy was developed to do this.

Working concurrently, existing equipment parameters (primary recipe components) can be analyzed and prioritized by significance while voids in present metrology capabilities are identified. Still working in parallel, existing sensors for key machine parameters should be evaluated and improvements planned while new sensor capabilities are established to monitor other relevant process parameters. The result of this parallel analysis effort is the establishment of statistically significant signals relevant to process results. These new control signals may be applied in various control paradigms such as statistical process control (SPC), closed loop predictive such as neural networks, model-based such as response surface methodology, or simply end point detection such as radio frequency monitoring.

Benefits of SBM

The proper application of SBM techniques completes the promise of single-wafer processors by giving the process engineer the capability for real-time SPC and other monitoring techniques. This improved monitoring capability results in the ability to detect and respond to shifts or drifts in process performance during processing. Detection of an out of control event during processing results in the opportunity to stop and evaluate a situation prior to the completion of wafer processing. The direct benefit of this SBM approach is in saving wafers that otherwise would have been damaged or misprocessed. As every fab manager knows, damaged or misprocessed wafers inevitably result in lower manufacturing yields.

As with all technology, SBM comes at a price. The most obvious price impact is in increased semiconductor equipment costs because of the addition of sensors to the equipment. However, it is important that semiconductor manufacturers comprehend the benefits associated with these costs. Figure 1 shows the benefits derived by incorporating SBM. The two major benefits associated with an investment in SBM are fewer inspection steps and an improved process capability index (Cpk).

Impact of SBM on Operations

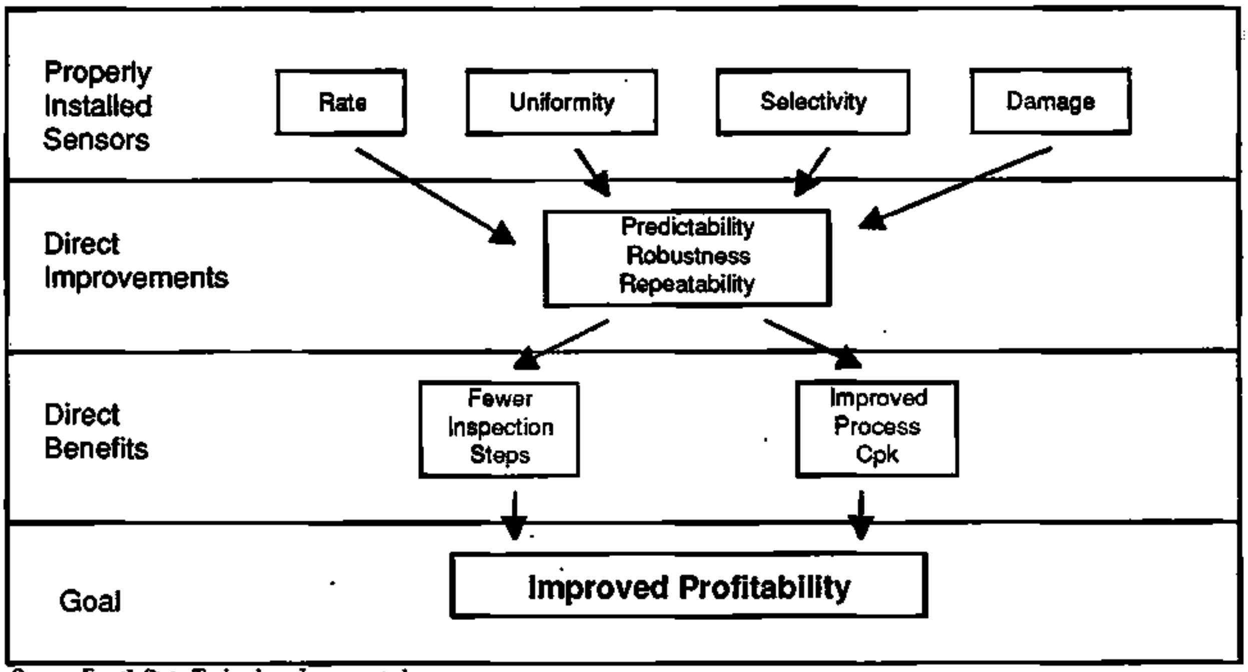
SBM can have a positive impact on semiconductor manufacturing cycle time, according to SEMATECH member company data. After implementing SBM, the required in-line inspection steps as a percentage of total process steps was reduced from 22 percent to 6.5 percent. Of the 6.5 percent remaining after the application of SBM, 65 percent were inspections for lithography equipment. Also, required in-line inspection tool costs as a percentage of total fab equipment costs went from greater than 30 percent without SBM to less than 10 percent with SBM. Product cycle time was also reduced from 14 days without SBM to 8 days with SBM.

The concept of improved process capability is achieved through the reduction of product variance, which drives overall yield. Improving process capability by the application of intelligent sensors to existing process equipment will increase a semiconductor manufacturer's return on investment because of the extension of the equipment's life, both in economic and technological terms. These improvements translate into one key attribute—product quality.

Dataquest Perspective

Present process control schemes are based only on hardware or machine parameters, yet wafer processing results are defined by plasma

Figure 1
Benefits Associated with Investment in SBM



Source: Fourth State Technology Incorporated

parameters. Therefore, shifting the focus of module control from the traditional machine parameters to the less conventional plasma parameters places the focus of control closer to the wafer and improves process performance. Implementing SBM can result in direct improvements in the process predictability, robustness, and repeatability. ■

By Terry R. Turner
Jeff Seerley

(This article was written by Terry Turner of Fourth State Technology Inc. in conjunction with Jeff Seerley. Fourth State technology Inc. is the first spin-off of SEMATECH. For further information, please contact Jeff Seerley).

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Delays and Downsizing of 200mm Fab Lines in Japan

Table 1 presents a summary of existing fabs and planned additions for all 200mm lines in Japan. Semiconductor manufacturers had originally planned to have a total of 11 of the 200mm fabs with a combined capacity of 57,000 wafers per month on-line by the end of 1991. However, production start dates have been pushed back and now there will be only 7 facilities on-line by the end of the year. These facilities will have a combined capacity of 22,000 wafers per month--a mere 38 percent of what had been originally planned.

The revised plans for capacity additions shown in Table 1 reflect serious cutbacks from original plans, particularly through the first half of 1992. Original plans had called for a total capacity of 132,000 wafers per month to be in place by mid-1992. Revised plans now call for a total capacity of only 50,000 wafers per month.

As shown in Table 1, 15 out of 24 existing or planned 200mm fab lines in Japan will have their production start dates pushed back and 6 out of 24 lines will see significant cutbacks in their initial production capacity. This slowdown in 200mm capacity additions is due in large measure to excess capacity that is currently hanging over the market. (Please refer to SEMMS Blast-O-Fax, "The 'Go For Broke' Boom of the Semiconductor Industry Comes To An End," November 21, 1991.)

Dataquest Perspective

200mm capacity in Japan will continue to grow, albeit it at a significantly reduced pace than originally planned. Fab construction, wafer fab equipment, and semiconductor materials companies must be prepared to scale back their 200mm business expectations accordingly. We believe that 200mm capacity additions will begin to grow at a much healthier pace in the second half of 1992, which will be reflected in a pickup of new 200mm business for the vendor base of the semiconductor industry.

Kunio Achiwa (Tokyo)
George Burns (San Jose)
Peggy Marie Wood (San Jose)

Table 1.
Status Update of All Existing and Planned 200mm Fab Plans in Japan
(///////// = Delay Time of Initial Production)

Company	Location	Fab Name	Type	Products	Wafer capacity (000's wafers per month) per facility							Production Status
					1990/2H	1991/1H	1991/2H	1992/1H	1992/2H	1993	1994	
Fujitsu	Iwate	Fab-2	F	16Mb DRAM				/////////	20	20	20	delayed
Hitachi	Kofu	K-2	P	4Mb DRAM, 16Mb DRAM	1	1.5	2	3	3	3	3	no change
	Naka	N-2	F	4Mb DRAM, 16Mb DRAM				/////////	10	10	15	delayed, downsized
IBM	Yasu	N/A	F	4Mb DRAM, 16Mb DRAM	5	5	5	10	10	10	10	no change
KTI	Nishiwaki	N/A	F	Advanced Logic, ASIC			/////////	3	6	9	9	delayed, downsized
Matsushita	Kyoto Lab	R&D	P	16Mb DRAM			/////////	.5	1	1	1	delayed
	Tonami	Fab 2	F	16Mb DRAM, 64Mb DRAM					/////////	10	10	delayed
Mitsubishi	Kita-Itami	R&D	P	16Mb DRAM		1	1	1	1	1	1	no change
	Saijo	A-1F	F	16Mb DRAM				3	7	10	10	downsized
NEC	Sagamihara	G-2	P	16Mb DRAM	1.5	1.5	1.5	1.5	1.5	1.5	1.5	no change
	Kyushu	Fab 8	F	16Mb DRAM, RISC MPU			/////////	15	15	20	20	delayed
	Hiroshima	Phase 2	F	4Mb DRAM, 16Mb DRAM, EPROM							/////////	delayed
NKK	Ayase	Phase 1	P	4Mb SRAM, ASIC, MPU					/////////	5	5	delayed, downsized
Oki	Miyagi	M2	F	16Mb DRAM						/////////	20	delayed
Sanyo	Niigata	No. 6	F	16Mb DRAM						/////////	15	delayed
Sharp	Fukuyama	R&D	P	16Mb DRAM	1	1	1	1	1	1	1	no change
	Fukuyama	Fab 3	F	4Mb SRAM, MASK ROM				/////////	6	12	12	delayed, downsized
Sony	Atsugi	Lab	P	SRAM, ASIC						2	2	no change
TI	Hiji	Mos 8	F	4Mb DRAM, 16Mb DRAM	3	5	10	10	10	10	10	no change
Toshiba	Tamagawa		P	4Mb DRAM, 16Mb DRAM	1	1	1.3	2	2.5	2.5	2.5	no change
	Central Lab	UL Lab	P	16Mb DRAM						/////////	10	delayed
	Yokkaichi	Step 1	F	4Mb DRAM, 16Mb DRAM			/////////	/////////	15	20	40	delayed, downsized
	Oita	Step 5	F	4Mb DRAM, 16Mb DRAM						/////////	20	delayed
	Iwate	Step 7 & 8	F	16Mb DRAM							/////////	delayed
Revised Capacity Plan					12.5	16.0	21.8	50.0	109.0	148.0	238.0	
Original Capacity Plan					12.5	16.0	56.8	131.5	171.0	241.0	266.0	
Revised Capacity as a Percent of Original Capacity					100%	100%	38%	38%	64%	61%	89%	

P = Pilot line
F = Full production line
1H = First half of calendar year
2H = Second half of calendar year

Source: Dataquest (December 1991)

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Dataquest Perspective

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Technology Analysis

It's a Wide, Wide World

In recent months, much of the attention of the lithography industry has been focused on phase-shift masks because of their promise to provide improved resolution and depth of focus with existing stepper and resist technology. This article concentrates on what Dataquest believes is a second but no less important development: the move by stepper manufacturers to wide-field stepper systems. During the last two years, the industry has seen a veritable explosion of wide-field product offerings.

Why the move to wide-field systems? The fundamental reason is that chips are getting larger as semiconductor manufacturers continue to increase device densities and pack more functionality onto a single integrated circuit. Wide-field lens systems allow steppers to expose and print the larger die sizes associated with advanced devices. In addition, wide-field lenses accommodate more devices in the image field than the standard 15mm × 15mm field and thus have a significant impact on system throughput.

New Wide-Field Stepper Product Offerings

As device manufacturers move below 0.8-micron geometries, the lithography tools of choice are i-line (365nm) and excimer/deep-UV (248nm/240-255nm) stepper systems. Table 1 identifies the wide-field i-line and excimer/deep-UV stepper offerings available today. In this table, field size is listed in three different descriptions: circular lens diameter and the largest square and rectangular dimensions that can be imaged within the field. The systems with the largest field size overall are the Micrascan from SVG Lithography and the Ultratech 1x steppers. These wide-field stepper systems can achieve large rectangular field sizes because they are designed around optical principles that are different from reduction lithography.

Five of the steppers listed in Table 1 reflect new product introductions. On November 18, Nikon Corporation will announce its new 20mm × 20mm excimer laser stepper, the NSR-2005EX8A. During the first week of December at SEMICON/Japan, Ultratech Stepper will introduce its new Model 2244i 1x, i-line stepper with a 22mm × 44mm field size. Also at SEMICON/Japan, Canon will introduce two new wide-field i-line steppers, the FPA-2500i2 and FPA-2500i3, and will discuss its wide-field excimer stepper offering, the FPA-3000EX1. Table 1 clearly illustrates that all of the stepper manufacturers are active participants in the wide-field arena.

Why Is Getting Wide Getting So Tough?

One of the key goals in lithography is to maximize resolution, depth of focus, and the associated critical dimension (CD) control. At the same time, lithography companies are striving to increase the usable image field size. The problem for reduction steppers, however, is that the goals of large image field and high resolution are difficult to achieve simultaneously.

Members of the industry wryly observe that today's wide-field lens systems have reached the physical size of a fire hydrant or even a small keg of beer!

For a reduction stepper system, increasing the lens image field size for a given numerical aperture (NA) requires the use of larger-diameter lens elements and/or more individual elements in the lens design. In either case, increasing the lens image field results in a total lens system that is both larger and more complex. Members of the industry wryly observe that today's wide-field lens systems have reached the physical size of a fire hydrant or even a small keg of beer! Lens manufacturing difficulties increase significantly with the move to wide-field lenses because lens aberrations and distortions are a function of both the lens element diameter and the image field diameter.

At the same time that the field size of a lens is being increased, stepper manufacturers are also increasing lens resolution. Lens resolution can be improved by employing a higher NA lens or by using a shorter wavelength light source. To improve resolution by increasing the NA compounds the lens manufacturing dilemma by again increasing the lens diameter, which in turn drives up lens distortions. The move to a shorter wavelength light source will also

Table 1
I-Line and Excimer/Deep UV Wide-Field Stepper Systems

Company	Year Intro	Stepper Model	Reduction	Wave Length	Circular Lens Diameter (mm)	Field Size (mm × mm) Largest Square	Largest Rectangle	Numerical Aperture	Resolution (Microns)
ASM Lithography	1991	PAS 5500/20	5x	365nm	29.7	21 × 21	27.4 × 11.5	.40	.70
ASM Lithography	1991	PAS 5500/60	5x	365nm	25.5	18 × 18	24.2 × 8	.54	.45
ASM Lithography	1991	PAS 5500/80	5x	365nm	29.7	21 × 21	27.4 × 11.5	.48	.50
ASM Lithography	1991	PAS 5500/90	5x	248nm	29.7	21 × 21	27.4 × 11.5	.50	.35
Canon	1990	FPA-2000i1	5x	365nm	28.2	20 × 20	22.5 × 17.1	.52	.50
Canon	1991	FPA-2500i2	5x	365nm	31.1	22 × 22	26 × 17	.54	.45
Canon	1991	FPA-2500i3	5x	365nm	28.2	20 × 20	22.5 × 17.1	.60	.35
Canon	1991	FPA-3000EX1	5x	248nm	28.2	20 × 20	unrestricted	.45	.40
GCA	1991	XLS 7250	4x	365nm	25.0	17.7 × 17.7	23.7 × 7.9	.50	.50
GCA	1991	XLS 7300	4x	365nm	28.2	20 × 20	25 × 13.3	.50	.50
GCA	1991	XLS 7600	4x	248nm	28.2	20 × 20	25 × 13.3	.50	.35
Hitachi	1990	LD-5015iCW	5x	365nm	24.8	17.5 × 17.5	21 × 13	.50	.50
Nikon	1991	NSR-2005i8A	5x	365nm	28.2	20 × 20	20.4 × 19.2	NA	.50
					30.0	21.2 × 21.2	25.2 × 15.9	NA	.50
Nikon	1990	NSR-1755EX8A	5x	248nm	24.8	17.5 × 17.5	20.1 × 13.4	NA	≤ 0.45
Nikon	1991	NSR-2005EX8A	5x	248nm	28.2	20 × 20	20.4 × 19.2	NA	≤ 0.40
					30.0	21.2 × 21.2	25.2 × 15.9	NA	≤ 0.40
SVG Lithography	1989	Micrascan I	4x	240-255nm	NM	NM	20 × 32.5	.357	.50
Ultratech	1991	M2020i	1x	365nm	NM	20 × 20	34 × 15	.32	.80
Ultratech	1991	M2244i	1x	365nm	NM	27 × 27	22 × 44	.32	.80

NA = Not available
NM = Not meaningful
Source: Dataquest (November 1991)

improve resolution but contributes its own unique set of problems brought about by a different optics system and resist chemistry. These problems, coupled with tighter specifications on field curvature and other parameters, result in a dizzying set of challenges for the lens-manufacturing community.

For Ultratech Stepper, the move to wide-field steppers has been more straightforward than for the reduction stepper companies. To achieve a wider field size on a 1x stepper, the relatively few elements of the optical configuration are scaled up in size. No additional optical elements need to be added.

Trends in DRAM Die Sizes

The highly competitive DRAM market reflects the largest commodity device market in the semiconductor industry. To achieve profitability in DRAMs requires that zealous attention be paid to controlling manufacturing costs. In addition to being a manufacturing cost driver, DRAMs also drive lithography technology for producing increasingly smaller patterns. The move to wide-field lenses, thus, has particular impact on DRAM manufacturing because wider fields can accommodate the larger die sizes of advanced DRAMs and can image multiple die per exposure for improved throughput. For example, only a single 16Mb DRAM can be imaged in a standard 15mm × 15mm image field, whereas three 16Mb chips can be imaged in a 20mm × 20mm wide-field system.

Table 2 identifies average DRAM die sizes for the 16Mb, 64Mb, 256Mb, and 1Gb devices. The die sizes for the 16Mb and 64Mb reflect actual product announcements made at ISSCC conferences in 1989 and 1990. The estimates of die size area for the 256Mb and 1Gb DRAM listed in Table 2 are based on industry estimates.

Table 2 illustrates the long-held view that DRAM die sizes are increasing approximately 50 percent in area per generation.

Uncertainty Ahead

Lithography companies have a clear understanding of the tasks they face for the development of lithography tools for the 64Mb DRAM. However, some serious concerns exist in the lithography community about how to manufacture reduction optics to achieve the field sizes necessary for the 256Mb DRAM generation and beyond. At Dataquest's Korean semiconductor conference in September, Mr. Yoshida of Nikon remarked that it is not clear if optical lens designers will be able to manufacture lenses of sufficient quality much beyond the anticipated 25mm × 25mm field size of the 256Mb DRAM. Some of the alternative strategies being explored that can deal with the larger field sizes required for advanced DRAMs include the following:

- Stitching—In this technique, sections of a single chip are imaged and exposed at partial dosage rates. This procedure is repeated several times to build up a fully exposed chip pattern. This technique has been under discussion for several years, but Dataquest believes that there will be a natural reluctance on the part of semiconductor manufacturers to consider field stitching until all other alternatives have been exhausted.
- Step-and-scan lithography—Currently, SVG Lithography is the only manufacturer of step-and-scan lithography equipment. It is rumored, however, that other stepper vendors are exploring the development of such technology. Step-and-scan lithography is anticipated to achieve field sizes of 20mm × 50mm. The technology, however, is both costly and complex to develop.

Table 2
DRAM Die Size—16Mb through 1Gb

DRAM Density	Average Length (mm)	Average Width (mm)	Approximate Area (Square mm)
Product Announcements			
16Mb	17.2	7.9	135
64Mb	19.8	11.0	200-220
Industry Estimates			
256Mb	NA	NA	300-325
1G	NA	NA	450-480

NA = Not available
Source: ISSCC, Dataquest (November 1991)

- 1x stepper lithography—One of the advanced stepper technologies under development is the Markle-Dyson 1x technology from Ultratech Stepper. This technology, utilizing a deep-UV source, is targeted at 0.25-micron manufacturing. The nature of the 1x optical configuration allows for wide fields to be achieved with relative ease compared with reduction optics.
- X-ray lithography—These tools have been designed with large field sizes in mind. Hampshire Instruments' Model 3500 has an initial field size of 22mm × 22mm, which is expected to increase to 27mm × 27mm in the next-generation design of the system. Sumitomo Heavy Industries has recently developed an X-ray vertical-exposure system with a range of 25mm × 25mm. This exposure system, targeted at 256Mb DRAM production, uses synchrotron orbital radiation (SOR) as its source and will be used in conjunction with the Aurora superconductive SOR system.

One factor that still is not clearly understood is how future packaging strategies will impact die sizes. One of the fundamental factors that has influenced the die sizes of DRAMs has been the restriction of fitting into a standard 300-mil package. This packaging has dictated the well-known rectangular dimensions of today's DRAM. Future packaging strategies, such as lead-on-chip and multichip modules, may well loosen up specifications on die size because for some portion of the device product mix, individual chips will no longer need to fit into an individual package. Changes in packaging strategies that affect changes in die sizes may, in turn, potentially affect the requirements for wide-field lithography in the future.

Dataquest Perspective

Today's advanced lithography equipment represents the most technologically complex piece of hardware on the fab floor. Regardless of which technology is employed, ultimately, lithography products are judged on technical merits and tool performance. Resolution, depth of focus, alignment, and CD control have been the traditional measurements of advanced lithographic processing. In the 1990s, wide-field capability must be added to the list. ■

By Peggy Marie Wood

Market Analysis

A Renaissance in High-Tech Plumbing

Bulk chemical distribution technology, pioneered in Japan, is quickly being adopted in the U.S., Asia/Pacific, and European semiconductor industries. These systems are replacing bulk-to-bottle methods because of advantages in purity—especially particulate control—cost, and safety.

In Japan bulk chemical distribution equipment is sold by the large diversified chemical suppliers, whereas in the United States and Europe small equipment companies have pioneered the development of this technology (see Table 1) for the most part. However, structural changes and competitive pressures in the global electronic chemical business may soon force the U.S. and European chemical industries to move closer to the Japanese model.

Market Size

The size of the chemical distribution systems market is tied very closely to capital spending for new fabs. Dataquest estimates the 1991 market to total between $67.4 million and $106.6 million (see Table 2). Market size is based on the assumption that spending on chemical distribution systems will range between $1.5 million and $3.0 million for a production fab and $0.5 million to $1.1 million for a pilot line.

Our analysis does not include retrofits of existing facilities. A retrofit is defined as installing a chemical distribution system around an existing process line. Historically, chemical distribution systems have not been sold into retrofit applications, although we believe that this is a potential future upside opportunity for vendors.

Because our analysis is based on new fabs, we have forecast the market out only two years. The confidence factor for new fab construction falls off dramatically past 1993. There appears to be little growth in the worldwide market for the next several years because of the slow pace of new fab construction. Furthermore, many Japanese device makers recently announced capital spending cuts that may delay their plans for new fabs. Consequently, our current estimates for Japan may be optimistic.

Table 1
Companies Manufacturing Chemical Distribution Systems, by Region

Japan	United States	Europe
Kanto Chemical	Applied Chemical Solutions	Fell Group
Sumitomo Chemical	CFM Technologies	Hoechst
	FSI International	L'Abeille
	Integrated Design	E. Merck Electronic Chemicals
	MEGA Systems & Chemicals	Sapi Equipment
	Santa Clara Plastics	Vinylglass Limited
	SCI Systems	
	Semiconductor Process Equipment	
	Stainless Design Corporation	
	Systems Chemistry	
	Universal Plastics	

Source: Dataquest (November 1991)

Table 2
Estimated Chemical Distribution Market Size

	New Fab Lines		Market Size (U.S.$M)	
	Production	Pilot	Low	High
		1991		
Japan	15	7	34.9	52.7
United States	7	1	11.0	18.2
Europe	3	0	4.5	7.5
Asia	11	1	17.0	28.2
Total			67.4	106.6
		1992		
Japan	20	6	44.2	66.6
United States	6	1	9.5	15.7
Europe	4	0	6.0	10.0
Asia	5	0	7.5	12.5
Total			67.2	104.8
		1993		
Japan	11	0	22.0	33.0
United States	6	1	9.5	15.7
Europe	3	0	4.5	7.5
Asia	5	0	7.5	12.5
Total			43.5	68.7

Source: Dataquest (November 1991)

Companies

Japanese companies Kanto Chemical and Sumitomo Chemical are the major players in the Japanese chemical distribution equipment market (see Table 1). They are also the two largest companies in the world supplying chemical distribution systems. Dataquest estimates that Kanto's sales totaled $19 million and that Sumitomo's sales totaled $11 million in 1990. Both companies are vertically integrated and supply chemicals and chemical distribution equipment to the semiconductor manufacturers in Japan.

Kanto and Sumitomo are also migrating overseas, following Japanese device makers building fabs around the world. Both companies have won business in the United States; Sumitomo is working with NEC Corporation in Roseville, California, and Kanto with Sony in San Antonio, Texas. Kanto is also in a joint venture with E. Merck Electronic Chemicals in Germany.

The United States has a number of small equipment companies supplying chemical distribution systems. However, two companies dominate this relatively small segment of the semiconductor equipment market. FSI International has the largest installed base of equipment. In 1990, it sold approximately $8.5 million in chemical distribution systems worldwide. The next largest company is Systems Chemistry, which has a much smaller base of installed equipment but is building momentum. Its 1990 worldwide sales totaled $4.0 million. Systems Chemistry has also won business in the Asia/Pacific market.

The majority of suppliers in the United States and Europe are small and typically accounted for less than $1 million in chemical distribution system sales in 1990. The number of companies participating reflects that the semiconductor industry is in the early stages of adopting chemical distribution technology. In fact, IBM Corporation is still putting its own systems together in-house rather than buying commercially available systems. It is conceivable that a breakthrough in system design could easily push one of these smaller companies into a leadership position. However, the market size will not support this many players over the long term. Industry consolidation is definitely in the cards.

Consolidation

Historically, the chemical industry outside of Japan has not kept pace with changing requirements of the semiconductor industry. Lack of investment in leading-edge technology can be attributed largely to U.S. device companies placing little emphasis on wet process technology through most of the 1980s. They chose to rely on dry etching/cleaning technology in planning their future processes.

The Japanese took a different route. Chemical distribution systems evolved from the Japanese device manufacturers' efforts to extend the life of wet process technology. Distribution systems helped to improve the purity of the chemicals supplied to the wet process equipment. The idea was eventually picked up by U.S. device makers in the later half of the 1980s.

Encouraged by the device makers, a number of small U.S. and European equipment suppliers made the first wave of investment in bulk chemical delivery technology. Dataquest believes that a second wave of investment is on the horizon. We believe that a number of the large chemical/gas suppliers selling to the semiconductor industry (see Table 3) will make investments in or acquire some of the smaller companies.

Perhaps the most compelling argument driving a second wave of investment is a trend toward on-site management of materials. As chemical/gas specifications move into the parts-per-trillion regime, device makers are under growing pressure to relinquish management of chemical/gas distribution systems because the level of expertise needed to run these systems is climbing. This is an opportunity for the materials vendor. On-site management contracts provide another source of revenue for materials suppliers. Moreover, these contracts provide materials companies with an opportunity to differentiate themselves from their competitors. A company with

Table 3
Potential Acquirees of Companies Supplying Chemical Distribution Systems

Company	Industry
Air Products	Industrial Gas
Airco	Industrial Gas
Ashland Chemical	Chemical
BOC	Industrial Gas
LaPorte	Chemical
Liquid Air	Industrial Gas
Olin Hunt	Chemical

Source: Dataquest (November 1991)

a service organization having a broad breadth of material handling know-how is not forced to compete strictly on price and product specifications for on-site management contracts.

U.S. chemical suppliers may feel an additional pressure to bring chemical distribution technology in-house. The U.S. electronics chemicals industry will experience mounting competitive pressures as Japanese vendors such as Kanto and Sumitomo increase their presence in the U.S. market. Both Japanese vendors are fully integrated and supply both chemicals and chemical distribution systems. They are supplying Japanese fabs located in the United States. Eventually, they will look to penetrate U.S. fabs in order to build their base of business. Dataquest expects U.S. chemical vendors to move defensively and acquire bulk chemical distribution product lines by purchasing some of the small equipment vendors.

Dataquest Perspective

Chemical distribution systems are evolving. The number of companies participating in this equipment segment is a barometer of the range of system designs being offered. But market forces will become a more important driver as device makers become more familiar with chemical distribution technology and as this technology is more widely adopted. Dataquest believes that this shift is not too far off and will be recognized when some of the large materials vendors begin acquiring the small equipment companies in order to support the materials vendors' growing service organizations. ■

By Mark FitzGerald

Semiconductor Manufacturing

Is A Revolution Brewing in the Semiconductor Industry?

Dataquest believes that the rapidly escalating costs of submicron technology development and manufacturing will lead to fundamental changes in the semiconductor industry structure in the decade ahead. A convergence of independent market forces such as escalating fab costs, divergence between DRAM and ultralarge-scale integration (ULSI) logic process technology, emergence of industry-standard open systems architectures and merchant CAD tools, and shortened product life cycles may result in a dramatically different semiconductor industry structure that will have far-reaching implications up and down the electronics industry food chain. In this article, Dataquest examines some of the key forces shaping this impending semiconductor industry revolution.

How Will Key Pieces of the Semiconductor Market Pie Grow?

Figure 1 shows the relative proportions of the worldwide IC market in 1990 and 1995. MOS memories, based on traditional megafab production strategies, have been the catalyst behind escalating costs of advanced wafer fab facilities. However, MOS microcomponents—including microprocessors, microperipherals, and application-specific standard products (ASSPs)—and MOS logic—including ASIC—will grow at a faster compound annual growth rate (CAGR) between 1990 and 1995, compared with MOS memory. The increasingly fragmented, application-specific nature of the MOS microcomponents and MOS logic business may require a different semiconductor manufacturing strategy than the monolithic MOS memory business.

Escalating Wafer Fab Costs

Wafer fab equipment average selling prices (ASPs) have skyrocketed dramatically in the last five years. For example, stepper ASPs jumped from $800,000 in 1986 to $1.4 million per unit by 1990. Chemical vapor deposition reactors jumped from $400,000 in 1986 to $850,000 per unit by 1990. A typical 1Mb, 6-inch DRAM fab (20,000 wafers per month) cost approximately $200 million in 1988. An equivalent-capacity 256Mb, 8-inch DRAM fab may cost $1 billion by the year 2000.

A recent study by the National Agency for Competitiveness in Semiconductors suggests rapid consolidation in the megafab business to a point where only 10 to 15 megafabs the world over can be economically viable for leading-edge 0.25-micron, 256Mb DRAM production by the year 2000. Even long-term-oriented Japanese DRAM manufacturers are reexamining megafab return-on-investment issues and may scale down their DRAM fab investments in the face of increased competition and commodity-style price pressures.

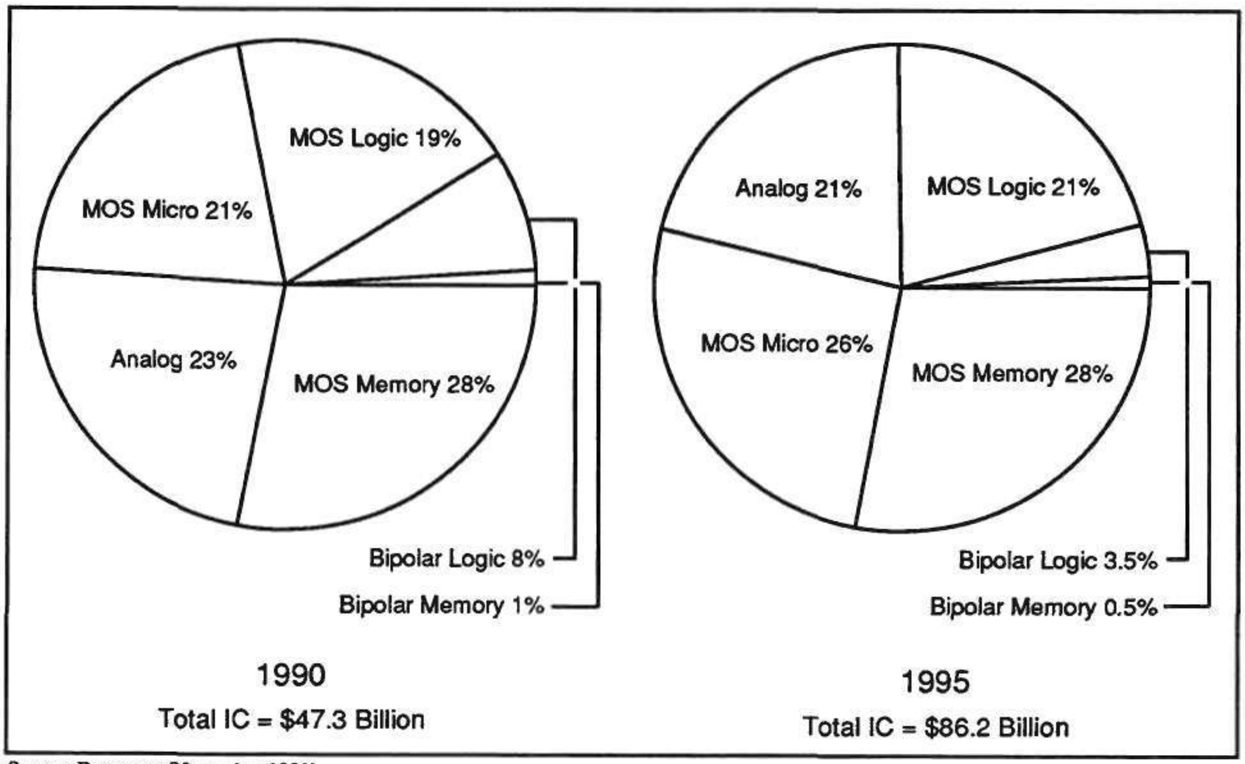
Divergence of DRAM and ULSI Logic Process Technologies

DRAMs drive transistor packing density. For example, the number of transistors on a DRAM chip has increased by a factor of 225 from approximately 20,000 transistors on a 1980-generation 16K DRAM to 4.5 million transistors on a 1990-generation 4Mb DRAM. DRAM process technologies have emphasized silicon-level transistor device scaling and memory cell-size issues because of the constant need to cram four times the DRAM bits into a chip size that is allowed to increase by 50 percent, at best, between successive DRAM generations because of production costs and yield issues. Submicron lithography techniques, three-dimensional trench, and stacked capacitor cell schemes have evolved in response to the need for small cell sizes. Because of the regular layout of a DRAM core array, the interconnect process for the word-line and bit-line access is relatively straightforward.

Electronics industry product life cycles are rapidly shortening because of market forces such as increased pace of technology development and increased competition.

ULSI logic devices such as 500K CMOS gate arrays, 32-bit microprocessors, and ASSP chip sets drive multilevel interconnect technology.

Figure 1
Worldwide Merchant IC Revenue, by Segment



Source: Dataquest (November 1991)

The number of transistors has increased only by a factor of 30 from 40,000 on a 1980-generation Intel 8086 8-bit microprocessor to 1.2 million transistors on a 1990-generation Intel 80486 32-bit microprocessor. However, the number of interconnect levels has grown dramatically from single-level metal 8-bit microprocessors to triple-level metal 32-bit microprocessors and even four-level metal million-gate CMOS gate arrays. In most ULSI-level random logic applications, gate utilization is limited by place-and-route design factors and bonding pad pitch limitations. Thus ULSI logic semiconductor companies will lead the interconnect technology pack by resorting to advanced techniques such as four-, five-, and six-level interconnects, multichip modules, and fine-pitch bonding technology.

Fragmenting Markets and Shortened Product Cycles

Electronics industry product life cycles are rapidly shortening because of market forces such as increased pace of technology development and increased competition. The fabless semiconductor company has evolved as a new breed that specializes in applications, design, marketing, and quick time-to-market areas. CMOS gate arrays and cell-based embedded gate arrays are being used for their easy design and time-to-market capabilities. As industry standards and competition evolve, the second-generation product is optimized as a silicon area-efficient, high-performance ASSP device. Rather than megafabs, flexible application-specific minifabs performing interconnect customization on masterslice prediffused base wafers are more viable manufacturing routes for value-added customized ASSPs. Is it conceivable that future PC and workstation companies will build their own interconnect minifabs to customize industry-standard ASSP building blocks?

Emergence of Open Architecture and Multiple Source Licensing

Emergence of open architecture RISC microprocessor standards such as Sun SPARC, MIPS R4000, and IBM/APPLE POWER OPEN suggests future semiconductor manufacturing strategies based on value-added customization of base masterslice wafers from multiple foundry sources. Emergence of open architecture and industry standards in other semiconductor markets such as graphics, peripherals, LAN/wide area networking, multimedia, wireless personal communications networks, and digital TV/HDTV also suggests value-added customization using geographically dispersed interconnect minifabs close to the customer. Emergence of advanced merchant CAD tools and software will empower systems designers to move closer to ULSI chip design.

Dataquest Perspective

Dataquest believes that fundamental changes will occur in semiconductor industry manufacturing practices over the next five years. There will be a gradual parting of ways between cost-driven, high-volume DRAM megafab technology and time-to-market, medium/low-volume microprocessor and ASSP chip set technology. Base-wafer masterslices with multimillion-transistor chips will become available from multiple foundry sources. Smaller semiconductor companies and fabless semiconductor companies can add value through time-to-market-oriented flexible, low-volume manufacturing in interconnect minifabs that process prediffused base wafers embodying the core ASSP building blocks.

For their part, wafer fab equipment companies can provide enabling solutions by offering cost-effective, flexible, low-volume turnkey production equipment for advanced multilevel interconnect technology processes. Requirements for flexible, low-volume, submicron interconnect equipment will be significantly different than for the traditional DRAM-driven high-volume production equipment. Wafer fab equipment companies offering a turnkey interconnect product and service solution can create a potentially huge market that complements and smoothens their traditional lumpy DRAM-driven business cycles. ■

By Krishna Shankar

New Fab Lines in Europe

The year 1991 has been one of slow economic growth at best. The U.S. economy has been in a recession and may "double-dip" further into negative economic growth. Europe, the scene of rosy forecasts because of the integration of the European Community (EC) countries in 1992, does not look so rosy as 1992 actually approaches. The best that can be said of any of the major countries of Europe is that economic growth is slow and Europeans look for the markets of North America to grow and stimulate demand for their economies.

The semiconductor industry in Europe reflects this uncertainty. Although capital spending for new fabs in 1991 was vigorous, we believe that, because of the current economic uncertainty, capital spending for new fabs will be much less vigorous in 1992.

This article examines recent fab activity in Europe and possibilities for new construction in the near future—and assesses implications of this activity on capital spending in Europe in 1992.

Current New Fab Line Activity

Currently, there are nine fab lines in Europe that either will begin production in 1991 or are in preproduction phases of construction, facilitization, and equipping the fab (see Table 1). Of the nine lines listed, four already have completed construction. Most equipment-buying decisions for these fab lines have been made, although actual purchases and deliveries will occur over a two- to three-year period.

Note that only four of the fabs in Table 1 are entirely owned by European companies. One additional fab (the IBM/Siemens 16Mb DRAM line at Corbeilles, France) is a joint venture between a U.S company and a European company. In other words, four of the nine fabs are owned by offshore semiconductor companies. This fact illustrates globalization in action. Major semiconductor companies want manufacturing facilities close to their major markets. And Europe, with the integration ("harmonization" is the term Europeans are beginning to use) of the EC markets fast approaching and with wealth and population exceeding that of the United States, is indeed a major market.

The Hitachi fab in Landshut, Germany, is reportedly stretching out its equipment order delivery dates. Dataquest believes that the reason for this stretch-out is the soft market for DRAMs worldwide.

New Fab Line Activity in 1992-1993

In addition to four fabs in the preproduction phases of construction, facilitization, and equipping, we believe that two fabs could begin

Table 1
New Fab Lines in Europe
(1991)

Company	Location	Status
ABB-HAFO	Jarfalla, Sweden	Production line (in production)
Fujitsu	Newton-Aycliffe, England	4Mb DRAM production line (in production)
Hitachi	Landshut, Germany	4Mb DRAM production line (equipping)
IBM/Siemens	Corbeilles, France	16Mb DRAM production line (equipping)
Intel	Leixlip, Ireland	32-bit MPU production line (under construction)
Mietec	Oudengaarde, Belgium	Production line (construction 1991/1992)
Quodos	Sheffield, England	Fast-turn metalization fab (in production)
SGS/Thomson	Grenoble, France	Developmental line (under construction)
Texas Instruments	Avezzano, Italy (Phase 1)	4Mb DRAM production line (equipped for production)

Source: Dataquest (November 1991)

Table 2
Possible New Fab Lines in Europe
(1992-1993)

Company	Location	Status	Probability
Matra MHS	Nantes, France	Production line (construction 1992)	High
Mitsubishi	Alsdorf, Germany	DRAM production line (construction 1992)	Medium to High
Texas Instruments	Avezzano, Italy (Phase 2)	DRAM production line (construction 1993)	Medium to High

Source: Dataquest (November 1991)

construction in 1992. We also believe that one more fab line could begin to be equipped in 1993 (see Table 2). These plans for 1992 and 1993 are not yet officially announced. They represent Dataquest's best estimate of probable future fab activity based on informal discussions with clean room construction companies and semiconductor companies.

Clearly, there is not much new fab activity to look forward to in 1992. Dataquest has a high level of confidence that the Matra fab will begin construction in 1992. However, the Mitsubishi fab in Alsdorf, Germany, has had its construction start delayed for at least nine months, and it is possible that actual construction could be delayed even longer, if soft business conditions continue in the DRAM market. Market uncertainty, particularly in DRAMs, has also delayed equipping of Phase 2 of Texas Instruments' Avezzano fab in Italy. Originally, Phase 2 was scheduled to begin at the end of 1992.

Spending by European companies on new fabs in 1992 and 1993 is likely to be less than spending by offshore semiconductor manufacturers because the facilities of Mitsubishi and Texas Instruments will be large DRAM facilities.

Thus, these facilities will represent a proportionately higher percentage of equipment spending.

Dataquest Perspective

As judged by the number of new fabs either coming on-line or likely to be built next year, 1992 does not look like a good year for new capacity spending in Europe in comparison with 1991. Indeed, given the current business uncertainty, even fabs beginning production are being ramped at such a slow rate that new equipment sales are pushed back. Semiconductor manufacturers are waiting for business conditions to improve. Dataquest's current worldwide semiconductor consumption forecast calls for 6.2 percent growth in the fourth quarter of 1991 and weak 0.7 percent growth in the first quarter of 1992. Beginning in the second quarter, we expect steady growth in semiconductor demand. We believe that when that happens, instead of pushing orders back, semiconductor manufacturers could well pull orders forward as they accelerate production ramps.

With integration (or harmonization) of the EC markets into one integrated market, Europe will continue to be a magnet for systems manufacturers and semiconductor companies.

We also believe that the slowdown of new DRAM fab activity in Europe reflects semiconductor manufacturers' uncertainty about the life cycle of advanced DRAMs. Hitachi, Mitsubishi, and Texas Instruments have pushed back start dates of their new 4Mb DRAM facilities.

With integration (or harmonization) of the EC markets into one integrated market, Europe will continue to be a magnet for systems manufacturers and semiconductor companies. Offshore manufacturers from Japan and the United States—and, possibly, Korea—will continue to build in Europe. The question is: Will European companies be able to match them? We believe that European manufacturers currently account for 65 percent of all semiconductor production in Europe. Will European companies eventually become minority shareholders of the semiconductor manufacturing base in their own region? ■

By George Burns

Company Analysis

SemiconductorEquipment Companies: Strong Start for 1991 but a Weak Finish

Table 1 compares the performance of 15 public U.S. and European semiconductor equipment companies for the first six months of 1991 versus the first six months of 1990. Sales in the first half of calendar year 1991 started out fairly well for most companies listed; and, for the 15 companies all together, 1991 sales were up 15 percent over 1990. However, orders started to slow in the second quarter of 1991 as semiconductor manufacturers began to delay placing orders and to push out delivery of already-placed orders. Dataquest believes that, in most cases, sales were maintained in the second quarter of 1991 by drawing down backlogs. For instance, Applied Materials and Varian Associates—two larger semiconductor equipment companies—had backlogs that declined by 14 percent and 30 percent, respectively, during this period.

Dataquest Perspective

Semiconductor manufacturers are announcing plans to cut back on capital spending for 1992. Several say they have sufficient capacity for the near term. We are now in the fourth quarter of 1991, and semiconductor equipment companies are still reporting soft order rates and near-term uncertainty in the marketplace.

Dataquest believes that the next six months will be crucial to the prospects of any marginal equipment companies in the semiconductor industry.

Because of declining orders, equipment companies will have to either continue drawing down their backlogs, if they have a sufficient backlog cushion, or reduce their sales. Reducing sales will negatively affect profits, however, and

Table 1
Semiconductor Equipment Companies Performance Comparison (January - June)

	Sales First 6 Months of 1990	Sales First 6 Months of 1991	Sales 1991/1990 Percent Change	Net Income First 6 Months of 1990 ($M)	Net Income First 6 Months of 1991 ($M)
Front-End Companies					
Applied Materials[1]	287	333	16	20.0	15.7
ASM International	101	131	30	-0.7	3.7
BTU International	35	26	-26	-1.5	-4.4
Cognex	11	15	34	2.9	4.3
FSI[2]	27	24	-11	-1.1	-1.3
Genus	31	27	-12	-4.3	-2.1
KLA Instruments	81	77	-4	4.3	0.8
Lam Research	66	75	13	-13.4	3.5
Machine Technology[2]	11	16	51	0.4	1.8
Novellus	32	39	22	6.7	8.2
Plasma-Therm[2]	16	12	-27	0.8	-0.6
Varian	154	206	33	NA	NA
12 Companies' Total	852	981	15	14.1[3]	29.6[3]
Back-End Companies					
Kulicke and Soffa	52	50	-3	-0.4	0
LTX[1]	79	106	34	9.8	3.5
Teradyne	222	248	12	-11.6	-3.8
3 Companies' Total	353	404	15	-2.2	-0.3
All 15 Companies' Total	1,205	1,385	15	11.9[4]	29.3[4]

[1]Feb-July 6-month period
[2]Dec-May 6-month period
[3]Total for 11 companies
[4]Total for 14 companies
NA = Not available
Source: Company Reports, Dataquest (November 1991)

many companies listed in Table 1 are already at unprofitable levels.

For the 14 companies listed in Table 1 (Varian does not publicly disclose net income for its equipment operation), the ratio of net income to sales for the first half of 1991 was only 2.5 percent, a very low aggregate industry profit level. In fact, only a few companies listed in the table are at acceptable rates of return.

Dataquest believes that the next six months will be crucial to the prospects of any marginal equipment companies in the semiconductor industry. Thus, if orders do not soon turn up for these struggling companies, we are likely to see further cost-reduction measures beyond what has already taken place in the industry. ■

By Joseph Grenier

News and Views

Investment in Photoresist Climbs

Sumitomo Chemical completed its Phase 1 Osaka photoresist plant expansion in October 1991. Phase 2 will be completed in the spring of 1992. The estimated capital spending for both phases is between ¥5 billion and ¥6 billion. Sumitomo photoresist plant capacity will increase from ¥2 billion in revenue to ¥9 billion at the completion of Phase 2. The company's business plan calls for its photoresist business to total ¥15 billion by the year 2000.

The Japanese photoresist market is dominated by one company: Tokyo Ohka Kogyo. But JSR and Sumitomo Kagaku are increasing their market shares in advanced products such as i-line resist used to make the 4Mb DRAM. Sumitomo has already evaluated photoresist for the 16Mb DRAM and started sample supply.

Sumitomo is exporting to Korea, Europe, and the United States. Exports accounted for 20 percent of its sales in 1990. By the year 2000, the company expects exports to account for 30 percent of its photoresist business.

OCG is investing $12.4 million to expand production of polyimides and photoresist in Europe at a new facility is Zwijndrecht, Belgium, west of Antwerp. The new building will occupy an area of 4,180 square meters, and approximately 50 people will be employed there.

Toray Dow Corning has started volume production of 64Mb DRAM photoresist. It is a negative-type resist used for excimer and e-beam applications, and current shipments are 10 gallons per month. NEC is assisting the company in evaluating the material.

Finally, Tokyo Rika University has developed a negative-type e-beam resist, which, it claims, has four to five times better resolution than conventional e-beam resists. ■

By Kunio Achiwa (Tokyo)

Semiconductor Industry Conference: The Focus Is on Applications

Departing from previous practices, the 17th annual Dataquest Semiconductor Industry Conference (October 14 and 15, 1991) broke new ground this year by combining into a single forum representatives from semiconductor equipment companies, semiconductor device manufacturers, and semiconductor users. The discussion here will not track each presentation in a comprehensive manner, but rather it will highlight some key points that kept recurring throughout the conference proceedings.

A New Way of Looking at Electronics

This year's semiconductor industry conference seemed to be the occasion for much soul-searching on the part of industry participants. Once again, the industry appears to be on the threshold of a new era in microelectronics. As we heard in many of the conference speeches, as the once distinct application areas of data processing, communications, and consumer start to converge, concerns arise that the fundamentals for competing in the semiconductor industry will shift again and that some segments of the industry will find themselves outpaced in the race for the mass markets.

The U.S. electronics industry has been under extreme competitive pressure, having witnessed its once preeminent positions in semiconductor equipment and devices decline as Japanese competitors overtook U.S. companies. Heightened global competition has brought once seemingly invincible systems companies to the forefront as the vanguard for the anticipated next onslaught. Against the current backdrop of soft semiconductor demand, increasing company revenues, but disappointing profitability levels, companies are concerned about what the future can bring to stimulate earnings. In such a capital-intensive business, adequate returns are a prerequisite to enable semiconductor companies to continue investing. Pressure is mounting as companies strive to position themselves to ensure their participation in the next industry upswing.

Today the spotlight is focused on the computer industry. Change is happening at a rapid rate in this industry, where profit levels are currently under pressure. Turmoil and apparent confusion in the industry are causing users to think very carefully about their computer-buying decisions, while U.S.-based and Europe-based computer companies have heightened concerns over their places in the next industry growth phase.

There are profits to be derived from delivering the hardware to the customer, but the question is not just what the piece of equipment should be but, increasingly, who will deliver it. Shifting market dynamics raise the question of whether the future will favor those companies with extensive expertise in computers or those that dominate the channels of distribution. Or will it take carefully managed strategic relationships to combine the requisites from each area?

True Richness of Life

Today's semiconductor user is "awash in chips" and is in fact faced with an excess of technological capability. At least one conference attendee voiced strong convictions about the useful exploitation of so much advanced technology. Marc Canter of MacroMind gave an enthusiastic presentation on the subject of multimedia. His speech echoed many of the ideas that were sprinkled throughout the other presentations. He sees multimedia as the third wave of computing—the first two being text and graphical user interface (GUI). Multimedia will incorporate video, animation, and sound; it will be pen-based, portable, networked, and miniature, and it will have fast SCSI. Multimedia represents the promise of technology delivering true richness of life to the consumer. Mr. Canter was extremely bullish on the host of opportunities that multimedia will bring to semiconductor vendors.

In his presentation, Stagg Newman, assistant vice president of technology at Pacific Telesis Group, reiterated Mr. Canter's view that because people are visual creatures, image communications will add to the richness of life that technology can achieve. Semiconductors are an enabling technology to the 1990s telecommunications trends of personal communications, image communications, and distributed processing. It is also Dataquest's position that communications applications may well be one of the most lucrative opportunities for semiconductor companies in the next several years. Pacific Telesis believes that the enabling technologies of digitization, speech and image processing, fiber optics, and intelligent control will fuel an explosive growth in voice, data, and visual telecommunications during the 1990s, both tethered and tetherless.

Dataquest Perspective

In his presentation reviewing Dataquest's expectations with respect to electronic equipment production trends driving semiconductor consumption, Dataquest's Greg Sheppard reiterated Dataquest's contention that the market dynamics are undergoing a shift in value added and that the driving applications for semiconductor consumption will have as their target the consumer.

Despite the fact that the electronics industry is maturing, Dataquest still sees it as an industry offering many application opportunities. Table 1 lists the opportunities that Dataquest predicts will drive semiconductor consumption on a regional basis.

With the boundaries between what constitutes a data processing application and what constitutes a consumer application getting ever more fuzzy, Gene Norrett of Dataquest exhorted U.S. companies to look to the consumer market for future prosperity. Mobility and miniaturization

Table 1
Regional Market Drivers

Europe	Japan	North America	Asia/Pacific
ISDN	Video/multimedia	Networking	Consumer
Cellular/PCN	Cellular/PCN	Portable PC	Peripherals
Automotive	ISDN	Workstation/servers	Portable PC
PC/peripherals	Factory controls	Multimedia	Communication
Consumer	PC	ISDN	Automotive
		Cellular/PCN	

Source: Dataquest (November 1991)

are driving forces in the semiconductor industry. Expertise in marketing and distribution is as important as, if not more important than, the product. ■

(This article is excerpted from a larger article and reprinted with permission of Dataquest's Semiconductors Worldwide service.)

By Patricia Galligan

In Future Issues

The following topics will be featured in future issues of Semiconductor Equipment, Manufacturing, and Materials *Dataquest Perspective:*

- Semiconductor capital spending forecast
- Wafer fabrication equipment forecast
- Silicon forecast

The topics covered by SEMM newsletters are selected for their general interest to SEMM clients, which include wafer fab equipment suppliers, semiconductor materials companies, and semiconductor device manufacturers. The topics selected indicate the broad range of research that is conducted in the SEMM group. Clients, however, often have specific information requirements that either go beyond the level of detail contained in the newsletters or beyond the scope of what is normally published in the articles. In order to provide complete decision support to our clients, Dataquest has a consulting service available to handle these additional information needs. Please call Stan Bruederle at (408) 437-8272 or Joe Grenier at (408) 437-8206 to discuss your custom requirements.

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Dataquest Perspective

Special Edition

October 28, 1991

Market Analysis

0011610

Market Analysis

Worldwide Semiconductor Industry Forecast: Fourth Quarter 1991

Summary

Dataquest expects the worldwide semiconductor market to grow 13.5 percent in 1992, up from 9.3 percent growth in 1991, and to further grow 15.7 percent in 1993 (see Figure 1). Recovery of the U.S. economy will stimulate worldwide systems production, which in turn will stimulate semiconductor consumption. In the short term, the cyclical upturn of the data processing market will help boost MOS memories' contribution to overall growth and help firm the foundation of microcomponent growth. In the long term, semiconductor market growth will be driven by networking the stock of data processing capability, computer-based graphics, and image-based processing, placing new demands on processing power and the associated complement of memory capacity.

Dataquest's Semiconductor Forecast Methodology

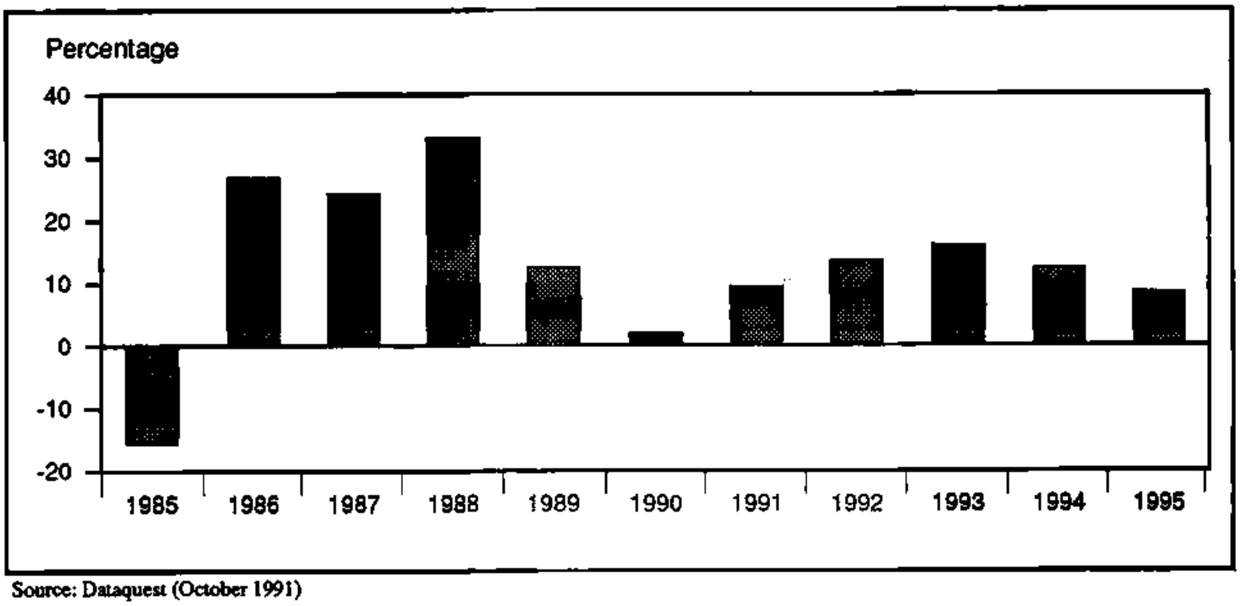
Dataquest's semiconductor forecast methodology leverages the resources of its parent, The Dun & Bradstreet Corporation, as well as the considerable internal resources of Dataquest.

Dun & Bradstreet information is used to develop the macroeconomic forecasts for the world's major economies. This forecast identifies trends in the economic health of the world's leading consumers and producers of electronic equipment. Using this forecast in conjunction with input from Dataquest's regional offices, Dataquest identifies the likelihood of whether a particular region or country will increase or decrease its consumption of electronic equipment.

Dataquest's Semiconductor Applications Market group, along with Dataquest's various electronics systems groups, provides a long-range outlook for the overall growth of the electronic equipment market. Semiconductor content ratios are developed by region to reflect the growing penetration of semiconductors into electronic equipment. This establishes a five-year compound annual growth rate (CAGR) for total semiconductors for a five-year period from a demand-side perspective.

Dataquest's worldwide Semiconductor service and its Semiconductor Equipment, Materials, and Manufacturing service, in conjunction with its various regional offices, collaborate to formulate expectations of semiconductor market short-range fluctuations around the long-range trend. Tactical market issues and anticipated semiconductor materials demand significantly impact the

Figure 1
Worldwide Semiconductor Consumption (Factory Revenue, Dollar-Based Annual Growth)



Source: Dataquest (October 1991)

short-range forecast out to 12 months. Semiconductor equipment purchases and semiconductor device trends drive the forecast in the 12- to 24-month time frame. Semiconductor fab facilities and long-term semiconductor device trends have the greatest impact on the forecast period covering two to five years.

The final step in the forecast process is to reconcile expected fluctuations in the electronics market and trends in the semiconductor industry so that the fluctuations do not inexplicably diverge from semiconductor industry trends. Dataquest anticipates that, in the absence of shocks to the market, market fluctuations converge toward the long-term trend.

Forecast Assumptions

The worldwide economic climate is expected to improve in 1992. The Dun & Bradstreet Corporation forecasts the following outlook for the Group of Seven (G7) countries (see Figure 2):

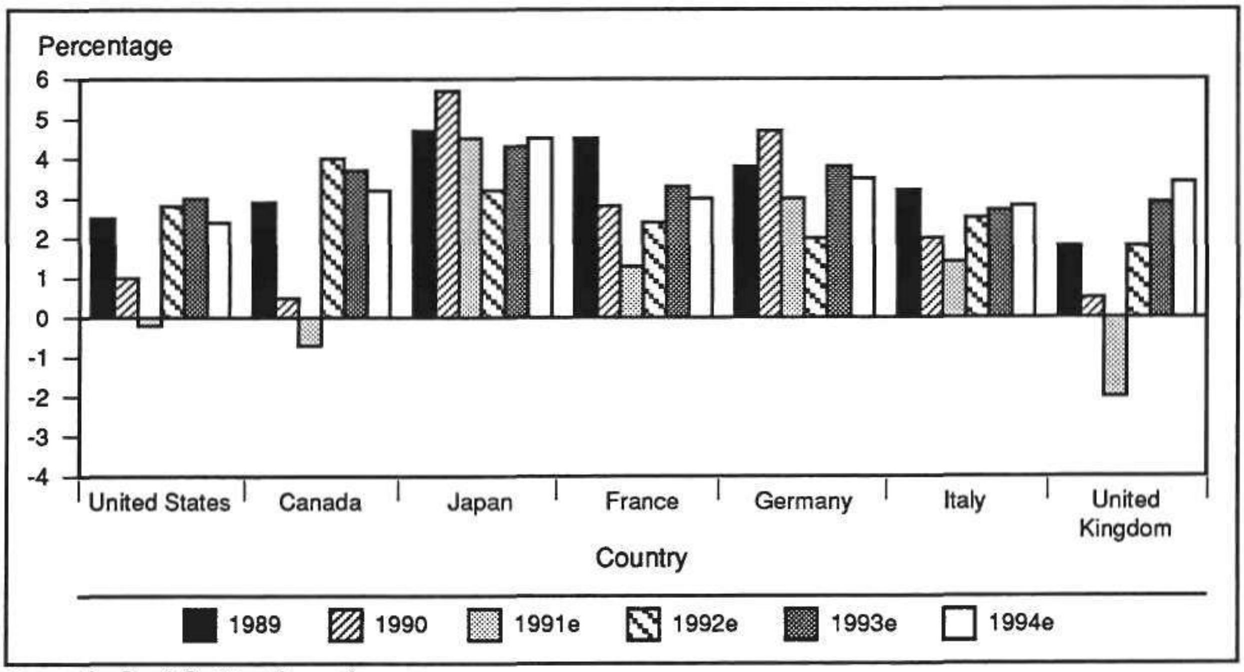
- The U.S., Canada, and U.K. economies will register negative real economic growth in 1991 but recover at rates of 2.8, 4.0, and 1.8 percent real gross national product/gross domestic product (GNP/GDP), respectively, in 1992.
- Real GNP/GDP growth is expected to accelerate in France and Italy during 1992, from 1.3 percent in 1991 to 2.4 percent and from 1.4 percent in 1991 to 2.5 percent, respectively.
- Real GNP/GDP growth is expected to decelerate in Germany and Japan during 1992, from 3.0 percent in 1991 to 2.0 percent and from 4.5 percent in 1991 to 3.2 percent, respectively. The cost burden of Germany's reunification and the rise in Japan's cost of capital are moderating these countries' short-term growth prospects. Both economies are expected to reaccelerate in 1993.

Growth in the G7 economies is expected to converge toward the countries' respective steady-state rates through 1994.

The improved economic prospects bode well for the semiconductor industry outlook, given that computers and related electronic gear represent a significant share of the G7 economies' business fixed investment.

Acceleration of worldwide systems production growth—to 9.0 percent in 1992 from 5.4 percent in 1991—will be accompanied by the

Figure 2
G7 Countries' Estimated Economic Outlook
Real GNP/GDP Growth, Local Currencies



Source: The Dun & Bradstreet Corporation resumption of economic growth (see Figure 3), as shown by the following factors:

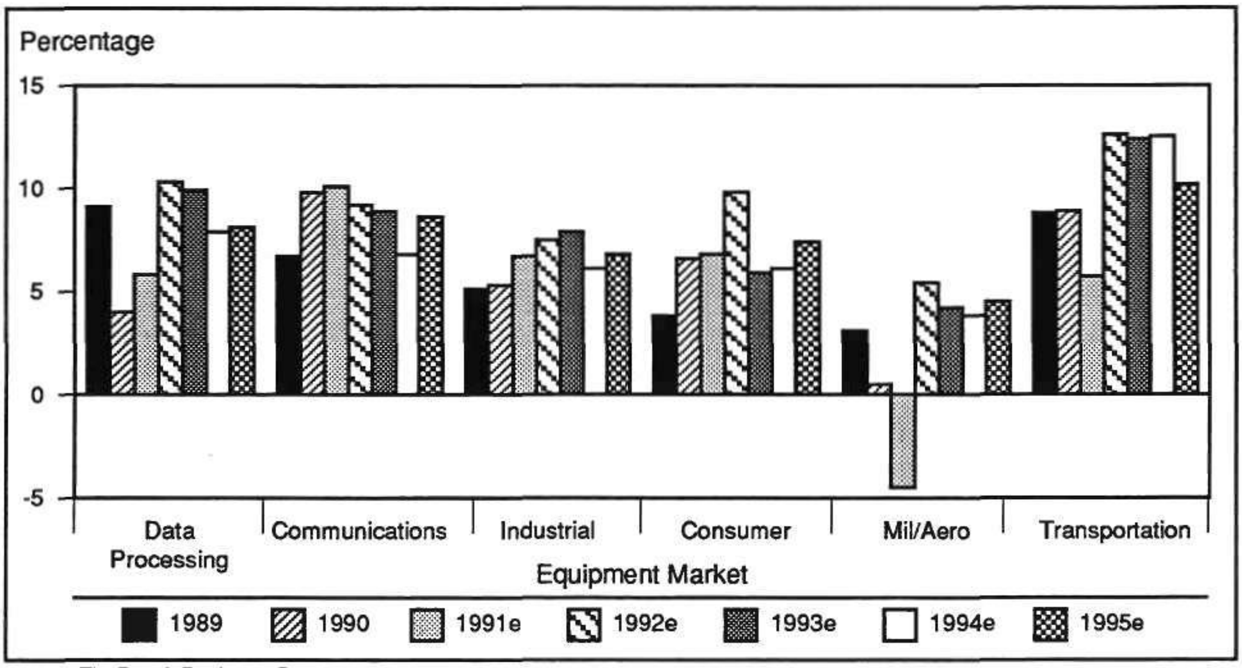
- Business conditions in the data processing and consumer markets are expected to show significant improvement as businesses and households begin to relax their budget constraints
  - Data processing up 10.3 percent in 1992 from 5.8 percent in 1991
  - Consumer up 9.8 percent in 1992 versus 6.8 percent in 1991
- Transportation electronics production growth is expected to more than double—to 12.6 percent in 1992 from 5.7 percent in 1991—spurred by increased consumer spending, combined with increasing share of electronic systems' added value to new vehicles.
- Communications and industrial electronics growth are expected to remain positive and stable. Spending on medical electronics and analytical instruments helped bolster the industrial segment from recession-induced decreased spending on measuring and controlling electronics.
- Military/civilian aerospace electronics was hit hard by Washington budget cuts in 1991, but this segment is expected to resume modest growth (at a permanently lower dollar level) as western defense agencies upgrade existing systems with more sophisticated electronics.

Semiconductor Outlook: Overview

Dataquest expects the worldwide semiconductor market to grow 9.3 percent in 1991 to $63.6 billion, up from $58.2 billion in 1990, and 12.1 percent in 1992 to $72.2 billion (see Table 1). (Note that Table 1 expresses the value and growth of the Japan and Europe markets in local currencies' terms. In addition to valuing the worldwide market assuming *current* exchange rates, the worldwide market is valued in U.S. dollars, assuming *constant* 1990 exchange rates, which removes the effects of exchange rate variation on growth.)

Our October 1991 forecast represents a downward revision to our May 1991 forecast when we forecast the market to grow 13.7 percent in 1991 and 16.6 percent in 1992. *Approximately 65 percent of the revision in 1991 and 50 percent of the revision in 1992 is accounted for by appreciation of the U.S. dollar against the Japanese yen and major European currencies since the May forecast.*

Figure 3
Worldwide Electronics Production
(Factory Revenue, Dollar-Based Annual Growth)



Source: The Dun & Bradstreet Corporation

Table 1
Worldwide Semiconductor Consumption by Region—1990-1995
(Factory Revenue in U.S. Dollars and Local Currencies)

	1990	1991	1992	1993	1994	1995	CAGR (%) 1990-1995
North America ($M)	17,386	18,483	20,728	23,888	26,758	28,816	10.6
Annual Growth (%)	-3.1	6.3	12.1	15.2	12.0	7.7	
Japan ($M)	22,508	25,544	29,524	33,341	37,208	40,232	12.3
Annual Growth (%)	-2.1	13.5	15.6	12.9	11.6	8.1	
Japan (¥B)	3,241	3,501	4,074	4,601	5,135	5,552	11.4
Annual Growth (%)	2.1	8.0	16.4	12.9	11.6	8.1	
Exchange Rate: ¥ per U.S.$1	144.00	137.06	138.00	138.00	138.00	138.00	
Europe ($M)	10,661	10,828	11,556	13,777	15,335	16,368	9.0
Annual Growth (%)	9.3	1.6	6.7	19.2	11.3	6.7	
Europe (EcuM)	8,380	8,890	9,799	11,683	13,004	13,880	10.6
Annual Growth (%)	-6.0	6.1	10.2	19.2	11.3	6.7	
Exchange Rate: Ecu per U.S.$1	0.786	0.821	0.848	0.848	0.848	0.848	
Asia/Pacific-ROW ($M)	7,670	8,792	10,405	12,532	14,486	16,246	16.2
Annual Growth (%)	17.6	14.6	18.3	20.4	15.6	12.1	
Worldwide ($M)	58,225	63,647	72,213	83,538	93,787	101,662	11.8
Annual Growth (%)	1.8	9.3	13.5	15.7	12.3	8.4	
Worldwide ($M in 1990 U.S.$1 Exchange Rates)	58,225	62,899	71,894	83,235	93,446	101,276	11.7
Annual Growth (%)	0.7	8.0	14.3	15.8	12.3	8.4	

Source: Dataquest (October 1991)

Although 1991 is shaping up as a modest-growth year—worldwide market growth averaged 19.1 percent per annum in the 1985 through 1990 period—it is nonetheless a rebound over last year's 1.8 percent growth.

Growth in 1991 was hampered by the following three factors:

- Deeper- and broader-than-expected U.S.-led economic recession
- The recession's growth-arresting affect on computer spending
- Military spending cuts

Growth is forecast to accelerate through 1993 but will be constrained by the relatively moderate rate of overall economic recovery and the effects of saturation and maturity in the relatively developed markets.

Semiconductor Outlook: Regions

North America

The North America systems and semiconductor markets were hit hard by the economic recession of 1991. Both 1992 and 1993 are expected to be years of accelerating growth as businesses resume computer and related equipment spending in an environment of renewed vigor in fixed investment. The following three factors will tend to restrain semiconductor growth below the peak rates experienced in the last decade:

- Two-thirds of desktops have computers on them—After 30 years of innovation and booming sales, there are inevitably fewer opportunities for investment.
- The computer market's share of U.S. capital investment more than *doubled,* from less than 3 percent in 1977 to about 7 percent in

the mid-1980s, but has remained unchanged since then.

- Previously, new systems—those *without* close substitutes—enabled the computer industry to increase its share of capital spending faster than overall investment fell.

These factors should *not* be construed to mean that opportunities for further semiconductor penetration are absent through the forecast horizon. Indeed, the next round of computer and computer-related equipment spending will involve connectivity/networking and higher-level graphics and image-based processing. Both of these areas represent the new frontier for microcomponents and the associated memory complement and for analog and mixed-signal ASIC.

Japan

Japan's growth was hit hard in the first quarter of 1991 by the combined effect of a recession that was already under way in the United States and complicated by the Gulf war. We expect Japan's market to revive in 1992 in response to the resumption of chip and systems export growth to the United States and Europe. Renewed vigor in the computer arena will help firm MOS memories, while advances in camcorders, large-screen TVs, wireless and car telephones, and robot systems designs will boost microcontroller unit (MCU), MOS logic, and analog device growth.

Japanese manufacturers will use the remainder of 1991 to position themselves to take full advantage of the market's upturn in 1992.

Europe

A recession in the United Kingdom plus the reunification-induced drag on the German economy restrained Europe semiconductor market growth in 1991. However, appreciation of the U.S. dollar against the major European currencies masks the true situation of the market: In dollar terms, the market is expected to decelerate to 1.6 percent growth in 1991 from 9.3 percent growth in 1990. In European currency unit (Ecu) terms—a good proxy for a weighted basket of European currencies—market growth is expected to *resume expansion* at a rate of 6.1 percent in 1991 from a 6.0 percent *shrinkage* in 1990 and to accelerate to 10.2 percent growth in 1992.

Improved overall business conditions will help firm up indigenous PC production and consumption in 1992, which will translate into improved prospects for ASICs, microcomponents, and, in particular, MOS memories. In the long term, however, the ASIC market will be fraught with severe average selling price (ASP) pressure stemming from increasing integration and smaller production volumes per design.

Asia/Pacific-Rest of World

Growth in Asia/Pacific-Rest of World (ROW) is and will continue to be fueled by domestic companies' investment, but more importantly from foreign direct investment. The inflow of foreign capital, combined with the relative immaturity of the industry, shields the semiconductor business from the wide swings in activity that tend to rock the other, more established regions. Even so, memory and microcomponent consumption have been severely hurt by the softness of PC business, while analog consumption has felt the pinch of households' curtailed consumer electronics purchases.

Dataquest expects semiconductor consumption growth to accelerate in 1992 and 1993 as the western export markets stimulate data processing and consumer electronics production.

Semiconductor Outlook: Devices

Table 2 presents worldwide detail of the semiconductor device forecast. Volatile pricing make MOS memories the swing factor accounting for year-to-year changes in overall market growth. Microcomponents provide more stable growth in both the short and long term. Overall, worldwide revenue growth is expected to accelerate in 1992 following recovery of the systems markets and peak in 1993. We expect growth to moderate in 1994 and 1995.

Bipolar Digital

The bipolar logic market was hit hard in 1991 by the recession: Businesses postponed major purchases of mainframe and high-end computer equipment, the largest users of these devices. Standard logic, as a share of total bipolar logic, declined at a faster-than-expected rate, also in response to slower-than-expected market conditions.

Compounding the recession's cyclical effects are important structural and technological dynamics: Through 1995, bipolar logic will continue to be replaced by CMOS, BiCMOS, and GaAs ICs as these devices become more cost competitive. Also, as chip functionality and integration increase, unit volumes of ASIC designs will decrease; that is, ASIC manufacturers face the

Table 2
Worldwide Semiconductor Consumption by Device—1990-1995
(Factory Revenue in Millions of U.S. Dollars)

	1990	1991	1992	1993	1994	1995	CAGR (%) 1990-1995
Total Semiconductor	58,225	63,648	72,211	83,537	93,786	101,661	11.8
Annual Growth (%)	1.8	9.3	13.5	15.7	12.3	8.4	
Total IC	47,303	51,863	59,672	69,840	79,106	86,141	12.7
Annual Growth (%)	0.8	9.6	15.1	17.0	13.3	8.9	
Bipolar Digital	4,440	4,095	3,966	3,843	3,637	3,390	-5.3
Annual Growth (%)	-1.6	-7.8	-3.2	-3.1	-5.4	-6.8	
Bipolar Memory	459	414	407	407	378	352	-5.2
Annual Growth (%)	-15.0	-9.8	-1.7	0.0	-7.1	-6.9	
Bipolar Logic	3,981	3,681	3,559	3,436	3,259	3,038	-5.3
Annual Growth (%)	0.3	-7.5	-3.3	-3.5	-5.2	-6.8	
MOS Digital	32,292	35,926	42,496	50,980	58,661	64,546	14.9
Annual Growth (%)	-2.2	11.3	18.3	20.0	15.1	10.0	
MOS Memory	13,091	13,418	15,958	19,378	22,583	24,447	13.3
Annual Growth (%)	-20.0	2.5	18.9	21.4	16.5	8.3	
MOS Microcomponent	10,068	12,063	14,494	17,465	19,982	22,216	17.2
Annual Growth (%)	22.8	19.8	20.2	20.5	14.4	11.2	
MOS Logic	9,133	10,445	12,044	14,137	16,096	17,883	14.4
Annual Growth (%)	7.9	14.4	15.3	17.4	13.9	11.1	
Analog	10,571	11,842	13,210	15,017	16,808	18,205	11.5
Annual Growth (%)	12.6	12.0	11.6	13.7	11.9	8.3	
Total Discrete	8,235	8,777	9,241	10,040	10,656	11,172	6.3
Annual Growth (%)	7.5	6.6	5.3	8.6	6.1	4.8	
Total Optoelectronic	2,687	3,008	3,298	3,657	4,024	4,348	10.1
Annual Growth (%)	2.3	11.9	9.6	10.9	10.0	8.1	

Source: Dataquest (October 1991)

prospect of increasingly complex chips and smaller volume production runs.

Bipolar logic's remaining life cycle will be driven by the quick-processing and switching requirements of centralized, high-end computer systems.

MOS Memory

Slow DRAM bit growth in 1991, which in turn added to ASP softness, combined to make 1991 revenue only marginally improved over 1990. Weak market conditions have also permitted users to extend the 1Mb life cycle until higher density per-bit prices fall to appropriate levels. The anticipated recovery of computer production in addition to the emergence of memory-intensive PC applications—including more powerful operating systems, user-friendly graphical user interfaces, and digital video—will help drive DRAM bit growth in 1992 and beyond. The emerging generation of laptop, hand-held, and pen-based PCs is also expected to give renewed vigor to the DRAM market.

Softness in the PC market, vendors in oversupply, and customers selling off inventory have combined to make for very slow SRAM bit growth and rapidly falling ASPs. Slowing bit growth and Korean/Taiwanese manufacturers "buying" market share will constrain revenue growth. Actual future revenue growth may be further constrained as manufacturers follow through with plans to switch fab capacity to SRAM devices, exacerbating an existing overcapacity situation. On the positive side, expected growth will be bolstered by further application of caches in PCs, and slow SRAM bit growth will be fueled by new applications in consumer markets.

The nonvolatile memory market will be bolstered by continued penetration of flash memories but at the expense of EEPROM market growth. We expect flash growth to accelerate in the forecast period, fueled by consumer and data processing applications. Acceptance of palm-top and pen-based computers and the substitution of memory cards for disk drives for the task of mass storage will be critical to flash's future growth. In the long term, consumer acceptance of electronic photography will be the wild card that adds a superlative increment to growth.

MOS Microcomponents

Notwithstanding the slowdown in PC shipments, microcomponents is expected to be the fastest-growing device family in 1991, 1992, and, on average, through 1995. Two factors contribute to this situation. Intel's proprietary position in the 80486 MPUs places a floor underneath prices and MCUs are steadily penetrating consumer electronics and telecommunications. Furthermore, Dataquest expects microcomponent growth to be fueled by the trend toward higher-performance PCs that include multimedia and networking functions, which in turn will require a higher level of dedicated processing power for implementation.

Market revenue will be boosted by Intel's proprietary edge in the MPU market with its 80486 chip. Helping to constrain revenue growth, however, will be ASP pressure originating from competitive alternate sources to an Intel-based PC (for example, the AMD-led price pressure in 80386 MPU applications).

MOS Logic

Workstations, laptop PCs, and telecom applications are the driving forces behind today's MOS logic growth, although the lackluster showing in the PC arena at large tends to drag unit and revenue growth below what it would be otherwise. The recession has spelled lower unit volumes per ASIC design, putting a further squeeze on manufacturers' profit margins. We look to field-programmable gate arrays, MOS gate arrays, CBICs, and application-specific standard products to drive future device growth and to MOS full-custom chips to restrain growth.

Analog

Dataquest's analog forecast remains essentially unchanged from the May forecast. As 1991 draws to a close, Dataquest will be looking to consumer confidence to improve, forming a firm foundation for 1992 growth. Beyond peak growth in 1993, analog as a product family faces the prospect of decelerating growth resulting from product maturity in large segments of the market plus decelerating growth in some (mature) end markets. Integration of analog functions to MPU and digital signal processing chips, however, will provide continued vitality to analog technology. We expect telecom-specific applications and computer-related mass-storage and graphics applications to be the areas driving incremental growth.

Dataquest Perspective

Dataquest expects the 1990 through 1995 period to be characterized by relatively moderate market growth: Average growth in the 1990 through 1995 period is forecast to be 11.7 percent per annum versus 19.1 percent per annum in the 1985 through 1990 period. Part of this growth deceleration is a result of the moderation of the major world economies' growth prospects vis-à-vis the decade of the 1980s. More important, however, are the combined effects of the maturing end-use markets on the demand-side and the increasing incremental costs associated with marginal changes in manufacturing technology and system/chip performance.

In the 1980s, the workplace and households in the world's major industrialized economies could be characterized as a vacuum waiting to be (further) filled by the breath of solid-state technology. The void was filled with desktop processing systems and VCRs, systems that were unrivaled by close product substitutes.

The task of the 1990s will be to continue to *add* to the stock of electronic gear but also (and at least as important) to enhance the stock's productivity through, for example, networking and image-based processing. Both these areas are new and fruitful ground for cost-competitive, innovative, and technology-oriented semiconductor companies. But because of the relative complexity of these systems, their investment profiles will likely be more smooth—less "peaked" than, for instance, the booming PC market of the 1980s.

Semiconductor manufacturers are advised not to miss out on the plodding progress the workplace segment is making toward connectivity and image-based processing while waiting for the next PC boom. ■

By Terrance A. Birkholz

The Downside and Upside to Our '92 Forecast

Dataquest's semiconductor forecast for 1992 calls for 13.5 percent growth in worldwide device sales, up from 9.3 percent growth in 1991. A critical assumption of the forecast is an improvement in the semiconductor end-use markets—data processing, consumer, communications, industrial, military/aerospace, and transportation. Our forecast assumes that a moderate recovery in the major end-use markets will be well under way by the first quarter of 1992.

This assumption has a downside. Currently, there are few signs of a recovery in most of the semiconductor end-use segments. If the major end-use markets, i.e., data processing or consumer, fail to turn up soon, as we have assumed in our forecast, then our estimated growth for the worldwide semiconductor industry in 1992 may be too high.

On the other hand, there is also an upside to our forecast. The semiconductor end-use markets have historically seen strong growth as the electronic equipment industry pulled out of a recession. If history repeats itself and there is a strong recovery in end-use markets rather than the moderate growth assumed in our forecast, then our estimated growth for the worldwide semiconductor industry in 1992 may be too low.

Perhaps the best methodology for bracketing the upside and downside of our forecast is to consider different outcomes in terms of probabilities (see Table 1). In order to better understand the qualitative arguments for assigning these probabilities, a more careful review of the factors driving individual end-use markets must be considered.

Applications

Data Processing

Data processing applications accounted for 45.3 percent of the semiconductors shipped in 1990 (see Figure 1). This segment includes mainframe computers, minicomputers, workstations, personal computers, and peripheral equipment. It is quite obvious from the size of this end-use market that the health of the semiconductor industry is tied very closely to the fortunes of the data processing equipment industry.

Table 1
1992 Semiconductor Forecast Probability Distribution

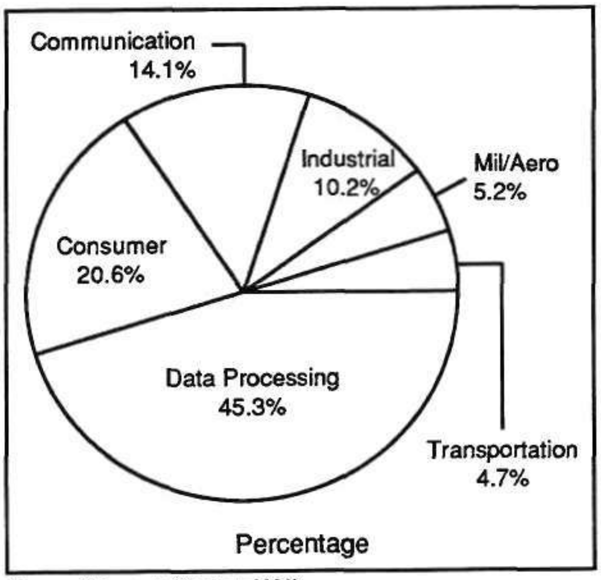
Annual Growth Rate (%)	Probability
<9	0.15
≥ 9 but <12	0.25
≥ 12 but ≤ 15	0.50
>15	0.10
Total	1.00

Source: Dataquest (October 1991)

Dataquest believes that business conditions in data processing will show improvement in 1992 as businesses begin to relax their budgets. Data processing is forecast to grow 10.3 percent in 1992 versus 5.8 percent in 1991.

To achieve our estimated growth in 1992, the computer equipment cycle must begin to turn up in the fourth quarter of 1991. However, August data from the U.S. Department of Commerce (DOC) on office and computing equipment are still giving mixed signals (see Table 2). Orders were up 9.0 percent in August 1991 versus monthly orders a year ago. Yet, last year's data were very weak because of the Mideast crisis, so 9.0 percent growth over an August 1990 base cannot be viewed as a strong positive signal.

Figure 1
Semiconductor End Use by Application Segment



Source: Dataquest (October 1991)

Table 2
Office and Computing Equipment Data
U.S. Department of Commerce
Monthly 1991 Growth Rate versus Same Month in 1990

	June 1991	July 1991	August 1991
Orders	4	-13	9
Shipments	-3	1	-1
Backlog	1	-4	-1
Inventory	-16	-14	-16
Production	-5	-1	-3

Source: U.S. Department of Commerce

An optimistic note in the DOC data is the inventory cycle. Inventories were depleted at an 11 percent clip, while shipments declined by 1 percent. At some point, we anticipate that computer companies will be forced to begin ramping production in order to replenish their inventories. Assuming that inventory levels are very lean, a strong recovery in data processing will cause semiconductor demand to snap back, and growth could well surpass the 13.5 percent we have forecast.

But the bottom line is that orders for data processing equipment have been weak through the third quarter of 1991. And although it is a little early to be an alarmist, if orders continue to run at current levels through the fourth quarter, we expect our forecast to be optimistic. Needless to say, any delay in an upturn for data processing will only push the semiconductor industry recovery out further.

Consumer

Consumer applications accounted for 20.6 percent of the semiconductors shipped in 1990 (see Figure 1). Consumer electronics is forecast to grow 9.8 percent in 1992 according to Dataquest. To achieve this growth, U.S. consumers will have to increase their spending within the next several quarters.

Yet the Conference Board, a private business research firm, reported that the level of consumer confidence in the United States continued to deteriorate in September (see Figure 2). The survey showed that, compared with a month ago, consumers are a good deal less positive in their assessment of prevailing conditions and also somewhat less optimistic in their expectations for the months ahead. The consumer confidence index is well below its level of just prior to the beginning of the Mideast crisis. Moreover, employment data released on October 3 show little improvement in the U.S. unemployment rate, which is stuck in the 6.7 percent area.

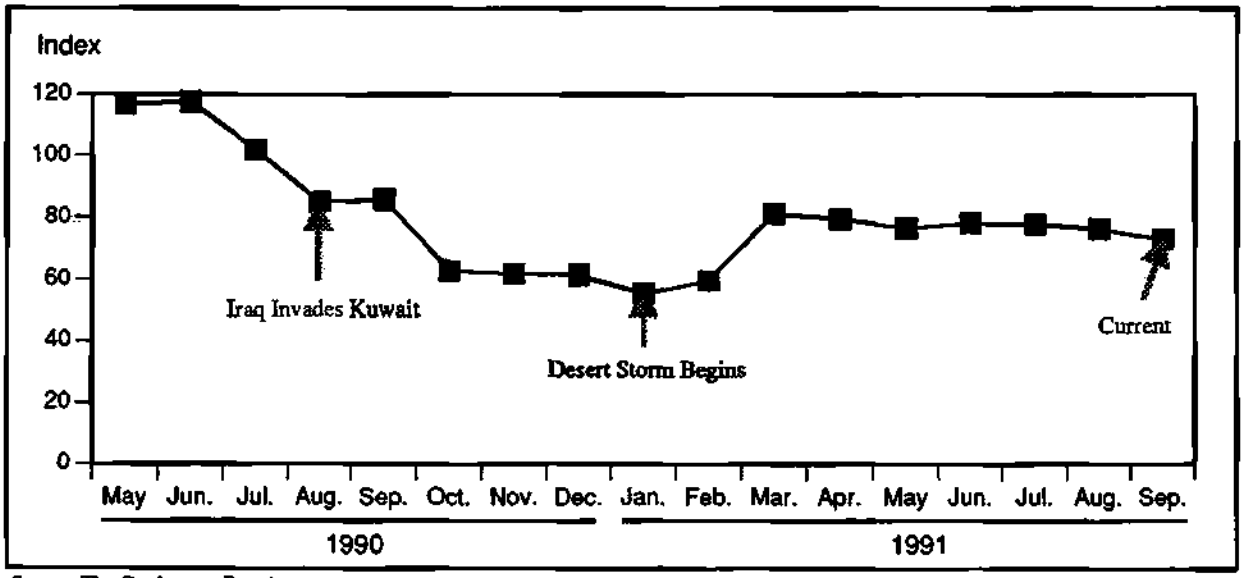
In Japan and Germany, consumers have maintained a strong level of spending through 1991, although their continued spending into 1992 is questionable considering that, according to The Dun & Bradstreet Corporation, both economies are decelerating. In Japan, the growth in gross national product (GNP) is expected to fall from 4.5 percent in 1991 to 3.2 percent in 1992; in Germany, growth in GNP is forecast to fall from 3.0 to 2.0 percent.

It can be argued that an uneven recovery in the United States and the weakening economic climate in Japan and Germany will delay consumer electronic equipment purchases. However, the consumer is getting help. Monetary policymakers in both the United States and Japan are loosening the reins. Interest rates have fallen to a 20-year low in the United States and are creeping lower in Japan. Stock market activity in both countries also seems to be pointing to better times: The U.S. market is reaching an all-time high, and the Japanese market has stabilized and is moving higher. This factor bodes well for consumer confidence; the demand for consumer electronics could well surpass our expectations. If this happened, our 1992 forecast would err on the conservative side.

Communication

Communication applications accounted for 14.1 percent of the semiconductors shipped in 1990 (see Figure 1). This end market, albeit small, remains a bright spot in terms of drivers for the semiconductor industry. The largest segment of communications equipment is telecommunications. Because of the weak global economic climate, there has been a slowdown in the ordering patterns of long distance and

Figure 2
Consumer Confidence Index



Source: The Conference Board

cellular companies in the industrialized countries. It appears that companies are delaying purchases of switching equipment at this time and are settling for stripped-down versions of some switching equipment until volumes pick up.

On a positive note, the fastest-growing regional markets for telecommunications equipment are the less-developed countries, and there has been no slowdown in this segment. Many of developing countries are quickly upgrading their antiquated analog systems with digital lines. Smaller segments of the communications equipment market—i.e., LANs and personal communication—are also experiencing strong growth.

Industrial

Industrial applications accounted for 10.2 percent of the semiconductors shipped in 1990 (see Figure 1). The industrial segment is expected to show marginal growth in 1992. Spending on medical electronics and analytical instruments helped bolster the industrial segment through 1991 and should perform well through 1992. The measure and control electronics segment is in a recession, and Dataquest expects little increased spending in this segment in 1992.

Mil/Aero

Mil/aero applications accounted for 5.2 percent of the semiconductors shipped in 1990 (see Figure 1). The mil/aero segment will provide little growth for semiconductor demand any time soon. U.S. President George Bush's recent announcement concerning changes in the U.S. government's nuclear strategy is expected to put several programs in immediate jeopardy of losing funding. The rail-mobile MX missile program, Boeing's Short Range Attack Missile, the U.S. Navy's nuclear-armed Tomahawk cruise missile, and perhaps the B-2 bomber are all expected to suffer when Congress evaluates the defense budget.

Automotive

Automotive applications accounted for 4.7 percent of the semiconductors shipped in 1990 (see Figure 1). The automotive segment is expected to improve during the next several months. U.S. domestic auto sales are forecast to increase from the depressed level of 6.0 million in August to 6.5 million in October and November according to Morgan Stanley, a New York investment bank. The big problem in the automotive segment is the consumer with his disastrous real disposable income and lack of consumer confidence.

On a more positive note for the semiconductor industry, there was a 20-year low in auto inventories at the end of model year 1991. According to industry estimates, in early September the 1992 models had only a 50-day supply when 65 days is normal. Therefore, a small increase in demand by the consumer is expected to cause auto manufacturers to ramp their production, increasing the demand for automotive electronics.

Dataquest Perspective

The growth in semiconductor demand is forecast to accelerate in 1992. But, in order to achieve the forecast growth rates, the major semiconductor end-use markets—the data processing and consumer segments—need to begin showing more life soon.

The fourth quarter of 1991 will be pivotal. If the U.S. economy pulls itself out of recession and if Japan and Germany experience only a moderate deceleration of their economies, then our 1992 forecast is very reasonable. In fact, Dataquest's forecast may be conservative if the major end-use markets perform better than our expectations. ■

By Mark FitzGerald

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Dataquest Perspective

Semiconductor Equipment, Manufacturing, and Materials

Vol. 1, No. 12 **October 21, 1991**

Market Analysis

VTR Technology Wins Big in the HTR/VTR Equipment Market Battle

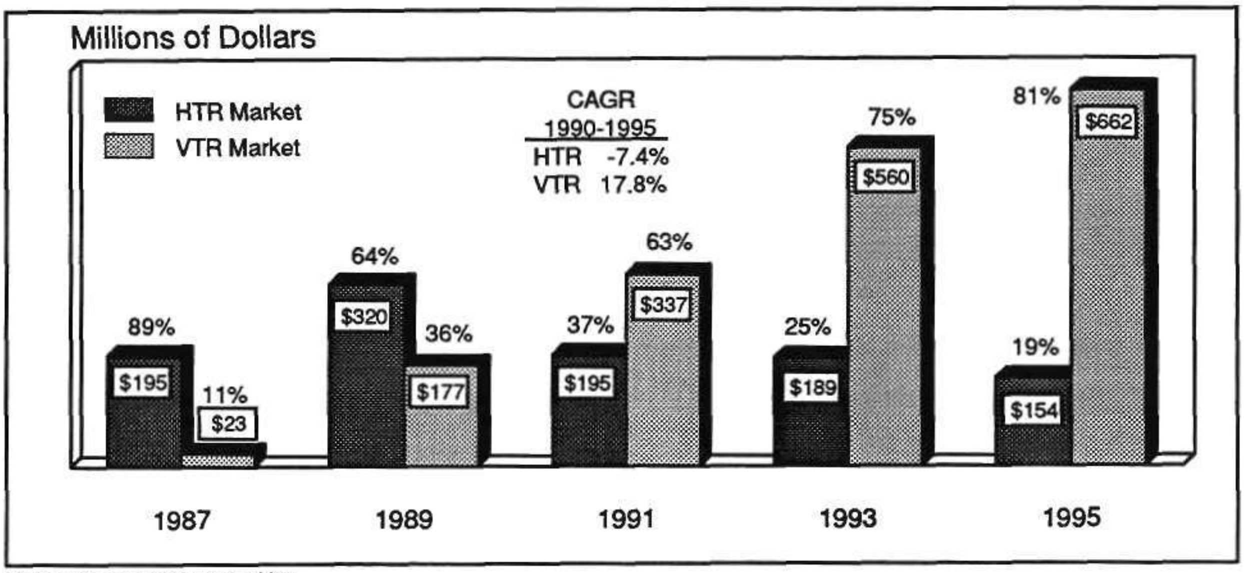
Horizontal thermal reactor (HTR) tubes and vertical thermal reactor (VTR) tubes are used in the wafer fabrication cycle for several key process technologies such as dry/wet thermal oxide growth, implant anneal/drive-ins, PSG/BPSG glass densification and reflow, polysilicon chemical vapor deposition (CVD) and doping, thermal nitride CVD, and undoped and doped high-temperature oxide (HTO) and low-temperature oxide (LTO) CVD. There has been a revolution in the tube equipment business in the last few years. Traditional HTR technology is being swept out in favor of VTR technology for all major tube process applications, especially for submicron 6- and 8-inch wafer fabs. VTRs have the advantages of smaller clean room footprint, easier automation, better uniformity, and better process control for large-size wafers. Japanese wafer fab equipment companies such as Kokusai Electric and Tokyo Electron Ltd. (TEL) have essentially created and dominated the VTR business thus far. Competition, however, has heated up in the VTR business as European and North American companies scramble to abandon the low-margin, stagnant HTR business in favor of the high-margin, high-growth VTR business.

VTR and HTR Markets: A Study in Contrast

Figure 1 shows the history and Dataquest's estimates for future growth of the HTR/VTR equipment markets. The HTR and VTR markets include atmospheric diffusion/oxidation/implant anneals/drive-ins and thermal low-pressure CVD (LPCVD) tube applications such as polysilicon, thermal nitride, and HTO/LTO dielectrics. Dataquest does not include the plasma-enhanced CVD tube market within the VTR/HTR market. The 1990 market was the transition year for the emergence of the VTR segment as the dominant portion of the HTR/VTR market. Worldwide VTR revenue of $291 million made up 56 percent of the combined $518 million 1990 HTR/VTR market, and 1990 HTR revenue of $227 million made up the remaining 44 percent.

Dataquest projects that the VTR market segment will grow to represent an overwhelming 81 percent ($662 million) of the $816 million combined 1995 HTR/VTR market, and the HTR segment will shrink to a replacement and mature capacity expansion market. The projected VTR market compound annual growth rate (CAGR)

Figure 1
Growth of the Worldwide HTR/VTR Markets (Millions of Dollars)



Source: Dataquest (October 1991)

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of 17.8 percent between 1990 and 1995 contrasts vividly with the projected HTR market CAGR of negative 7.4 percent.

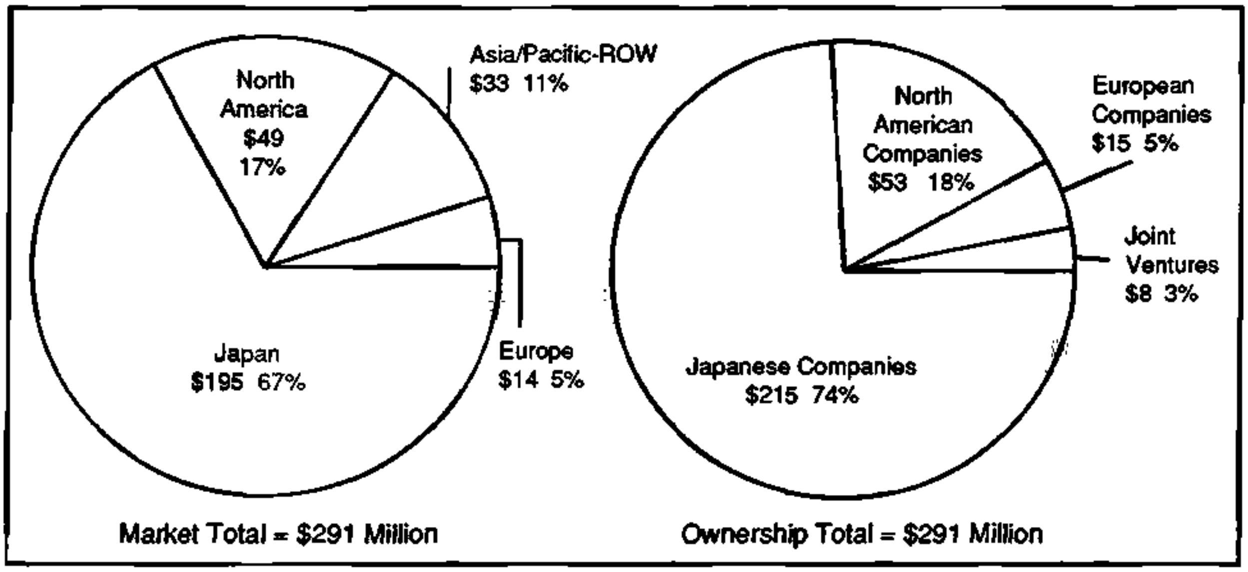
When the VTR process was first introduced in the 1986 to 1987 time frame, many semiconductor manufacturers dismissed it as a fad. They were quite pleased with the performance of their field-proven HTR tube banks. However, the Japanese wafer fab market gradually converted to all-VTR fab layouts because of the inherent automation, process control, and footprint advantages of VTRs for 6- and 8-inch high-volume DRAM fabs. VTRs, with a 1990 average selling price (ASP) of $325,000 per tube, command a price/performance premium over mature commodity HTRs, which had a 1990 ASP of $185,000 per tube. VTR manufacturers have attempted to differentiate themselves on the basis of automation, maintenance, and process-control features in order to achieve high margins through premium pricing. Dataquest, however, expects premium VTR pricing policy to give way to discount pricing strategies in the near future because of the twin factors of intense VTR market competition and the standardization of VTR product features. As always, quick time to market is the key to reaping profits from revolutionary technology market transitions.

Regional VTR Markets and Ownership

Figure 2 shows Dataquest's estimates for the 1990 VTR market segmented by region and company regional ownership. Japan, with 67 percent of the $291 million 1990 VTR market, represented the largest regional market. Not suprisingly, Japan-based equipment companies that pioneered the VTR market in their large DRAM-oriented domestic backyard owned an astonishing 74 percent of the 1990 VTR market. Dataquest anticipates that new non-Japanese VTR market entrants, together with the global adoption of VTRs for advanced production fabs, will gradually change the future balance of power in the VTR market.

Table 1 shows the 1990 worldwide VTR company rankings. Two Japan-based VTR companies, Kokusai Electric and Tokyo Electron, collectively owned 63 percent of the 1990 worldwide VTR equipment market. Kokusai Electric was the original pioneer in the VTR market; it is now the market leader in the VTR business, with 34.8 percent of the 1990 market. Kokusai Electric has recently begun to address the growing North American and European VTR markets by opening regional sales and customer support centers in both regions. TEL, the second-ranked VTR company with a 28.2 percent market share, initially participated in the HTR tube equipment business through the TEL/Thermco joint venture. TEL subsequently bought out Thermco's share of the joint venture in 1988. TEL has displayed tremendous momentum in diversification and new products aimed at the burgeoning VTR market. TEL is also aggressively globalizing its VTR business through the

Figure 2
Regional Markets/Ownership Trends in 1990 VTR Market (Millions of Dollars)



Source: Dataquest (October 1991)

Table 1
Worldwide VTR Market Rankings Based on 1990 Market Shares
(Millions of Dollars)

Company	Regional Ownership	Vertical Diffusion	Vertical LPCVD	Total VTR	VTR Market Share (%)
Kokusai Electric	Japan	46.1	55.1	101.2	34.8
Tokyo Electron	Japan	48.0	34.0	82.0	28.2
Silicon Valley Group	United States	16.2	11.2	27.4	9.4
ASM International	Europe	8.8	6.0	14.8	5.1
BTU International	United States	6.0	5.0	11.0	3.8
Varian/TEL	Joint Venture	2.1	2.7	4.8	1.6
Ulvac/BTU	Joint Venture	3.3	0	3.3	1.1
Others		29.3	17.3	46.6	16.0
Total Worldwide Market		159.8	131.3	291.1	100.0

Source: Dataquest (October 1991)

Varian/TEL joint venture in North America and Europe.

Silicon Valley Group (SVG), which acquired Thermco in 1988, is refocusing its efforts on the VTR market. The company's share of the VTR market has grown rapidly to represent 9.4 percent of the total 1990 market. SVG recently won several major VTR orders in the North American market, including the high-visibility Motorola MOS 11 8-inch VTR order in Austin, Texas. Two North American companies, SVG and BTU International, were awarded Equipment Improvement Program contracts by SEMATECH in 1990. ASM International and BTU International round out the top five VTR company rankings.

Regional HTR Markets and Ownership

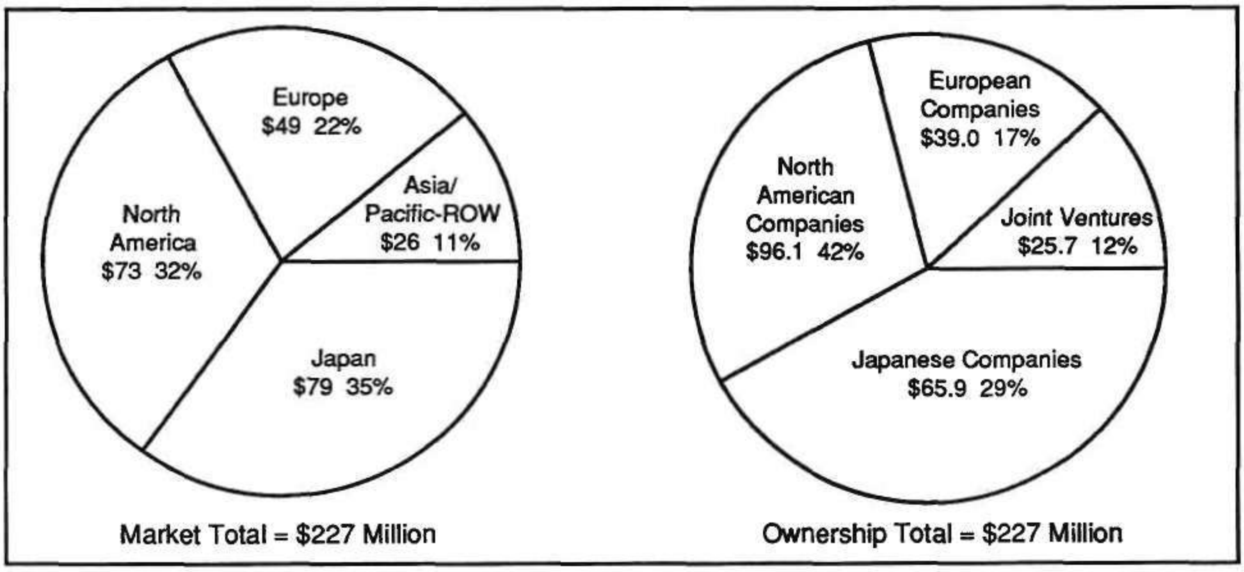
Figure 3 shows Dataquest's estimates for the 1990 HTR market segmented by region and company ownership. In contrast to the VTR market, there is a much higher regional market and ownership balance in the HTR market because of its mature characteristics. Japan represented 35 percent of the $227 million 1990 HTR market, and North America represented 32 percent of the 1990 market. North American companies, which pioneered HTR technology 25 years ago, owned a dominant portion (42 percent) of the 1990 HTR market. However, North American companies' familiarity and attachment to HTR technology proved to be their Achilles heel. They were slow in recognizing the paradigm shift to VTR technology for advanced device fabrication. However, North American and European companies have now jumped on the VTR bandwagon in response to the global VTR market evolution.

Table 2 shows the worldwide 1990 HTR market rankings. The top two companies, TEL and SVG, together captured 43.7 percent of the $227 million 1990 HTR market. TEL and SVG's commanding position in the HTR market is basically an endorsement of the core Thermco HTR technology in the product offerings of both companies. Incremental innovation in automation, particle reduction, and process-control features have allowed these two companies to maintain their commanding lead in the highly mature HTR market. SVG and TEL have effectively used their HTR business lines as cash cows in order to fund their new advanced-technology VTR business lines. ASM International and BTU International, the third- and fourth-ranked HTR companies, respectively, own approximately 11 percent of the 1990 HTR market. It is interesting to note that Kokusai Electric, the top-ranked VTR company, is the sixth-ranked HTR company with only 4.1 percent of the 1990 market. Clearly, Kokusai positioned itself well for market leadership by making an early entry into the nascent VTR business.

Dataquest Perspective

Competition has heated up in the high-growth VTR equipment business, which is projected to be $662 million by 1995, representing 81 percent of the $816 million 1995 combined HTR/

Figure 3
Regional Markets/Ownership Trends in 1990 HTR Market (Millions of Dollars)



Source: Dataquest (October 1991)

Table 2
Worldwide HTR Market Rankings Based on 1990 Market Shares (Millions of Dollars)

Company	Regional Ownership	Horizontal Diffusion	Horizontal LPCVD	Total HTR	HTR Market Share (%)
Tokyo Electron	Japan	44.2	6.9	51.1	22.5
Silicon Valley Group	United States	38.0	10.0	48.0	21.2
ASM International	Europe	15.6	10.0	25.6	11.3
BTU International	United States	18.0	7.2	25.2	11.1
Ulvac/BTU	Joint Venture	13.2	6.2	19.4	8.6
Kokusai Electric	Japan	4.8	4.5	9.3	4.1
Varian/TEL	Joint Venture	4.2	2.1	6.3	2.8
Others		24.6	17.2	41.8	18.4
Total Worldwide Market		162.6	64.1	226.7	100.0

Source: Dataquest (October 1991)

VTR market. Global semiconductor manufacturers are adopting VTR technology for all of their critical thermal tube applications. The HTR business has been relegated to the status of a capacity replacement and mature fab expansion market. Dataquest believes that premium VTR prices and high margins will decline over the next few years as a result of multiple new market entrants and homogenized product features.

The VTR market is an illustration of the customer-driven, time-to-market nature of the wafer fabrication equipment market in which successful product leaders rake in substantial profits and distant me-too followers encounter severe price competiton and marginal returns. ■

By Krishna Shankar

Semiconductor Manufacturing

Microenvironments: Impact on Operations

Summary

Particle contamination of devices in semiconductor manufacturing is an ongoing concern. It is a well-known fact that particles added to a semiconductor device during manufacturing can cause the device to fail. A reduction in particle sources means that fewer devices will fail and yields will be higher. This article looks at the impact of microenvironments on yield and manufacturing operations.

Sources of Particles

Particles are generated from a variety of sources and come in contact with the wafer through many different means. Many studies have been conducted to account for the particle sources that cause devices to fail. These studies vary in their results because different manufacturing methods will account for different ratios. Some typical ranges are presented in Table 1.

Although the results differ depending on a wide range of variables, the common message is that by reducing the particles the yields will increase. Semiconductor manufacturers place great emphasis on process improvements. Every fab has a staff of process engineers who dedicate resources to improving process particle performance. The equipment suppliers also marshal resources toward improving process particle performance to gain competitive advantage and respond to customers' particle goals. The material suppliers also funnel resources toward improving the purity level of their materials.

A manufacturing technique now exists that will greatly reduce particle levels contributed to the device by the environment, the human, and the tool. Microenvironments, custom designed for specific applications, isolate the wafers in an ultracontrolled environment at all times except during processing. A majority of the potential yield-limiting particle sources are almost eliminated with this form of isolation technique.

Table 1
Sources of Particles

Source	Percentage
Process	20-50
Materials	5-10
Environment	10-30
Human	8-20
Tool	25-60

Source: Bainer/Yeaman Engineering Inc.

Yield—The Leverage Exists

Because particle contamination affects yield and a small increase in yield can amount to many millions of dollars in revenue, a significant reduction in the number of particles added to the wafer during manufacturing is the highest-leverage item for return on investment in a fab operation. As previously reported by Dataquest, semiconductor manufacturers are spending $350 million to $500 million building facilities that can produce advanced devices in ultracontrolled fabs capable of Class 1 particle control. Older fabs that are manufacturing devices with tighter geometries than for which they were designed spend tens of millions of dollars to upgrade to Class 10. Microenvironments, custom designed for each tool and work area, provide particle control of between 10 and 100 times better than do Class 1 clean rooms. In terms of real particle control, this means that when the air in the wafer vicinity is sampled over time, there are less than 3.5 particles of 0.1 micron in size in every three cubic feet of air. It is clear that the purity of air a microenvironment provides translates into increased yields.

Applications

Because the device geometries are defined and printed at the lithography step and because the wafers travel through the lithography tools more than any other set of tools in the fab, the area of the fab that benefits the most from the use of microenvironments is lithography. Microenvironments also control temperature and humidity better than what is currently accomplished in a room, and temperature and humidity are sensitive parameters in lithography. Temperature and humidity control is one reason stepper manufacturers have provided microenvironments or environmental chambers for their tools for several years. With the devices protected the entire time they are at each lithography tool and during transport between tools, a yield improvement should be realized.

Impact on Operations

Microenvironments have a very positive impact on yield by providing 100 percent isolation between operator and product and by keeping environment-generated and many tool-generated particulates away from devices. However, microenvironments do slightly change the way the fab operators move product. The general principle in a low-cost, microenvironment-equipped fab is to never allow the run box to be opened outside of a microenvironment. From the time the wafers arrive from the silicon supplier to the time they are passivated or encapsulated, they are handled only inside an isolated environment.

In a lithography area, many wafers will arrive in a Fluorware-style run box. The run box may be placed in a clean storage area before processing. When it is time to process that lot, it is transported to the tool and placed in a manual access port (MAP). The MAP is a microenvironment that provides a manual access door for loading in run boxes and a set of manual-access Gore-Tex gloves to provide isolation between the operator and the product while allowing for complete dexterity for manually loading the tool. A more expensive but automated method of loading the tool is the SMIF-Arm and the SMIF-Pod. The SMIF-Arm attaches to the tool and serves the same function as do the operator and the MAP. The SMIF-Pod serves the same function as does the Fluorware-style run box.

Any type of fab upgrade from Class 10 or 100 to Class 1 can have an impact on operations while the upgrade, including microenvironments, is occurring. However, microenvironments minimize this impact. The goal of semiconductor manufacturers is to have a fully loaded fab that is utilized at all times, which is the way to absorb large fixed costs. Fab managers cannot afford to shut a fab down for retrofit or even cut back on production because a potential reduction in device sales may result. Fortunately, microenvironments can be installed one at a time in about four hours each on average. No tool modifications are required with the manual system, further reducing the potential impact on operations. An older fab with a Class 10 or Class 100 clean room can be operating at better than Class 1 with no major impact on operations.

Dataquest Perspective

Because microenvironments provide a substantial and needed benefit at a low cost, many semiconductor manufacturers are already embracing the technology. Some pressure is currently being applied by semiconductor manufacturers to provide tools with microenvironments already integrated on the tool. If semiconductor manufacturers continue to apply pressure with their purchasing power, they will be able to buy equipment outfitted with controlled microenvironments and be able to install the equipment in Class 1000 clean rooms by the end of the decade. ■

(This article was written by Chris Laramore of Briner/Yeaman Engineering Inc. in conjunction with Jeff Seerley. For further information, please contact Jeff Seerley.)

By Chris Laramore
Jeff Seerley

Technology Analysis

Phase Shift Mask Enthusiasm at Fourth MicroProcess Conference in Japan

Attendees of the Fourth MicroProcess Conference held in Kanazawa, Japan, in July are highly optimistic about the potential implementation of phase shift mask technology. At the 11th Annual BACUS Symposium in September, Mark Levenson of IBM, inventor of the phase shift mask, reported the results of an informal survey of the approximately 400 attendees of the Kanazawa conference. Almost half of the survey respondents expect phase shift masks to be used in the 64Mb DRAM, while 74 percent of survey respondents believe that phase shift mask technology with either excimer/deep-UV or i-line lithography will be used to manufacture 256Mb DRAMs (see Table 1). The Fourth MicroProcess Conference, a technical symposium focused on advanced lithographic processing, is sponsored by the Japan Society of Applied Physics in cooperation with the American Vacuum Society and the IEEE Electron Devices Society.

Dataquest Perspective

Dataquest believes that many of the Kanazawa conference attendees were process engineers; thus the lithography trends shown in Table 1 most likely demonstrate a high degree of reliability. Clearly, the enthusiasm and activity surrounding phase shift mask technology is concentrated in Japan, the manufacturing center for DRAM devices. One of the victims of the phase shift mask has been X-ray lithography, which

Table 1
Advanced DRAM Lithography Strategies—Survey Responses from Fourth MicroProcess Conference

DRAM Generation	Lithography Strategy	Respondents (%)
64Mb	I-line with phase shift masks	48
	Excimer/deep-UV with conventional masks	29
	I-line with conventional masks	17
	X-ray	6
256Mb	Excimer/deep-UV with phase shift masks	54
	I-line with phase shift masks	20
	X-ray	26
1Gb	X-ray	54
	E-beam	30
	Excimer/deep-UV with phase shift masks	16

Source: 11th Annual BACUS Symposium, Dataquest (October 1991)

once again has been moved out to future device generations as a result of the continuing advances in optical lithography. The survey results of the Kanazawa conference show, however, that X-ray lithography is expected to capture more than one-fourth of anticipated 256Mb DRAM strategies and account for over half of the anticipated 1Gb DRAM lithography activities. On a cautionary note, however, Dataquest reminds the reader that historically the industry's expectations for lithography have not always come to pass when expected because of the ability of equipment, materials, and semiconductor manufacturers to extend the existing technology base to new limits. ■

By Peggy Marie Wood

In Future Issues:

The following topic will be featured in a future issue of Semiconductor Equipment, Manufacturing, and Materials *Dataquest Perspective:*

- Sensor-based manufacturing

The topics covered by SEMM newsletters are selected for their general interest to SEMM clients, which include wafer fab equipment suppliers, semiconductor materials companies, and semiconductor device manufacturers. The topics selected indicate the broad range of research that is conducted in the SEMM group. Clients, however, often have specific information requirements that either go beyond the level of detail contained in the newsletters or beyond the scope of what is normally published in the articles. In order to provide complete decision support to our clients, Dataquest has a consulting service available to handle these additional information needs. Please call Stan Bruederle at (408) 437-8272 or Joe Grenier at (408) 437-8206 to discuss your custom requirements.

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Dataquest Perspective

Semiconductor Equipment, Manufacturing, and Materials

Vol. 1, No. 11 October 7, 1991

Semiconductor Manufacturing

New Fab Lines in North America

The year 1991 was the year that the U.S.S.R. collapsed. This was an epoch-shattering event, beside which everything else seems but a footnote of history. Nonetheless, economic life goes on. And the salient fact about our economic life today is uncertainty. The year began with uncertainty about whether or not we were in a recession. Now there is uncertainty about whether there will be a "double-dip" recession in the United States. Reflecting the uncertainty of the world's major economies, many semiconductor manufacturers (including major Japanese companies) are uncertain about when growth and profits will return. Process equipment vendors have scaled back their expectations for 1991 and 1992 as they, too, look for reliable indicators of a solid recovery.

New fab activity is one such indicator. As the fab line is built, capital is spent on the facility; after the facility is built, capital is spent on new processing equipment. This article looks at new fab line activity in North America in 1991 and 1992 and assesses the implications of this activity on capital spending in North America.

Current New Fab Line Activity

Currently, there are eleven new fab lines in North America that either are presently under construction or have completed construction and are now in the process of installing equipment (see Table 1).

Indeed, there is such a dearth of new fab activity in North America that several clean room construction companies have been forced to make staff reductions.

Of the 11 lines in Table 1, 9 already have completed construction and are in the process of buying equipment and running wafers. Most of the equipment buying decisions for these fab lines have already been made, although actual purchases and deliveries will take place over a two- to three-year period.

That leaves only two fab lines currently under construction. This number represents a very thin "pipeline" for new equipment sales in North America. Indeed, there is such a dearth of new fab activity in North America that several clean room construction companies have been forced to make staff reductions.

Table 1
New Fab Lines in North America
1991

Company	Location	Status
Hewlett-Packard	Palo Alto, California	Developmental line—under construction
Intel	Aloha, Oregon	Developmental line (D1A)—under construction
	Albuquerque, New Mexico	Production line—in production and installing equipment
Linear Technology	Milpitas, California	Production line—installing equipment
Motorola	Chandler, Arizona	Developmental and production lines—installing equipment
	Oak Hill, Texas	Production line—in production and installing equipment
	Tempe, Arizona	GaAs line
NEC	Roseville, California	Beginning production—installing equipment
Silicon Systems	Santa Cruz, California	Production line—installing equipment
Sony	San Antonio, Texas	Production line—installing equipment
Western Digital	Irvine, California	Production line—in production

Source: Dataquest (October 1991)

New Fab Line Activity in 1992

Clearly, if there are only three fab lines under construction, 1992 will not be a banner year for capital spending in North America. There is good news, however. Based on informal discussions with clean room construction companies and with semiconductor companies, Dataquest believes that, although they are not yet officially announced, up to 11 new fab lines could be added in North America in 1992 (see Table 2).

Although there are only three fab lines currently under construction in the United States, a host of new fab lines will be waiting in the wings in 1992.

Some companies will build these fab lines primarily because of the strategic necessity to be close to markets: Hitachi, Mitsubishi, Oki, SGS-Thomson, and Toshiba. Others will build fab lines primarily for capacity reasons: AMD, AT&T, Intel, Micron, National, and Zilog.

Dataquest Perspective

Although there are only three fab lines currently under construction in the United States, a host of new fab lines will be waiting in the wings in 1992. They are waiting for a solid economic recovery.

Five of the eleven new fab lines that we expect in 1992 will be built by offshore manufacturers.

Dataquest's forecast for worldwide semiconductor consumption calls for 15 percent growth in 1992. Our forecast for North American semiconductor consumption calls for 12 percent growth in 1992. This forecast is predicated on a continuing economic recovery worldwide and on a firming of memory prices, particularly DRAMs. If these conditions are met, then we believe that it is quite likely that there will be significant new fab activity in the United States in 1992.

It is worth pointing out that the health of the clean room construction industry and the process equipment industry in the United States is to a large degree affected by the presence of offshore manufacturers in the United States. Five of the eleven new fab lines that we expect in 1992 will be built by offshore manufacturers. Four of the eleven will be Japanese fabs.

It is also interesting to note that among the fab line possibilities in 1992, five are located in the

Table 2
Possible New Fab Lines in North America 1992

Company	Location	Status
AMD	Austin, Texas	Production line
AT&T	Orlando, Florida	Production line with microenvironments
Hitachi	Irvine, Texas	DRAM production line
Intel	Aloha, Oregon	Upgrade of D1 (will take place upon completion of D1A)
Micron	Boise, Idaho	DRAM production line
Mitsubishi	Durham, North Carolina	DRAM production line
National Semiconductor	Arlington, Texas	Production line with microenvironments
Oki	Tualatin, Oregon	Production line
SGS-Thomson	Carrollton, Texas	Production line
Toshiba	Portland, Oregon	Production line
Zilog	Nampa, Idaho	Production line

Source: Dataquest (October 1991)

Pacific Northwest (Oregon and Idaho). None is located in California. We believe that the abundance of water and low-cost power in the Pacific Northwest only partly explains the plethora of new fabs in this region and their dearth in California. The high cost of land, the high taxes, and the perception of onerous and unfriendly zoning and environmental regulations also play a large part. Because of these structural deficiencies, even with a worldwide economic recovery, we do not foresee a significant expansion of fab activity in California. ■

By George Burns

Semiconductor Equipment Cost Recovery: A Competitive Weapon

One of the most serious problems facing the U.S. semiconductor industry is the gap in capital spending between the United States and Japan. As illustrated in Figure 1, between 1985 and 1990 semiconductor capital spending in Japan totaled $23.1 billion versus $18.7 billion in the United States, representing a delta of $4.4 billion. Reducing the depreciable life of semiconductor equipment in the United States is one of the most effective ways to address the gap in capital spending. Legislation was recently introduced in Congress to shorten the depreciation life of semiconductor equipment for tax purposes from five years to three years.

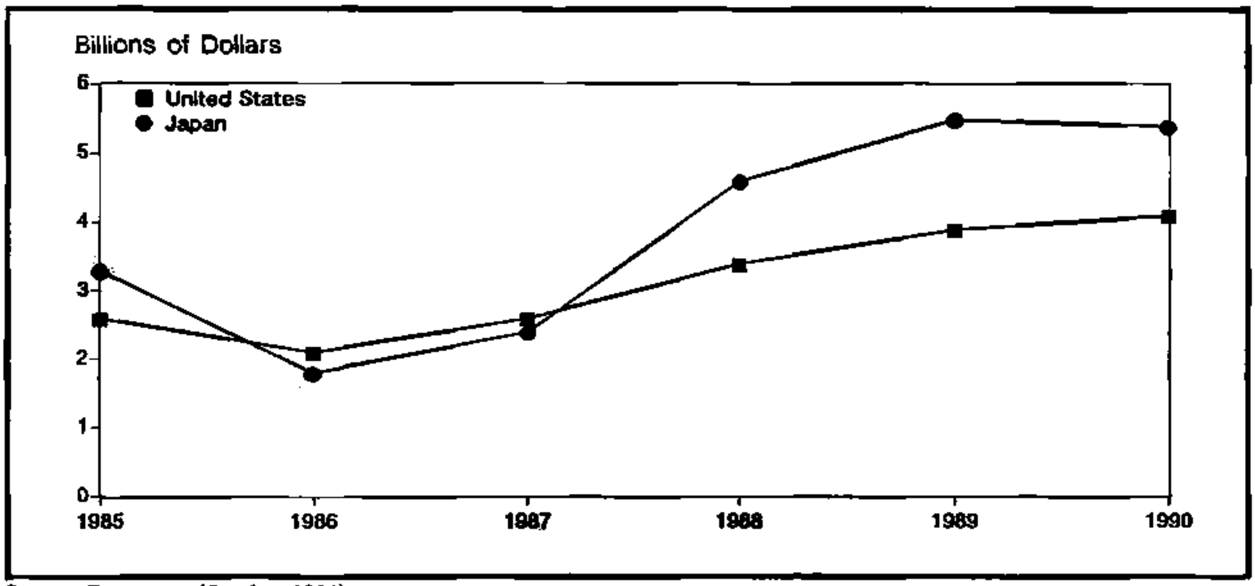
The main justification for going to a three-year depreciation schedule is that the technological life of a majority of semiconductor equipment is less than five years.

It is important to note that this bill will reduce the depreciation life for tax purposes, not for financial reporting purposes. The reason this is important is that depreciation for tax purposes is recognized as a deduction from ordinary income, which results in a lower tax liability. This article analyzes the advantage that U.S. semiconductor manufacturers would gain by going to a three-year life for semiconductor equipment depreciation.

Why Three Years?

The main justification for going to a three-year depreciation schedule is that the technological life of a majority of semiconductor equipment is less than five years. The pace of technological change is the main driver behind this rapid rate of obsolescence. Thus, the window in which

Figure 1
Semiconductor Capital Spending



Source: Dataquest (October 1991)

semiconductor manufacturers can hope to recover their investments is very narrow.

Another justification for a three-year depreciation schedule is to offset the tax advantages of America's competitors. For example, if a Japanese semiconductor manufacturer operates its equipment more than eight hours per day, it can write off up to 50 percent of the equipment cost in the first year, compared with 32 percent written off in the United States. This difference represents a significant advantage because most Japanese manufacturers have 24-hour-per-day operations. Also, Japanese manufacturers can recover 100 percent of the equipment cost in one year if the equipment is utilized for a joint R&D venture. Tax policy is important for an industry such as semiconductor manufacturing because of the high capital costs associated with this industry.

The Internal Revenue Code

The Internal Revenue Code allows semiconductor manufacturers to use either a modified accelerated cost recovery schedule (MACRS) or a straight-line method to compute depreciation for an asset with a useful life of five years for tax purposes. Straight-line depreciation is rarely used since it results in a slower cost recovery than MACRS. The current five-year MACRS is as follows:

- Year 1—20 percent
- Year 2—32 percent
- Year 3—19.2 percent
- Year 4—11.52 percent
- Year 5—11.52 percent
- Year 6—5.76 percent

Six years are listed because MACRS assumes that an asset is utilized for only one-half year during the first year.

The current three-year MACRS is as follows:

- Year 1—25 percent
- Year 2—38 percent
- Year 3—37 percent

It is clear that the three-year schedule would give semiconductor manufacturers a significant advantage over the five-year schedule.

A Real-Life Scenario

The following analysis assumes that $400 million of semiconductor equipment was purchased by a semiconductor manufacturer in 1991. Table 1 lists the results of the depreciation effect in terms of the allowable deduction from ordinary income for a five-year schedule versus a three-year schedule. As illustrated in this table, there will be a significant advantage for semiconductor manufacturers if they are allowed to go to a three-year depreciation schedule. For example, during the first two years of the equipment life, $252 million is recovered under the three-year schedule compared with $208 million under the five-year schedule. This difference represents a $44 million increase in the allowable deduction from ordinary income over this two-year time period.

Table 1
Allowable Deduction from Ordinary Income (Millions of Dollars)

Year	5-Year Schedule	3-Year Schedule
1	80.0	100.0
2	128.0	152.0
3	76.8	148.0
4	46.1	
5	46.1	
6	23.0	

Source: Dataquest (October 1991)

Treasury/Capital Spending Impact

According to a National Advisory Committee on Semiconductors report, implementing a three-year semiconductor equipment depreciation schedule in 1991 would result in a net cost to the U.S. Treasury of $180 million. However, the projected increase in capital spending by the semiconductor industry would be $450 million.

Dataquest Perspective

The justification for this bill is that three years—not five years—reflects the true economic obsolescence of semiconductor equipment. If approved, this bill would have a positive impact on U.S. semiconductor manufacturers and suppliers because accelerated cost recovery would allow manufacturers to recoup their investment sooner, which would increase U.S. semiconductor capital spending. Increased capital spending, in turn, would stimulate demand for semiconductor equipment. In the final analysis, Dataquest believes that a three-year depreciation schedule is a win-win situation for semiconductor manufacturers and semiconductor equipment suppliers. ■

By Jeff Seerley

Market Analysis

Semiconductor Materials: Silicon in the Rough

The demand for reclaim wafers (wafers collected from fab process monitors, dummies, and process fallouts and then recycled by removing device layers) is skyrocketing. Dataquest estimates that the worldwide wafer reclaim market totaled $52.9 million in 1990.

Dataquest believes that reclaim wafers will grow into a healthy niche market.

Consumption accounted for $26.7 million in Japan, $17.5 million in the United States, and $8.7 million in Europe (see Table 1). The United States is the fastest growing market for reclaim wafers. Growth in the other major silicon markets is also on the upswing.

Dataquest believes that reclaim wafers will grow into a healthy niche market. We believe that this market can grow at an 18 percent compound annual growth rate over the next five years. If this rate is achieved, the worldwide wafer reclaim market will total $121 million by 1995. However, our 1995 estimate could prove to be conservative if reclaim operations can achieve comparable virgin wafer specifications. If this were to occur, reclaim wafers would win a much larger portion of the test wafer market, which we estimate totaled $400 million in 1990.

Market Trends

The demand for reclaim wafers has grown very fast over the last two years. This growth is attributed to several trends. First, suppliers of silicon wafers have shifted their production to the higher-value-added prime wafers and away from virgin test wafers. The result is that virgin test wafers are in short supply, and reclaimed wafers are being used as replacements.

Second, yield improvements have been made in the production of prime wafers. Consequently, there is less fallout material from prime wafer production available for use as test wafers. This trend further aggravates the tight supply of virgin test wafers.

Dataquest believes that the U.S. market is just recognizing the benefits associated with reclamation.

Third, consumption of test wafers is increasing dramatically as a result of the shift from batch to single wafer processing. Dataquest estimates that a test wafer is used for every 10 to 20 wafer starts in a batch process. This ratio is expected to decrease to one test wafer for every three to five wafer starts for single wafer processing.

Table 1
1990 Worldwide Company Market Share
Wafer Reclaim
(Millions of Dollars)

United States		Europe		Japan	
Reclaimed Wafer Sales ($M)	Company	Reclaimed Wafer Sales ($M)	Company	Reclaimed Wafer Sales ($M)	Company
8.7	Exsil (U.S.)	5.2	Exsil (U.K.)	14.7	Rasa Industries
6.2	Silicon Material Service	2.2	Micropolish	7.9	Semicon Nagao
1.5	American Silicon Products	1.3	Adeck	2.3	Mimasu
1.1	Others			1.8	Hamada
17.5		8.7		26.7	

Source: Dataquest (October 1991)

Finally, the price of reclaim wafers provides significant savings. Dataquest estimates that the price of reclaim wafers currently is 30 to 70 percent of the cost of a prime wafer. Price will vary depending on lot size, diameter, and processing required to reclaim a wafer. As an example, the current price for a 200mm test wafer in the United States is $115 per piece. The price for a 200mm reclaim wafer is between $35 and $60 per piece.

Technical Trends

The most important specification for reclaim wafers is the particle specification. The current reclaim specifications call for removal of particles that are 0.5 micron or larger. The particle specification is expected to drop to 0.3 micron in the next several years and to 0.1 micron within five years. Eventually, particle specs will have to match those of prime wafers.

Dataquest expects wafer reclaim to be one of the fastest growing segments of the $3 billion silicon wafer market.

Over the next several years, wafer reclaim houses will be forced to invest heavily in clean room space to meet the tighter specs required. The ideal reclaim operation within the next several years will have a Class 100 area to clean incoming wafers and a Class 10 polishing area.

A difficult problem in hitting future particle specs is the lack of a cost-efficient double-sided scrubber. Reclaim houses must remove the particles from both sides of the wafer because particles left on the backside will contaminate device processes.

The basic outline for a reclaim line is as follows: lapping backside, chemical dips, caustic etch, polish, cleaning process. The manufacturing steps required to reclaim a wafer are dependent on the type of processing the incoming wafers have undergone. For example, wafers from bipolar processes will require more material to be removed because of deeply diffused areas. Wafers from MOS processes typically require fewer steps to reclaim because most of the processing has been built up on the surface of the wafer.

Regional Markets

United States

The demand for reclaim wafers currently outstrips capacity in the United States. The two major reclaim houses are adding additional capacity. Exsil (U.S.)—based in San Jose, California—is building a new reclaim plant in Sulphur, Oklahoma. Its parent company is Laporte plc, which is headquartered in Bedfordshire, England.

Silicon Material Service (SMS) is located in Garland, Texas. SMS is a wholly owned subsidiary of Air Products and Chemicals. The company currently is doubling its capacity by adding a new facility in the Dallas, Texas, area.

Most of the major North American device manufacturers are increasing their use of reclaim wafers. Dataquest is aware that IBM, Intel, Motorola, and Texas Instruments are all increasing their use of reclaim wafers. Also, IBM is reclaiming 200mm wafers.

Dataquest believes that the U.S. market is just recognizing the benefits associated with reclamation. The tight market for virgin silicon has forced semiconductor manufacturers to turn to reclaim wafers. As the device makers' experience with reclaiming wafers improves, it is unlikely that they will move back to virgin test.

Europe

Exsil (U.K.) is a reclaim operation located in Derby, England; the parent company is Laporte plc. Exsil (U.K.) is the dominant player in the relatively small European market. The second largest reclaim shop in Europe is Micropolish, a France-based company with a 200,000-wafers-per-year plant. Adeck is a small shop located in the Netherlands. Dataquest also believes that SMS is shipping a small volume of wafers out of Europe to its reclaim facility in Texas.

The European market is much smaller than the U.S. market, but the level of awareness concerning wafer reclaim is also low in Europe. The tight market for silicon wafers did not develop in Europe as it did in the United States and Japan because demand was small for 150mm—the critical diameter that was in short supply. As a result, European device makers were not forced to evaluate reclaim wafers to the same extent as U.S. and Japanese fabs; European fabs had a plentiful supply of virgin wafers. Even so, demand for reclaim wafers in Europe is expected to grow rapidly over the next five years as device manufacturers recognize the cost advantage associated with reclaiming and as more Japanese and U.S. companies build semiconductor fabs in Europe.

Japan

The Japanese merchant market for reclaim wafers is small relative to the total market for silicon wafers. Wafer specifications for prime and test wafers are very severe in Japan. Because reclaim wafer specifications do not currently match virgin wafer specifications, Japanese device makers use the reclaim wafers largely for transportation tests. However, transportation applications are only a small part of the total test wafer market in Japan.

Asia/Pacific

No reclaim houses are operating in this region at present. Some U.S.-based companies currently are doing business in this region, however, and Dataquest expects local production to begin within the next several years—most likely in Korea. Demand for reclaim wafers is forecast to increase quickly in Asia/Pacific.

Dataquest Perspective

Dataquest expects wafer reclaim to be one of the fastest growing segments of the $3 billion silicon wafer market. Oddly enough, none of the prime silicon wafer suppliers participates in this niche business directly. The absence of any of the major wafer suppliers can be attributed to two trends.

The growth of the reclaim business will be impacted by the overall cycles in the silicon business.

First, wafer reclaim operations grew up outside of the silicon industry's mainstream. As a result, traditional wafer vendors have little knowledge of the business and its potential opportunities. Second, most wafer vendors are trying to move their production away from low-margin test wafers into prime wafer production in order to improve their profitability. Therefore, the reclaim business, which is closely associated with the test wafer market, does not match many silicon wafer vendors' product strategy.

The growth of the reclaim business will be impacted by the overall cycles in the silicon business. We expect periods of excess capacity overhang in prime wafer production to slow the growth of reclaim wafers because virgin wafer manufacturers will be under pressure to keep their operations loaded. In the long term, however, the cost advantages of reclaim wafers and the headway being made in reclaim wafer specifications point to strong growth for this silicon wafer segment. ■

By Mark FitzGerald

Company Analysis

A Quick Look at Varian Associates

This newsletter provides a quick look at the financial performance and recent company activities of Varian Associates, a major supplier of semiconductor wafer fabrication equipment. It is part of the "Quick Look" series.

Financial Review

Figure 1 presents the Varian Associates Semiconductor Equipment Group (SEG) quarterly sales, orders, and backlog through the quarter ending June 28, 1991. Table 1 provides a summary of fiscal year (ending September 28) sales and pre-tax operating earnings for Varian SEG.

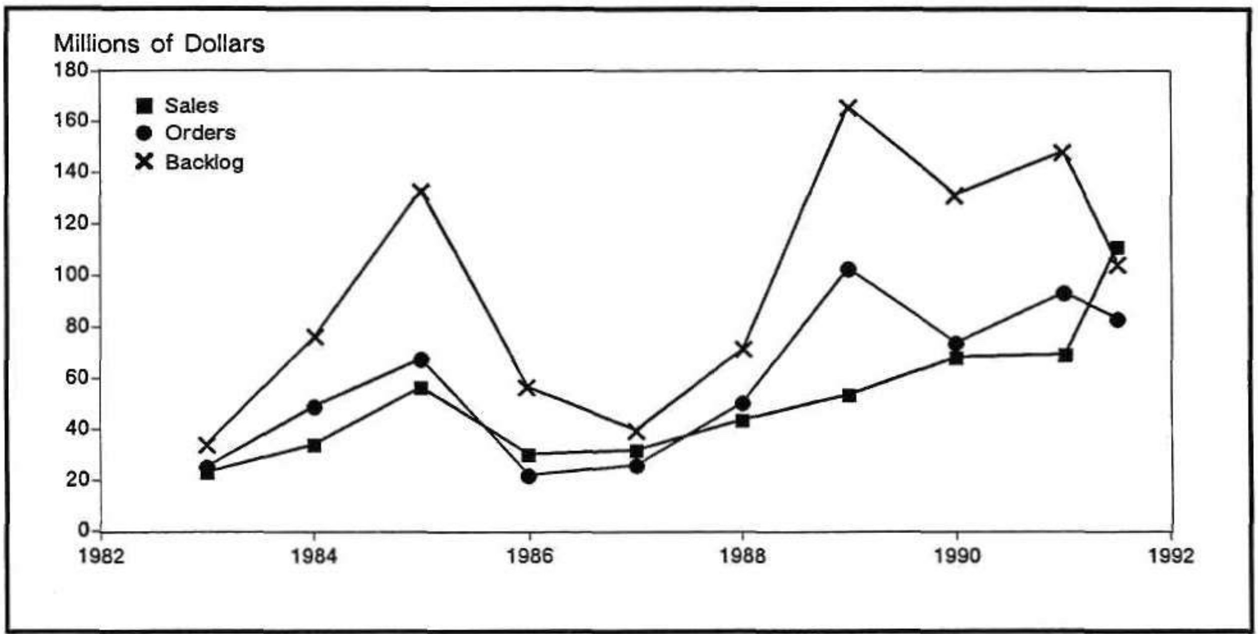
Varian's Wafer Fab Equipment Activities

Varian's SEG revenue is derived primarily from the sales of ion implantation and sputter equipment. Varian has also participated in five other segments of wafer fab equipment: e-beam lithography, etch, metal CVD, molecular beam epitaxy, and rapid thermal processing equipment. The company exited these markets in the 1980s through either discontinuance or the sale of specific product lines.

Varian's Joint Venture Activities

Varian has had a long-standing relationship with Tokyo Electron Ltd. (TEL) for over two decades. TEL represents Varian semiconductor equipment in Japan and is Varian's partner in two joint ventures. In turn, Varian represents TEL's track, etch, and LPCVD/diffusion furnaces in the

Figure 1
Varian Associates' Semiconductor Equipment Group
Sales, Orders, and Backlog by Quarter



Source: Varian Quarterly Reports, Dataquest (October 1991)

Table 1
Varian Associates' Semiconductor Equipment Group
Fiscal Year Sales and Pretax Operating Earnings
(Millions of Dollars)

Fiscal Year (Ends 9/28)	Sales	Pretax Operating Earnings (Loss)	Ratio of Operating Earnings to Sales (%)
1984	206	40	19.4
1985	231	8	3.5
1986	137	(28)	(20.4)
1987	143	(32)	(22.4)
1988	213	2	0.9
1989	323	25	7.7
1990	298	(24)	(8.1)

Source: Varian Financials, Dataquest (October 1991)

United States and Europe. This distribution agreement for the U.S. and European markets was established in 1988.

Under the joint venture agreements, TEL manufactures certain Varian implanters for sale to customers in Japan, and Varian builds certain TEL-designed systems in the United States. The TEL/Varian joint venture in Japan was established in 1982. The U.S. joint venture, Varian/TEL, was established in 1989. Varian/TEL is currently manufacturing TEL's LPCVD/diffusion furnace systems in Santa Clara, California.

Varian established Varian Korea Ltd. (VKL) in 1985 to support sales and service of Varian's semiconductor systems in that country. In 1989, VKL's activities were expanded to include semiconductor equipment manufacturing. Dataquest believes that Varian is the only U.S. company manufacturing wafer fab equipment in Korea today.

Company Highlights

The following discussion highlights recent significant events at Varian SEG.

- M2000/8 Sputter units ordered by ERSO and SEMATECH—In late summer of 1991, Varian received equipment orders for its M2000/8 sputter system from SEMATECH and ERSO, two major semiconductor industry manufacturing consortia. These are significant contracts for Varian because respective members of these two semiconductor consortia now have an opportunity to become familiar with performance benefits of the Varian sputter system. The M2000/8 is a 200mm, open-architecture modular system that makes it possible to perform several sputtering operations and other related processes such as preclean, RTP, or tungsten CVD in independent vacuum modules connected to a central, vacuum-isolated wafer-handling chamber. The M2000/8 creates an opportunity to have third-party modules attached to the system for process integration capability. ERSO has also announced its selection of Varian's E220 medium-current implanter for its new fab facility in Hsinchu Industrial Park in Taiwan.
- Varian/Rapro agreement for cluster tool environment—In July 1991, Varian announced the availability of integration of Rapro's rapid thermal processing system to its M2000/8 modular sputtering equipment. This integrated process capability provides sequential processing of wafer preclean at very low bias voltages, then sputter deposition of conformal refractory metal films, followed by rapid thermal processing in the Rapro module. The cluster tool environment requires fewer handling steps and thus reduces particulates and provides greater process control.
- New sputter source announced at SEMICON/West—In May 1991, Varian introduced its new Quantum planar magnetron sputter source for submicron metallization processes. The beneficial features of the Quantum source include highly symmetrical and uniform step coverage; uniform sidewall coverage; low pressure operation; and full-face target erosion, which reduces defect densities and doubles target life.
- MBE product line sold as part of corporate restructuring—As part of the company's corporate restructuring, Varian sold its molecular beam epitaxy (MBE) product line to Intevac Inc. in February 1991. Intevac is a newly formed, privately held company backed by an investor group that includes former Varian president Norman Pond. In addition to the MBE product line, Intevac also acquired Varian's vacuum systems operation and night vision unit. ■

By Peggy Marie Wood

News and Views

Japanese Capital Spending Plans

Matsushita is pushing ahead with plans for strong capital spending on semiconductor plants even as capital spending in Japan weakens. For fiscal years 1991 through 1993, the company plans to spend ¥300 billion. This amount is an increase of 50 percent over the previous three-year period; the company spend ¥205 billion on its semiconductor operations for fiscal years 1988 through 1990. For the current three-year period, the capital will be spent on the following four facilities:

- A new MOS plant at Tonami
- Expansion of microcontroller production at Fab Bin Uozu
- Expansion of memory capacity at Fab C in Uozo
- A new fab in Arai

Hitachi will freeze capital spending for fiscal year 1991. In order to keep capital spending flat, Hitachi decided not to proceed with plans to construct a new 4Mb DRAM fab. Instead, it will supply 4Mb DRAMs under an OEM agreement with NMB or Goldstar. ■

By Kunio Achiwa

LAM Research Enters Dedicated Tungsten Plug Etchback Equipment Market

The Rainbow 4720

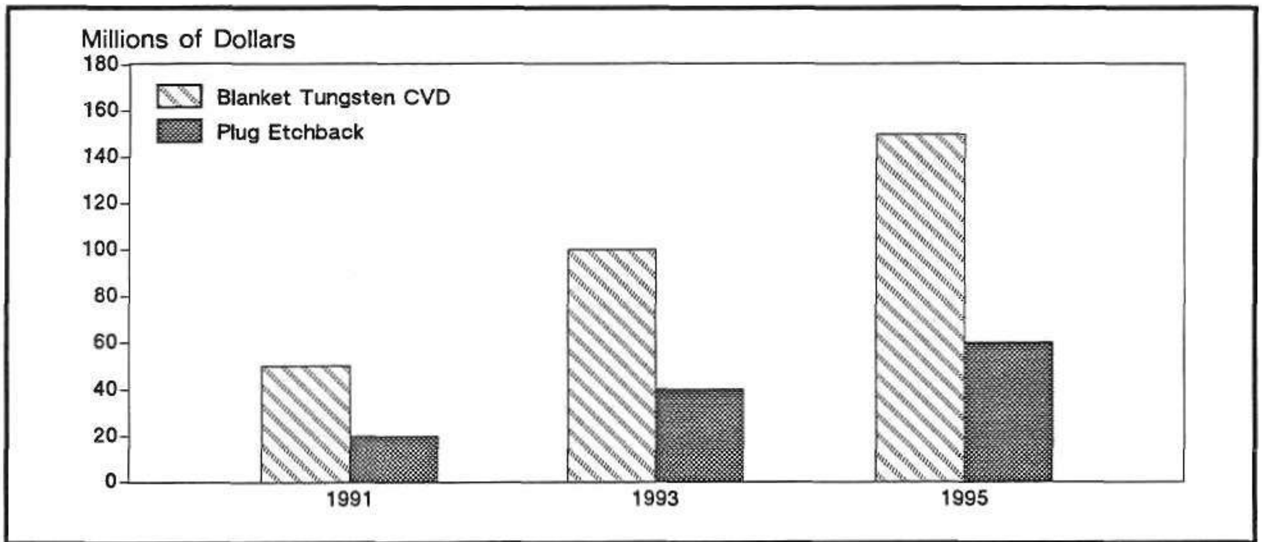
Lam Research recently announced its entry into the fast-growing tungsten plug process-application market with the Rainbow 4720 system. The product is targeted at 0.8-micron contact and via tungsten plug etchback applications in 16Mb DRAM, advanced microprocessor, ULSI logic, and ASIC devices. Lam Research claims that its system has successully addressed plug fabrication issues such as plug etchback uniformity, plug recess, trenching, selectivity to underlaying TiN and oxide, and residues. Lam is offering etchback uniformity of less than 9 percent at three sigma levels, selectivities greater than 10:1 for tungsten to TiN, plug recess less than 10 percent of full plug height, and particle levels less than 0.1/cm2 (size greater than 0.3 micron). Lam Research has used an active wafer-backside cooling technique, in combination with a proprietary wafer clamp design to offer the flexibility of either stopping on the TiN glue layer or etching through to oxide.

The Market

Figure 1 shows the growth of the worldwide blanket tungsten CVD and etchback equipment market between 1991 and 1995. The combined blanket tungsten CVD and etchback equipment market is forecast to grow from $70 million in 1991 to $210 million by 1995. Between 1990 and 1995, the blanket tungsten CVD equipment market segment will grow from $50 million to $150 million while the associated tungsten plug etchback equipment market will grow from $20 million to $60 million.

There are two competing approaches to tungsten plug fabrication. In the first approach, blanket CVD tungsten is deposited in dedicated standalone LPCVD reactors and subsequently etched back to form plugs in a separate RIE-mode dry etch system. In the second approach, an integrated plug process is achieved in a combined deposition/etchback "cluster tool." Blanket tungsten CVD companies such as Anelva, Applied Materials, Genus, and Novellus offer both standalone CVD solutions and integrated "plug" solutions, depending on the customer's preference. Dataquest believes that Genus and Novellus have worked closely in partnership with Lam Research to develop complete plug-integration solutions. For its part, Applied Materials offers its customers a one-stop capability for either dedicated blanket tungsten CVD and etchback tools or integration tools based on the versatile P5000 mainframe. Issues such as tool productivity, plug cost per wafer, process repeatability, flexibility, and defect levels will determine customer choices between the standalone etchback approach and the integration approach.

Figure 1
Worldwide Tungsten Plug Equipment Market



Source: Dataquest (October 1991)

Dataquest Perspective

Dataquest believes that blanket tungsten plug applications are gaining momentum toward full production for the 16Mb shrink (0.5-micron) and 64Mb (0.35-micron) pilot line applications. All the blanket tungsten CVD and etchback equipment companies are roughly on par with respect to process technology competence. The market winners in the tungsten plug application market will be decided on the basis of more intangible customer-specific factors such as tool cost of ownership per wafer, preference for integration versus standalone solutions, and strategic tool marketing and product positioning issues. ■

By Krishna Shankar

FSI International Wins Motorola's MOS 11 "Vendor of the Year" Award

FSI International has been selected by Motorola's MOS 11 facility as the first annual "Vendor of the Year." This prestigious award will become an annual event, and only one supplier per year will be selected to receive the award.

FSI received this award based on the performance of its ChemFill Chemical Management and Delivery Systems. To receive the award, FSI had to achieve the following three main criteria:

- On-time delivery of all equipment
- Equipment performance to both process and uptime specifications
- Superior postinstallation support

FSI's technology and high-purity design ensure that the purity requirements established by Motorola's MOS 11 facility are met.

Dataquest Perspective

This is a significant industry event. Supplier relations is one of the key areas on which semiconductor equipment suppliers and semiconductor manufacturers are focusing. FSI's selection as "Vendor of the Year" exemplifies FSI's ability to provide leading-edge equipment to a leading-edge fab. MOS 11 is the only noncaptive 8-inch wafer fab in the United States. It has a 70,000-square-foot clean room that exceeds the industry's Class 1 standards for particle filtration by three times. The fab was designed so that when device technology demands 0.35-micron capability, it will have that capability.

Maintaining control over purity requirements and uptime is mandatory in a fab such as MOS 11. The ability to maintain high-purity requirements has a positive impact on yield. On-time delivery of equipment and equipment uptime affect cycle time which in turn ultimately impacts time to market. These are two of the most important variables that determine a company's ability to be competitive in semicondutor manufacturing. FSI is helping MOS 11 achieve these competitive goals. ■

By Jeff Seerley

In Future Issues

The following topic will be featured in a future issue of Semiconductor Equipment, Manufacturing, and Materials *Dataquest Perspective:*

- Chemical distribution trends

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Dataquest Perspective

Semiconductor Equipment, Manufacturing, and Materials

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Market Analysis

Semiconductor Materials: Mississippi Riverboat Gambling

The Gamble

As lithography strategies multiply, established photoresist vendors are finding it increasingly difficult to maintain a leadership position in all the advanced resist technologies: excimer/deep-UV, e-beam direct-write, and x-ray lithography. Spiraling development costs and uncertainty as to which advanced resist will be widely adopted in the future make the resist business a high-stakes gamble. A number of small players and new entrants to the resist business are capitalizing on this uncertainty. They are trying to leapfrog the established resist vendors by focusing their efforts on the development of advanced resists. If their bet wins, the payoff could push them into a market leadership position.

Sumitomo Chemicals and Japan Synthetic Rubber are two companies that have successfully used this leapfrog strategy. These companies are leading in the development of i-line resists in Japan. Their sales are expected to benefit from the strong growth in i-line resist demand over the next 10 years.

The new group of companies betting on winning a share of the advanced resist market have two characteristics in common: They are all Japan-based companies, and they all have deep pockets. The fact that they are Japanese companies is no coincidence. Japanese stepper manufacturers are recognized as leading in the photolithography field. Therefore, it is quite reasonable to expect that an ancillary business such as the photoresist industry would also be thriving in Japan. The fact that they are deep-pocketed companies simply reflects the investment and staying power required to develop and commercialize a new resist.

The New Players

Chisso Corporation

Chisso Corporation and Tohoku University in conjunction with Belcoa, an American Telephone & Telegraph subsidiary, have developed a positive EB resist for use in the production of 1-gigabit DRAMS. The resist will allow the printing of line widths as narrow as 0.1 micron. Chisso is currently a minor player in the photoresist industry supplying resists primarily for maskmaking applications. Total company sales for fiscal 1991 are estimated to be ¥198,500 million.

Toagosei Chemical Industry

Toagosei Chemical Industry is a new entrant into the photoresist business. The company has developed an EB resist used to make 64Mb DRAM photomasks and also has an X-ray resist under development. Toagosei is a medium-ranking chemical company of the Mitsui group. The company is placing extra emphasis on fine chemicals, including high-purity chemicals and gases for semiconductor manufacturing. Toagosei completed a research lab in Tsukuba in June 1991. Total company sales for fiscal year 1991 are estimated to be ¥167,000 million.

Sony Corporation

Sony, the leading consumer electronics company in Japan, also has developed a novolak-based excimer/deep-UV resist for use in the production of 64Mb DRAMs. The photoresist is a negative resist that is used with 248nm-wavelength krypton fluoride excimer laser. The company has been successful in drawing a 0.35-micron circuit pattern.

Sony's sales in fiscal 1991 are estimated to total ¥3,680,000 million. The company is backward integrated into device production with semiconductor fabs in Japan and the United States. Sony's work on an excimer/deep-UV resist may signal its decision to aggressively pursue an excimer/deep-UV lithography strategy.

Dataquest Perspective

The downside of the leapfrog strategy is the small size of the photoresist market. The current worldwide photoresist market is estimated at $300 million for 1990. It hardly seems practical that this size market can support additional players pursuing a niche strategy.

Ultimately, skyrocketing capital investments in leading-edge microcontamination facilities and long lead times between development and commercialization may prove that the leapfrog strategy is not profitable. However, Japanese companies are well known for their long-term bets, and they may just play out their hand before they decide to fold.

By Kunio Achiwa (Tokyo)
Mark FitzGerald (San Jose)

Semiconductor Equipment: Medium- and High-Current Implanters—A Manic-Depressive Business Cycle Masks a Smoothly Changing Product Mix

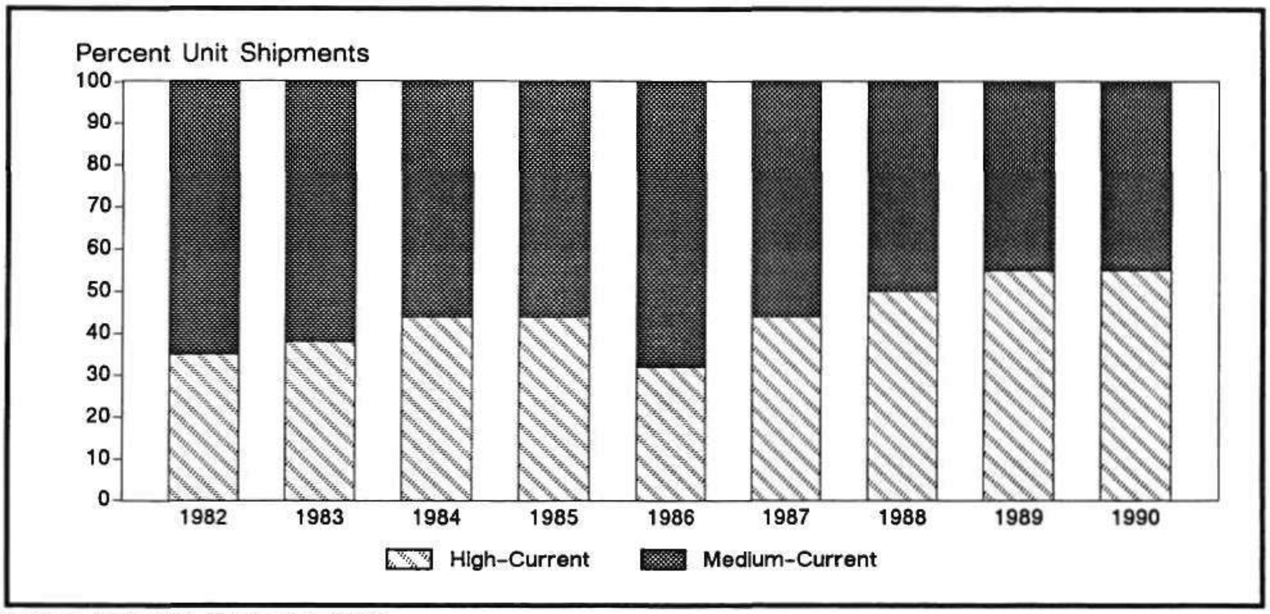
The ion implantation equipment market is best described as manic-depressive because of the exaggerated swings in its business cycle relative to that of the wafer fab equipment industry. Throughout the 1980s, however, the worldwide ion implantation equipment product mix has been steadily shifting toward a higher and higher percentage of high-current implanter unit shipments (see Figure 1). With the exception of 1986, a "depressive" year when the implant market plunged more than 60 percent, this change in product mix has been relatively smooth and steady. This article examines some of the factors behind this phenomenon and, in particular, the differences that have emerged in regional implanter product mix.

Why the Shift in Product Mix?

As shown in Figure 1, high-current implanters represented 35 percent of worldwide medium- and high-current implanter shipments in 1982. In 1990, high-current implanters had captured an additional 20 percentage points of the product mix to represent 55 percent of worldwide implanter shipments. What accounts for this shift in product mix in the 1980s?

In the early 1980s, one of the major process applications for implanters was threshold voltage adjustment. This application was performed by medium-current implanters; thus, this type of implanter dominated the product mix. Throughout the decade, however, NMOS device processing gave way to more and more CMOS processing. This change, in turn, had an impact on the demand for ion implanters. NMOS processing utilizes diffusion furnaces and phosphorous-based $POCl_3$ to establish n-type dopant profiles. CMOS processing, however, requires separate tailoring of both the n-type and p-type channels and wells. With the

Figure 1
Medium- and High-Current Implanters—Worldwide Product Mix



Source: Dataquest (September 1991)

emergence and eventual domination of CMOS processing in semiconductor manufacturing, applications for both medium- and high-current implanters have grown in number.

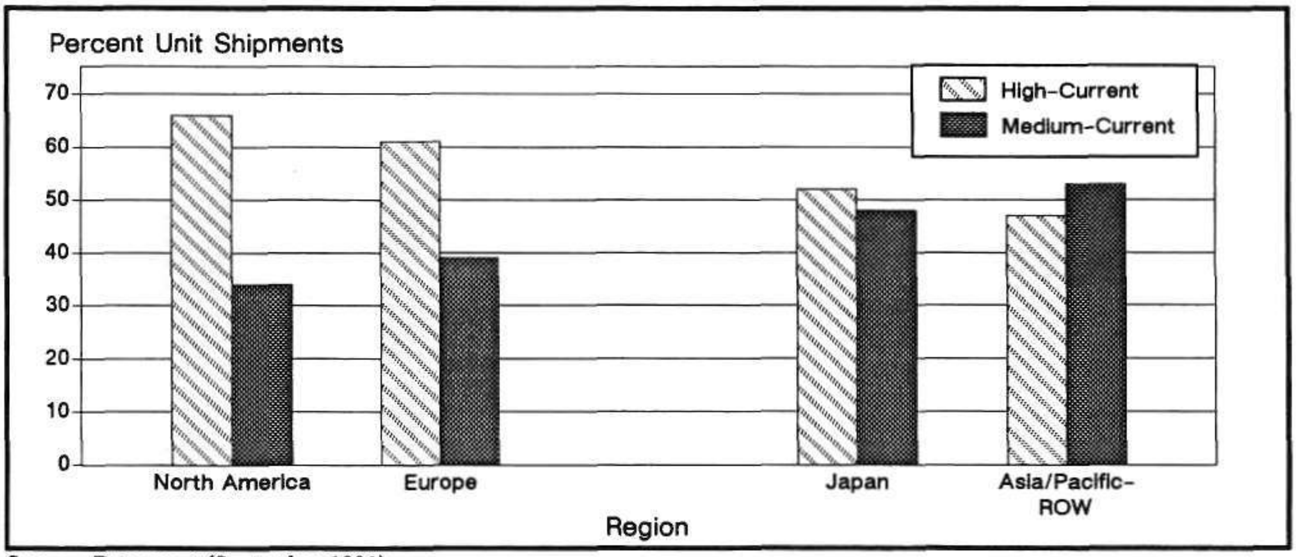
Dataquest believes that an additional factor contributing, to a lesser extent, toward the shift to high-current implanters is the greater flexibility of high-current tools compared with medium-current tools. High-current systems offer a much wider range in dosage rate than do medium-current tools, such that they can perform a variety of medium-current applications in addition to all high-current applications.

Even with its severe cyclical swings, the ion implantation equipment market has been steadily shifting toward high-current implanters throughout the 1980s.

For some manufacturers, the economics of using higher-current implanters for most or all applications cannot be justified. The average selling price for high-current tools is substantially higher than for medium-current systems (80 percent higher in 1990), plus the throughput of high-current tools is on the order of one-fourth to one-half the throughput of medium-current implanters. However, for some low-volume semiconductor manufacturers processing device structures that require a large number of high-current steps and relatively few medium-current steps, the purchase of a single high-current implanter may be easier to justify on an economic basis than the purchase of two separate tools.

One final factor that contributes to greater system flexibility for high-current systems has to do with ion sources. Implant manufacturers are building higher source capacity into their tools so that the implanter can be operated for a longer period of time before sources need to be replaced. In some systems, there is on-line capability to switch between different sources automatically. While these improvements in source capacity and automatic source switching have been directed at both medium- and high-current tools, these additional factors enhance the system flexibility that has come to be associated with high-current tools.

Figure 2
Medium- and High-Current Implanters—1990 Regional Product Mix



Source: Dataquest (September 1991)

Table 1
4Mb DRAM Implant Process Steps

	Steps	Sample Throughput (wafers/hour)	Number of Tools
Medium-Current Implanter	10	200	4
High-Current Implanter	4	50	4

Source: Dataquest (September 1991)

Regional Differences

Like the worldwide trend, the implanter product mix in each of the regional markets has been steadily favoring high-current implanters throughout the 1980s. However, one of the interesting aspects of the shift in the implanter product mix is that there are regional variations in this trend. As shown in Figure 2, semiconductor manufacturers in North America and Europe tended to favor high-current systems at almost a two-to-one ratio over medium-current tools in 1990. In Japan and Asia/Pacific-Rest of World (ROW), the product mix is split almost evenly between the high- and medium-current systems.

Dataquest believes that one factor favoring a higher percentage of high-current tools in the North American and European product mixes is that fabs in these regions are typically multiproduct, multiprocess facilities. Thus, the breadth of process applications performed by higher-current implanters is of particular benefit. Many of the fabs in Japan and Asia/Pacific can be characterized as single-product, single-process facilities, such as the large DRAM fabs. Dataquest speculates that in such high-volume single-product fabs, implanters are likely to be dedicated to a single process step or a set of specific process steps. Thus, the mix of implanters is well defined and optimized for a given fab's processing requirements.

The market for medium- and high-current implanters certainly cannot be considered homogeneous.

The specific devices being manufactured in a given region also have an impact on the implanter product mix. DRAM processing, for example, strongly influences the equipment requirements of semiconductor manufacturers in Japan and Asia/Pacific.

Table 1 presents the number of medium- and high-current implanter process steps for the 4Mb DRAM. The different number of process steps coupled with system throughputs that differ for medium- and high-current tools translates to a process time per finished wafer that is almost the same. Thus, the required number of medium- and high-current implanters is essentially equal for 4Mb DRAM processing. This example concurs with our findings of close to a 50-50 split in the implant product mix in Japan and Asia/Pacific-ROW in 1990.

Dataquest Perspective

Even with its severe cyclical swings, the ion implantation equipment market has been steadily shifting toward high-current implanters throughout the 1980s. High-current implanters dominated the unit product mix in 1990, accounting for 55 percent of all medium- and high-current tools. High-current implanters represent an even larger percentage of the revenue base because of their significantly higher average selling price as compared to medium-current tools. The market for medium- and high-current implanters certainly cannot be considered homogeneous. Dataquest believes that implant equipment companies need to carefully evaluate their product marketing strategies not only on a regional basis but also on the diversity of processes and products being fabricated in today's semiconductor fab facilities.

By Peggy Marie Wood

Semiconductor Manufacturing

Supplier Relations in the 1990s

A recent improvement in supplier relations—the willingness to partner—has helped foster successful business relationships between semiconductor manufacturers, equipment suppliers, and materials suppliers. Acting as catalysts for these relationships are the Joint European Submicron Silicon Initiative (JESSI) in Europe, SEMATECH in the United States, and the Ministry of International Trade and Industry (MITI) in Japan. If handled correctly, partnering will stimulate open dialog between manufacturers and suppliers that can result in continuous quality improvement and a reduction in the cost of ownership.

A Bit of History—Supplier Relationships in the 1980s

The 1980s were turbulent times for semiconductor equipment and materials suppliers. Factors contributing to these turbulent times include increased competition, falling chip prices, and rising manufacturing costs. New competitors were entering the market from Japan, Europe, and Asia/Pacific-Rest of World (ROW). Falling chip prices were caused by supply-and-demand forces at work. The rise in manufacturing costs was due to increasing process complexity.

These factors forced semiconductor manufacturers to implement cost reduction programs. The focus on cost reduction allowed manufacturers to get into a myopic mode of focusing only on price when dealing with suppliers. By focusing only on price, many adversarial relationships were developed between manufacturers and suppliers. However, many manufacturers realized by 1988 that in order for their operations to survive, they had to focus on more than just price. Manufacturers began to realize that service, mean time between failures (MTBF), and maintenance support were just as important as price.

Partnering and Quality

Why Partner?

Two-way communication is one of the principal benefits of partnering. Two-way communication will enable manufacturers to give suppliers better long-range visibility of product changes that will result in major process changes. These process changes will in turn require more advanced tools and ultrapure chemicals. By being given more lead time, suppliers will be able to focus on bringing the appropriate tools and materials to market in a timely manner with quality designed in.

SEMATECH'S Partnering for Total Quality Program

SEMATECH launched a "Partnering for Total Quality" program in 1990. According to SEMATECH, the purpose of this program is to promote a "desire and a commitment to excellence through continuous improvements in communication skills, quality, delivery, administration, and service performance." This program was developed using the Malcolm Baldrige National Quality Award application guidelines as a foundation. To better understand why this program was developed, we need to look at the evolution of quality within an organization.

The Evolution of Quality

Quality evolves within an organization through five stages, as follows:

- Stage 1—short-term focus
- Stage 2—product focus
- Stage 3—product and service focus
- Stage 4—process or system focus
- Stage 5—continuous improvement focus

Short-Term Focus

In this stage, a company places more emphasis on revenue and budgets than quality. The organization does not have a planning methodology in place. High levels of rework and scrap exist. Sales is the only department that has contact with the customer.

Product Focus

In this stage, quality is viewed as meeting specifications. The organization has a moderate to high scrap and rework rate. In this environment, senior executives limit their visits to key customers. Statistical analysis is rarely used as a tool for improvement. Financial, product, and product quality plans are short term.

Product and Service Focus

At this stage, the quality mission has become an executive priority. The company starts to develop long-term financial, product, and product quality plans. Statistical analysis is being implemented. Supplier qualification and certification programs also exist.

Process or System Focus

At this stage, a senior executive owns quality. Other senior executives drive customer partnering. Both short-term and long-term plans are based on benchmarking. Cross-functional quality teams are in place and functioning, and quality improvement trends are visible.

Continuous Improvement Focus

At the final stage, the organization's quality mission is totally customer driven and employees are empowered to fulfill this mission. Business plans, products, and services are benchmarked to world-class standards.

The benefits of partnering include continuous quality improvement and a reduction in cost of ownership.

In the past, suppliers have focused on stages 1 through 3, believing that by applying pressure for output they will receive the desired quality. However, to achieve the level of quality required for the Malcolm Baldrige National Quality Award, suppliers must expand their focus to include continuous improvement of the process and system that is responsible for product and service quality.

Suppliers have reported that the toughest part of the five-stage process is moving from stage 3 to stage 4. When they are able to make this move, they begin to see a major return on quality activities as the rate of improvement increases. When a supplier reaches stage 5, the company is recognized as an industry leader.

Resources Required for a Total Quality Program

Many of the Malcolm Baldrige Award recipients have been asked how one can afford to implement a total quality program. Their response is: How can one afford not to do it?

A serious commitment and significant resources are required to implement a total quality program. Typical investments required to implement a total quality program include the following:

- Training the organization
- Obtaining expert help to develop road maps
- Employee time to develop working relationships with customers
- Product design and production changes
- Employee recognition programs

Suppliers involved with a total quality program state that even though payback may take several years, the investment is a prudent one. According to SEMATECH, "typically in the semiconductor industry, the cost of quality is 25 to 40 percent of net sales when quality is approached through detection and correction. Companies that approach total quality through prevention often reduce the cost of quality to 10 percent or less of net sales."

Dataquest Perspective

Supplier partnering is a term that has become more prevalent in the semiconductor industry, especially over the past couple of years. The benefits of partnering include continuous quality improvement and a reduction in cost of ownership.

The late Dr. Robert Noyce was quoted as saying, "Partnering and cooperation need to be our watchwords. As an industry, better communication up and down the supply chain is mandatory. In the past, U.S. companies bought almost solely on the basis of price through competitive bidding. We need to change our attitude. Price is important, but not the only consideration. Partnering with both customers and suppliers is just as important."

By Jeff Seerley

Technology Development and Medium-Size Semiconductor Companies

Technology development—the generation and transfer of new ideas, device designs, processes, and methods of manufacture—is crucial to the advancement of semiconductor technology. Medium-size semiconductor companies must compete with larger competitors by being innovative or by attacking niche markets, but how do they compete with the larger companies on technology development? The large companies have the deep pockets and resources to drive technology development, while the smaller companies have more limited resources to pursue this important market driver.

...because they do not have the financial resources that large companies have, medium-size companies may not be able to develop a broad range of processes as quickly as large companies.

Medium-size companies, because of their size, do not have the barriers to communication that their larger cousins have. This is especially important in the developmental process: Good communication makes it easier to integrate manufacturing concerns with developmental concerns.

On the other hand, however, because they do not have the financial resources that large companies have, medium-size companies may not be able to develop a broad range of processes as quickly as large companies. They may also be limited in their ability to evaluate and select the latest state-of-the-art equipment for processes currently under development.

Medium-Size Companies' R&D Spending

Medium-size semiconductor companies (defined here as those that have revenue greater than $200 million and less than $500 million per year) generally spend a larger percentage of their revenue on R&D than the average for all U.S. merchants. For example, semiconductor R&D spending for medium-size companies in 1990 ranged from 14 to 25 percent of revenue, while the average of R&D spending as a percentage of revenue for all U.S. merchant companies was 14 percent (see Table 1).

Because the medium-size company is no longer small, the original market niche that was the basis for the company's growth and success is now large enough to attract the competitive eyes of larger companies. These large companies have R&D budgets several times the size of medium-size companies. Yet the medium-size companies must defend these niches (and try to develop new niches) with their limited R&D budgets. In order to grow beyond the $200 million to $500 million range, medium-size companies have to graduate from the niche markets.

Advantages of Medium-Size Companies in the R&D Process

Medium-size companies are able to compete as well as they do against the much larger R&D budgets of their large competitors because their smaller size enables them to implement changes quickly. Their smaller size enables them to

Table 1
Comparison of Percentage of Semiconductor Revenue Spent on R&D by Medium-Size Companies and U.S. Merchant Average—1990
(Millions of Dollars)

Company	Revenue	R&D Spending	R&D as % of Revenue
IDT	206	44	21
Cypress	219	55	25
Chips and Technologies	255	49	19
Hewlett-Packard	279	45	16
Micron Technology	286	41	14
VLSI Technology	322	54	17
Analog Devices	381	73	19
U.S. Merchants' Average			14

Source: Dataquest (September 1991)

communicate effectively and without bureaucratic red tape.

Cypress Semiconductor is a good example of a company making full use of the natural advantages that medium-size companies have in communication and in nimble response. Cypress has a unique means of fostering communication. It funds its own start-up subsidiaries. These subsidiaries then build their own fabs and feed back new processes to their parent. Thus, Cypress has been able to tap a continual source of new process ideas by fostering innovation and entrepreneurship.

Medium-size companies build their R&D facilities as joint production and R&D facilities, in large part because they do not have the finances for a separate R&D facility. This physical propinquity between R&D teams and manufacturing teams engenders cooperation and communication. The result of physical propinquity is that members of the development team are able to see the effects of their work on the factory floor every day. Manufacturing engineers can walk right up to a development engineer and talk about what is not working and why.

Size and physical proximity also make equipment purchasing decisions easier. Small teams, consisting of top-level manufacturing and developmental staff, can work together for all major equipment buys.

Size also helps with technology transfer. For example, IDT's new developmental fab is a joint R&D and production fab located in San Jose, California. IDT has another fab only 50 miles away in Salinas, California. When a new technology or process is due to be transferred, it is an easy matter for personnel from the technology center to drive to Salinas to help bring up the new process or technology.

Medium-Size Companies Look to Larger Companies for Equipment Evaluation

While being "not-big" does confer advantages of responsiveness, flexibility, and communication over Goliath-like competitors, not-big does have a drawback: Medium-size companies do not have the financial resources that larger companies have to develop a broad array of new processes, nor can they make an optimum evaluation of the next generation of equipment.

Regarding the evaluation of new equipment, one medium-size company's developmental manager put the problem this way: "We can't afford to take a chance on a new piece of equipment. We don't have the financial cushion that larger companies have to protect us against mistakes." This particular company solved its equipment information/evaluation problem by looking to larger companies for information. It did this through informal means, such as reading the trade press about equipment buys of large companies or through discussions with colleagues from larger companies at trade conferences and seminars.

Although this particular company saw such informal means of gathering equipment information as adequate to its needs, Dataquest believes that such a method limits a company's view of emerging equipment applications and capabilities. With this method, equipment is not available for the smaller company until after it has been evaluated by a larger company.

In order to grow beyond the $200 million to $500 million range, medium-size companies have to graduate from the niche markets.

Other medium-size companies have solved their equipment evaluation needs by also looking to larger companies, but in a much more formal arrangement. A good example of such a formal arrangement is the relationship between Hitachi and VLSI Technology. VLSI and Hitachi have joint licensing agreements and technology-exchange agreements. Through this partnership, Hitachi has access to VLSI's design tools, and, in exchange, VLSI has access to Hitachi's process technology.

As a result of this technology exchange, the parties in several instances use similar equipment sets. By using these same equipment sets, both VLSI and Hitachi are able to more easily duplicate each other's new and existing processes and work together on their joint programs.

Under this partnership, VLSI has moved from a 1.0-micron process to demonstrating a 0.45-micron transistor structure in just three years. With the assistance of VLSI's design tools and Hitachi's process technology, a completely documented 0.8-micron design, process, and complete equipment list including many important performance specifications was developed. The two companies have also jointly shared a 0.6-micron process.

The parties also share advice on how to modify the processes on equipment to meet each company's performance specifications. VLSI believes that this partnership significantly reduces its development cycle.

Dataquest Perspective

The requirements for R&D are the same in large and medium-size companies. Communication is essential to the developmental process, and in medium-size companies the barriers to communication that are the natural concomitants of size have not yet grown up.

Although they spend proportionally more on R&D than do larger companies, medium-size companies do not have the financial deep pockets that larger ones have. Therefore, they tend to be conservative in their equipment-buying plans. Medium-size companies tend to look to equipment that has been proven by the larger companies.

This dependence on larger companies for equipment evaluation and process applications can be either formal or informal. Formal relationships are mutually beneficial. They are also risky for the medium-size company. They can give away technology to a potential competitor. Obviously the medium-size companies are aware of this risk. They plan to meet it by relying on their natural strengths of good communication, flexibility, and quickness of response. Dataquest believes that although this is indeed a high-risk game, it is necessary if medium-size companies are to develop new processes as quickly as the marketplace demands. We believe that there will be more technology exchanges between medium-size and larger semiconductor companies in the future.

The search for information from larger companies can also take place through informal channels, such as reading the trade press for notices of large equipment buys. These informal relationships do not risk giving away technology to potential competitors, but they can limit a company's view of emerging equipment applications and capabilities.

Dataquest believes that working with equipment companies themselves as beta sites is another and fruitful way that medium-size companies can evaluate new equipment. An example of this is the recent announcement by Cypress and Hampshire that Cypress has acquired a Hampshire X-ray stepper to develop a 0.25-micron process. This strategy does not risk giving away technology to potential competitors and still allows the medium-size semiconductor company access to next-generation equipment. It should be noted, however, that equipment vendors generally do not use medium-size companies for beta sites. They are reluctant to do so because larger semiconductor companies represent larger potential orders.

Dataquest estimates that the companies with the 10 highest semiconductor capital spending budgets will account for approximately 50 percent of the worldwide wafer fab equipment market in 1991. However, because, to a great extent, many medium-size companies buy "what the larger companies buy," the size of the combined direct and indirect market represented by the top 10 spenders is probably much larger than 50 percent.

Also, when we consider that 10 semiconductor companies purchase 50 percent of wafer fab equipment and that 10 equipment manufacturers supply 50 percent of the world's wafer fab equipment, we realize that the concentration of semiconductor equipment buying power is very high.

Medium-size companies may be a constant source of product innovation and paragons of market responsiveness, but when it comes to financial resources for technology development, they are poor relatives compared with the larger semiconductor companies. Process development is increasingly becoming a game for large semiconductor companies. If medium-size companies want to play, they may have to ante up part of their competitive advantage, such as design tools, to their potential competitors—and hope they can remain nimble enough to stay a step ahead.

By George Burns

News and Views

Applied "Finally" Jumps into LCD Equipment Business

Not often does a company announce its intention to make an announcement. But that is exactly what Applied Materials did on September 4 as a prelude and teaser to its September 11 announcement of its entry into the fast-growing market for liquid crystal display (LCD) manufacturing equipment. What is almost of more interest than the company's decision to enter this market has been its glaring lack of presence up until this point. Many of its major competitors have been actively involved in supplying LCD manufacturing equipment for several years now.

Dataquest believes that Applied has several strong factors in its favor for success in this new market. The company already has an excellent presence established in Japan through its subsidiary, Applied Materials Japan. Because the world's LCD manufacturing activity is concentrated in Japan, many other equipment companies are having difficulty in penetrating this new equipment application. Also in its favor are Applied's broad product offering and strong technology base in etch, CVD, and PVD equipment—all of which are key technologies for LCD fabrication. A third factor facilitating Applied's entry into this market is that many of the company's major semiconductor customers in Japan are also the major LCD panel manufacturers. Thus, Applied's reputation for advanced technology, reliability, and service is already well established within the LCD panel manufacturing community.

By *Peggy Marie Wood*

Developer Improves Resolution

Companies have gradually pushed out to a later date the need for advanced lithography processes—i.e., excimer/deep-UV, e-beam direct-write, and X-ray—by improving stepper, photoresist, and phase shift mask technology. Now Tokuyama Soda is marketing a developer for positive i-line photoresists that the company claims will increase resolution margins by 15 to 20 percent.

The target application is 4Mb to 64Mb DRAM device production. Steppers with numerical aperture 0.52 can achieve 0.3-micron linewidths. Sales targets for the first year are 2 million litres.

By *Kunio Achiwa*

In Future Issues

The following topic will be featured in a future issue of Semiconductor Equipment, Manufacturing, and Materials *Dataquest Perspective:*

- A Quick Look at LSI Logic

Errata

The article entitled "How Big is the I-Line Resist Market?" in Semiconductor Equipment, Manufacturing, and Materials *Dataquest Perspective* Volume 1, Number 9, contained an error. One paragraph begins: "In Scenario 1, we assume that critical mask levels in the 4Mb will shrink and that all versions of 16Mb will use i-line resists." The sentence should read: "In Scenario 1, we assume that critical mask levels in the 4Mb shrink and all versions of 16Mb will use i-line resists." We apologize for any confusion this may have caused.

The topics covered by SEMMS newsletters are selected for their general interest to SEMMS clients, which include wafer fab equipment suppliers, semiconductor materials companies, and semiconductor device manufacturers. The topics selected indicate the broad range of research that is conducted in the SEMMS group. Clients, however, often have specific information requirements that either go beyond the level of detail contained in the enwsletters or beyond the scope of what is normally published in the articles. In order to provide complete decison support to our clients, Dataquest has a consulting service available to handle these additional information needs. Please call Stan Bruelerle at (408) 437-8272 or JoeGrenier at (408) 437-8206 to discuss your custom requirements.

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Dataquest Perspective

Semiconductor Equipment, Manufacturing, and Materials

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Market Analysis

Caution and Concern: Watchwords for the Wafer Fab Equipment and Materials Industries

Dataquest's most recent forecast for wafer fab equipment, based on our outlook of the industry from the first half of 1991, was published in July 1991. In that forecast, we anticipated modest growth of 9 percent worldwide in the 1991 wafer fab equipment market. Recent signals from the industry indicate that a number of companies are experiencing a softening market. The purpose of this article is to keep our clients apprised of the various factors that may impact future market growth.

Wafer Fab Equipment Company Slowdowns

Wafer fab equipment companies are both cautious and concerned when evaluating their business environment for the next six to nine months. Several major U.S. equipment companies have reported to Dataquest that activity in the Asia/Pacific-Rest of World (ROW) region is not developing as vigorously as was anticipated and that some device manufacturers in that region have either delayed orders or pushed delivery into 1992. Japanese wafer fab equipment companies report that semiconductor companies are canceling orders or asking for delivery schedules to be moved out anywhere from half a year to a year. Table 1 summarizes some of the signs of the market slowdown for six of the top eight wafer fabrication equipment companies. A number of other companies have expressed their concerns regarding a softening order rate and a declining backlog.

Silicon Wafer Companies Impacted

Business also appears to be slowing down significantly in the latter half of the year for the silicon wafer companies. Several major wafer manufacturers have reported to Dataquest that business is drying up because they are unable to receive firm orders from device manufacturers for future wafer shipments. Most significant, demand for silicon wafers in Japan appears to be softening. Orders had weathered the turmoil of the Middle East crisis in the first half of the year, but now appear to be succumbing to the general slowing of the Japanese economy. In the United States, wafer demand was weak for the first calendar quarter of 1991, picked up in the April-to-May time frame, and began to deteriorate again in July. European

Table 1
Signs of Slowdown in the Activities of Several Major Wafer Fab Equipment Companies

Company	1990 Worldwide Wafer Fab Equipment Market Ranking	Comments
Nikon	1	Company reports FY1991 (ending 3/92) stepper shipments revised downward from 450 to 330 units.
Applied Materials	2	Public financials show significant drop in backlog in last two reported quarters.
Tokyo Electron Ltd.	3	Company reports business outlook for FY1991 revised downward.
Hitachi	4	Company reports FY1991 stepper shipments revised downward from 120 to 70 units.
Canon	5	Dataquest believes that Canon will scale back its FY1991 stepper shipments from its originally anticipated shipment schedule of 190 units.
Varian	8	Public financials show significant drop in backlog in last reported quarter.

Source: Dataquest (September 1991)

demand has been very weak all year, and Dataquest sees little change for the rest of 1991. Asia/Pacific wafer demand is also soft, as many device companies are feeling the impact of weak export markets in the West.

Fab Plans Reevaluated

Changes in fab plans are contributing to the slowdown in both the silicon and wafer fab equipment markets. In Asia/Pacific-ROW, several facilities have been put on hold, including the Vitelic/Hualon facility in Taiwan and Hualon's planned facility in Malaysia. Dataquest understands that production activities at several 8-inch fab projects in Japan have been postponed or reduced in scope. In general, new DRAM fab lines are designed for production capability for two generations of devices. Production capacity and wafers are scheduled to come on-line in stages. It is the initial stages of several of these new 8-inch DRAM facilities that have been delayed or reduced in scope. NEC's 8-inch facility in Kumamoto is not expected to undergo any reduction in its activities. Thus, NEC is well positioned to be the manufacturing leader in Japan for 8-inch volume device production.

New DRAM fabs traditionally account for a significant portion of wafer fab equipment expenditures. Dataquest originally believed that the move to 0.5-micron, 16Mb DRAM manufacturing on 8-inch lines would propel the wafer fab equipment market onto a growth path starting in 1991. However, both 1Mb and 4Mb DRAM prices have continued to soften throughout 1991. Slow demand for DRAMs and increased levels of competition have prompted DRAM manufacturers to reevaluate return-on-investment issues for the huge capital outlays of new 8-inch DRAM facilities.

Dataquest Perspective

Weakness in the 1991 semiconductor equipment and material businesses can ultimately be traced to a global economic slowdown that started in late 1990. The economies of the United States, the United Kingdom, and France were especially weak in the first half of 1991, while the German and Japanese economies are currently slowing. Analyzing the pertinent elements of the economic slowdown, we note that PC shipments are being adversely affected by delayed business investment, consumer audio/visual and automotive is being hurt by low consumer confidence, and military electronics is off because of a decline in defense spending. These sectors combined account for about 50 percent of all semiconductor device consumption.

Dataquest believes that weakness in PC unit shipments is the factor with the most visible impact on the Japanese DRAM manufacturers. The main memory and display buffers of PCs account for about 50 percent of DRAM consumption. We expect PC unit shipments to the U.S. market, for example, to be flat this year. Furthermore, we expect PC unit shipments to the U.S. market to grow only about 6 percent next year. Although portable PC shipments are growing rapidly, they are still only a fraction of the market. We believe that these factors are contributing to slowing fab investments and accelerated DRAM density changes.

The outlook from Dun and Bradstreet economists is for a U.S.-led, slowly developing recovery starting in the third quarter of 1991 and building in 1992. The weak sectors noted previously, except military, should return to average to above-average growth rates, relative to recent history. Portable PCs, networking hardware, cellular communications equipment, and automotive electronics will be some of the high-growth application markets in 1992. ■

By Mark FitzGerald (San Jose)
Gregory Sheppard (San Jose)
Peggy Marie Wood (San Jose)
Kunio Achiwa (Tokyo)

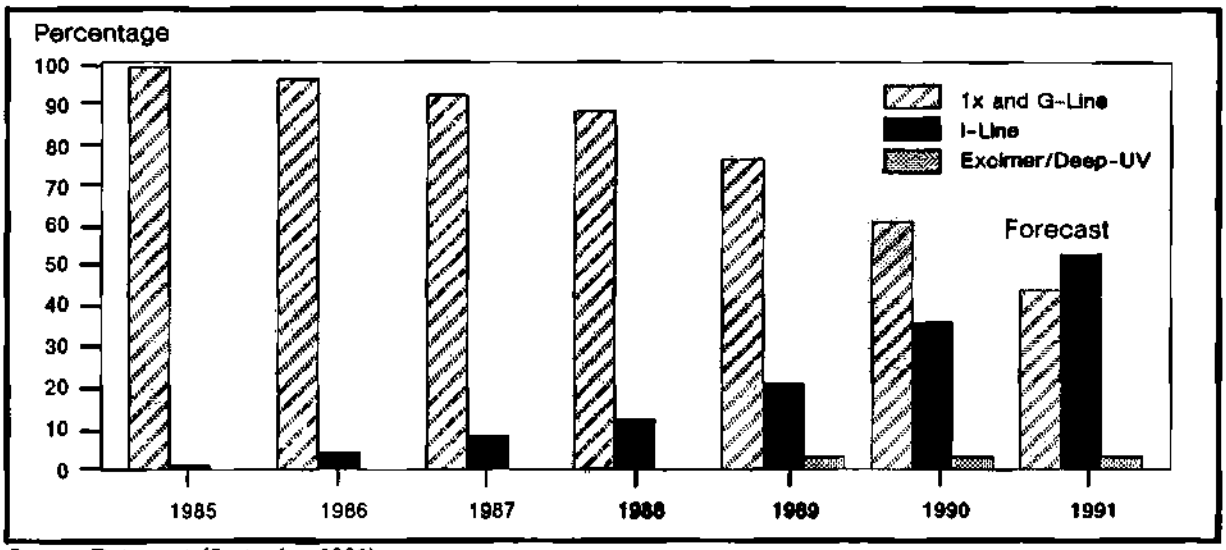
How Big Is the I-Line Resist Market?

Semiconductor device manufacturers are investigating numerous lithography strategies—i-line, excimer/deep-UV (DUV), e-beam direct-write, and X-ray lithography—for the half-micron regime and below. The multitude of strategies coupled with the emergence of no clear front-runner is creating havoc within the photoresist industry, which must formulate new resists to meet all the possible outcomes. Even with i-line lithography, which is rapidly moving into production, there are a number of unresolved issues that will determine how large the i-line resist market will grow and what types of resists will be required.

I-Line Steppers

It is quite evident that the demand for i-line resists will grow substantially over the next five years. Since the mid-1980s, i-line steppers have increased rapidly as a percentage of total steppers shipped (see Figure 1). In 1990, i-line

Figure 1
Worldwide Stepper Shipments by Technology



Source: Dataquest (September 1991)

systems represented 36 percent of worldwide stepper shipments. Dataquest projects that i-line steppers will account for more than half of all steppers shipped in 1991.

However, the lack of consensus surrounding phase-shift masks, the development of production-worthy DUV steppers and resist, and the technical issues associated with mix-and-match strategies, are all factors that will have a significant impact on future i-line resist volumes.

Therefore, one important question is just how large the i-line resist market will grow? And what impact will DUV technology have on the growth of i-line resists?

Scenario 1: Aggressive Push to I-Line

Rather than use a single set of assumptions, we have forecast i-line resist growth based on two scenarios. In scenario 1, referred to as the push to i-line, we forecast an aggressive increase in the demand for i-line resists (see Table 1). In this scenario, we estimate that i-line technology will be used to build devices with 0.7 to 0.4µ geometries. In addition, i-line resists can be expected to be used for sub-0.4µ lithography in conjunction with phase shift mask technology. The successful implementation of phase mask technology is a key assumption in determining future i-line resist demand because it significantly impacts DRAM manufacturing strategies.

Dataquest believes that DRAM device production will account for the largest share of i-line resist consumption over the next five years. Three generations of DRAMs—the 4Mb, 16Mb, and 64Mb generations—will all use i-line resist. Resist volumes will grow rapidly because these are all high-volume production devices and the number of mask levels for each successive generation will increase. There will be 18 average mask levels for the 4Mb generation, 22 for the 16Mb, and 28 for the 64Mb.

In Scenario 1, we assume that critical mask levels in the 4Mb will shrink and that all versions of 16Mb will use i-line resists. Moreover, i-line resist will be used for all the noncritical layers in the 16Mb and 64Mb devices. I-line resist volumes used in the production of other types of devices such as logic and ASICs are expected to lag the volume ramp for DRAM production. DRAM device makers traditionally push lithography trends further and faster than does the rest of the industry. However, we expect i-line resist usage in other device categories to surpass the usage in DRAM applications toward the end of the decade as DRAM manufacturers move beyond i-line lithography to more advanced resist strategies.

Phase-Shift Masks

The benefits of phase-shift mask technology to a semiconductor manufacturer are clear: higher

Table 1
Worldwide I-Line and Deep-UV Resist Forecast (Thousands of Gallons)

Worldwide	1990	1991	1992	1993	1994	1995	CAGR (%) 1990-1995
Scenario 1: Push to I-line							
I-Line Volumes Total	4,700	12,700	41,200	85,800	107,800	146,900	99.1
DRAM	3,400	9,200	27,500	56,800	65,500	93,400	
Others	1,300	3,500	13,700	29,000	42,300	53,500	
Deep-UV Volumes Total	1,000	2,000	3,000	4,000	5,000	8,000	51.6
I-Line plus Deep-UV	5,700	14,700	44,200	89,800	112,800	154,900	
Scenario 2: Push to Deep-UV							
Worldwide	1990	1991	1992	1993	1994	1995	
I-Line Volumes Total	4,700	12,700	35,200	80,000	99,900	118,000	90.5
DRAM	3,400	9,200	21,500	51,000	57,600	64,500	
Others	1,300	3,500	13,700	29,000	42,300	53,500	
Deep-UV Volumes Total	1,000	2,000	9,000	9,800	12,900	36,900	105.8
I-Line plus Deep-UV	5,700	14,700	44,200	89,800	112,800	154,900	

Source: Dataquest (September 1991)

resolution and greater depth of focus with existing stepper technology and photoresist processing. Along with the benefits, however, come a host of technical and marketing issues that must be overcome. Several technical and marketing issues must be resolved in order for our aggressive *i-line forecast* to be achieved.

Technical issues to be resolved include the following:

- Variety of different types of phase-shift masks—no clear winner
- Significant CAD data requirement for preparing phase-shift mask pattern
- Phase-shift materials limited: materials must be resistant to chemicals and high-pressure cleaning; must have acceptable transmission at the i-line (and potentially deep-UV) wavelength
- Two-layer structure (chrome and phase shift) requires defect-free resist coating during mask fabrication
- Mask inspection process more complicated: more types of defects; defects print larger; limited number of inspection tools available today
- Current phase-shift mask repair technology is limited to none

Marketing issues to be resolved include the following:

- Phase-shift masks only suited to devices with highly repetitive patterns; not all device types
- Phase-shift masks will only be used on a limited number of critical process layers, not for every mask level
- Cost of phase-shift masks is 5 to 10 times higher than for conventional chrome masks
- Potential of limited use for only one or two DRAM generations
- Viable competitive technologies: excimer/deep-UV and direct-write e-beam lithography in the 64Mb DRAM and 256Mb DRAM generations

Scenario 2: Aggressive Push to Deep-UV

In this second scenario, DUV resist begins to ramp several years earlier than in Scenario 1 (see Table 1). This growth occurs at the expense of i-line resist usage in DRAM production. Our push to deep-UV scenario hinges on the following three assumptions.

- Mask makers will not solve the problems necessary to commercialize phase-shift technology by the middle of 1992. If the major problems are not ironed out within the next year, DRAM makers will be forced to use DUV technology for the 16Mb shrink and 64Mb DRAM.

- Resist vendors will have a good DUV resist available within a year. An informal survey of semiconductor manufacturers reveals their belief that the availability of a commercial DUV resist is the single most important issue holding back DUV lithography.
- A variety of additional processing issues need to be solved for DUV. For example, antireflective coatings need to be developed because all levels reflect at DUV wavelengths. Device makers must also be able to etch these coatings with existing processes.

Excimer laser source stability and uniformity have been steadily improving over the past several years but will also remain a key issue in determining the success of DUV lithography.

If these hurdles are overcome, Dataquest expects DUV resists to begin growing in the 1993 time frame. The first applications for DUV resists will be in 16Mb DRAM device production. In Scenario 2, Dataquest expects DUV resist to be used for the critical layers in the production of the shrink version of the 16Mb. The 64Mb will use DUV resist for most of the 28 masking steps. Non-DRAM device manufacturers are expected to begin using DUV resist in production in the 1994 time frame.

Dispense Volumes

Over the past several years, photoresist dispense volumes have been steadily falling. Track vendors are developing new dispense nozzles and pump systems that provide more precise and repeatable dispense volumes, thus enabling smaller volumes to be used. Reduced dispense volumes on track equipment will cut hardest into the demand for i-line and DUV resists because new advanced track systems with improved resist dispense capabilities typically are purchased along with the more advanced lithography tools such as i-line and excimer/deep-UV steppers.

The current dispense volume for an i-line resist on a 150mm wafer is 2.7 to 3 cubic centimeters (cc) and 3.3 to 4cc on a 200mm wafer (see Table 2). As pump technology and nozzle design improves, Dataquest expects dispense volumes to decline even further. We estimate that leading-edge track equipment will deliver 1.5cc of i-line resist to cover a 200mm wafer

Table 2
I-line Dispense Volume Trends
(Volume in Cubic Centimeters)

Wafer Diameter	Current Dispense Volumes	Expected Volumes in 1995
150mm	2.7-3	1.5
200mm	3.3-4	2.5

Source: Dataquest (September 1991)

by 1995. The bad news for resist manufacturers is that i-line volumes will not grow as quickly as g-line materials have in the past. However, the good news for the resist companies is that i-line and DUV resist prices are expected to remain much higher than g-line prices.

Dataquest Perspective

The demand for i-line resist will grow rapidly over the next four years as device makers begin building devices with geometries less than 0.7μ. Volumes of i-line resist may well meet our aggressive forecast if device makers adopt phase-shift technology. Resist vendors with a strong i-line resist product offering will certainly benefit as the market demand ramps.

However, the most likely outcome is that i-line resist growth will fall somewhere between the two proposed scenarios. The breakthroughs in phase-shift technology are expected to come from the labs of a few large device makers such as IBM and Hitachi. These companies are expected to use phase-shift masks in production several years before the merchant mask makers will provide phase-shift masks to the semiconductor industry in general. Such a delay may well drive some device makers to a DUV strategy and cut into our aggressive i-line forecast.

The uncertainties and spiraling development costs associated with i-line resist point to a worrisome long-term trend for resist vendors. As lithography strategies and resist products multiply, the investment to move new resists from R&D to production is skyrocketing. So, resist vendors scrambling to stay in the game are often betting on a given outcome because they cannot afford to cover all the bases. For many companies it may well be an all-or-nothing bet. ■

By Kunio Achiwa (Tokyo)
Mark FitzGerald (San Jose)
Peggy Marie Wood (San Jose)

Semiconductor Manufacturing

Strategic Partnering for Contamination Control

"No man is an island, entire of itself. . . . Every man is a part of the main," wrote poet John Donne. He could very well have been talking about the semiconductor industry, where partnering has a long history.

Semiconductor companies have long been dependent upon other semiconductor companies for second-source arrangements. In recent years, cooperation has taken the form of joint ventures in both manufacturing and development because of the large expenditure necessary for manufacturing and development. Examples of these new forms of cooperation include a joint-venture fab by Texas Instruments Inc., the Singapore Development Agency, Hewlett-Packard Company, and Canon; AT&T and NEC Corporation's agreement to jointly develop a 0.35μ device; and the IBM and Siemens joint-venture 16Mb DRAM fab in France. These examples of strategic partnering by semiconductor companies are fairly well known in the industry.

Gas Companies and Partnering

Not so well known, however, is the scope of strategic partnering taking place in the semiconductor gas industry. Partnerships involving gas companies can exist anywhere in the manufacturing process: from the design of a fab before it is ever built all the way to the measurement of gas environments in the process chamber.

As in the case of partnerships between semiconductor companies, the main reasons for partnering in the gas industry are the rate and cost of technology change. Die sizes grow larger, line geometries shrink, mask and metal levels pile on top of each other, and process steps continue to accumulate.

Each one of these technology changes has an effect on contamination control. With the shift in focus of contamination control from people and air to equipment and materials (see SEMMS newsletter entitled "Equipment and Contamination in the 1990s," February 1991), a fab's gas supply system has emerged as one of the crucial battle lines in the war against microcontaminants.

Gas companies in this ongoing battle have formed alliances and worked with architectural and engineering (A&E) companies, general contractors, construction companies, pipe and valve companies, makers of analytical equipment, process equipment vendors, and semiconductor manufacturers. In each case the goal is to ensure that the gas delivered to the wafer surface is as clean as it can possibly be.

Gas Companies and Fab Construction

Gas companies now have the capability to take a gas delivery system from design to installation to certification. The success of such an endeavor depends on trust, teaming, and partnering with the major players involved in building a fab (the semiconductor company, A&E company, and construction companies).

Gas companies' expertise is important to the design team partly because of the cost of a fab's gas delivery system. The gas delivery system is one of the most expensive components of a new fab (see Table 1).

Gas companies' input in the design process can help to ensure that the best materials in process piping, valves, purifiers, and vaporizers are used in the gas distribution system.

The expertise that a gas company brings to bear in the fab design process is particularly important when it comes to evaluating the availability of materials used in construction. Availability of materials is crucial in fast-track fab builds, where construction begins before the design is fully completed. A gas company's knowledge of availability can help ensure that the materials actually designed-in for the gas

Table 1
Gas Delivery System for Large Facility (20,000 6-Inch Wafers/Month)

Specification	Price ($M)
Nitrogen	3
Bulk Tanks plus Vaporizer plus Filter	1
Cabinets	2
Piping (Bulk and Specialty)	12
Purifiers for Bulk Gases	1
Gas Monitoring Systems	1
Total	20

Source: Dataquest (September 1991)

delivery system will be available when needed, without any delays.

In addition to working with A&E and semiconductor companies, gas companies work with the general contractor and construction companies, particularly the suppliers of high-purity process piping. Ultraclean process piping is very important in process cleanliness. A rough inner surface in a process pipe can be a source of contamination, and for this reason advanced-process piping is electropolished and has a very low roughness average (RA).

Typically, what is known as a clean-build procedure is followed in the installation of high-purity piping. For example, all welding might be done in a Class 100 environment using argon purge gas from a liquid source. Gas companies not only provide expertise in specifying process piping, they also supervise the clean-build procedure itself.

Gas Purity Requirements

Such pains are taken during the construction process because impurities can have undesirable effects in many process technologies requiring gaseous environments. Gas purity requirements are now approaching one part per billion (see Table 2).

Impurities include particles, oxygen, moisture, metallics, and carbonaceous materials. Process technologies that are sensitive to impurities include the deposition of aluminum films, the deposition and growth of epitaxial films, the formation of silicides, and the overall quality and characteristics of metal-oxide semiconductors.

The measurement of such small levels of impurities is no easy task. Hitachi has developed an atmospheric pressure ionization mass spectrometer (API-MS) capable of parts-per-trillion measurement. Hitachi has already shipped several such units to gas vendors. Linde (a division of Union Carbide) has also recently completed a joint program with EXTREL Corporation of Pittsburgh, Pennsylvania, to develop an API-MS.

Table 2
SEMATECH's Goals for Gas Purity at Point of Connection and Point of Use

Phase	Year	Maximum Impurity Parts per Billion (ppb)
I	1989	<100
II	1990	<10
III	1993	<1

Source: SEMATECH, Dataquest (September 1991)

Partnerships within the Fab

To achieve and maintain these gas system purity goals, some semiconductor manufacturers are beginning to ask gas companies to take more responsibility for the gas distribution systems within their new fabs. This typically involves the gas company having a person onsite and reporting functionally to the semiconductor company.

Examples of on-site management include Air Products at Motorola Incorporated's MOS 11 in Oak Hill, Texas, and Texas Instruments' fab in Avezanno, Italy. Linde has on-site management at NEC's fab in Roseville, California, and also at SEMATECH's Austin, Texas, fab.

One advantage of on-site gas management is that it allows gas companies and semiconductor companies to focus on what they know best: gas companies on gases and gas distribution systems and semiconductor companies on device manufacture. Additional benefits of an on-site partnership include a reduction in the mean time to repair of gas systems, an ability to implement continuous improvement programs, and ongoing purity guarantees at the point of connection.

Gas companies also bring their expertise to bear in the process chamber itself by measuring trace contaminants in the chamber. By testing for contaminants after different phases of operation, they determine when a system is vulnerable to contamination and make effective recommendations to correct the problem.

Dataquest Perspective

Gas companies are engaged in strategic partnering during all stages of semiconductor manufacture. Gas companies work with A&E companies before a fab is even built, and they work in the process chamber after the fab is built. The common thread that ties the many partnerships of gas companies together is contamination control.

Contamination control presents opportunities for vendors from every aspect of semiconductor manufacturing to add significant value to their products and services. Eliminating potential contaminants from equipment and materials will be the focus of contamination control efforts in the foreseeable future. Dataquest believes that there will be significant partnering activity between diverse groupings of equipment companies, materials companies, fab construction companies, and semiconductor companies in the area of contamination control. We also believe that the ability to partner and bring particular focused expertise to bear on general industrywide problems will be a competitive advantage throughout the 1990s. ■

By George Burns

SEMATECH's Report Card

Summary

According to a recent GAO report on SEMATECH, member company executives are generally satisfied with SEMATECH's overall research priorities, progress on 54 ongoing research projects, and management control over its research program. However, the report also focuses on one key thrust area—lithography—where two "high-priority" projects are experiencing delays. The member company executives noted that SEMATECH's projects with the two principal U.S. suppliers of lithography equipment (GCA and Silicon Valley Group Lithography [SVGL]) are behind schedule. The GCA equipment is experiencing lens problems, and the SVGL joint development project (JDP) was delayed because of the sale of Perkin-Elmer. Even with these delays, SEMATECH is doing an overall good job of helping strengthen the U.S. semiconductor equipment industry.

Progress Toward Mission

SEMATECH's mission is to further semiconductor manufacturing technology and enable the U.S. semiconductor industry to regain world manufacturing leadership. SEMATECH will work with suppliers to improve equipment performance in the following key thrust areas:

- Lithography
- Multilevel metals
- Manufacturing methods, processes, and systems
- Furnaces and ion implant

SEMATECH members are generally satisfied with the thrust areas identified because they represent areas strategic to semiconductor manufacturing. By February 7, 1991, SEMATECH had 54 projects in work and had completed 9. The majority of the SEMATECH projects currently under way are scheduled for completion by 1992. Therefore, it is too early to determine exactly what effect SEMATECH has had or will have on helping the United States regain world manufacturing leadership. Even after the projects are completed, it will be several years before some of the equipment suppliers SEMATECH is working with can compete in the turbulent worldwide semiconductor equipment market.

Progress Toward Milestones

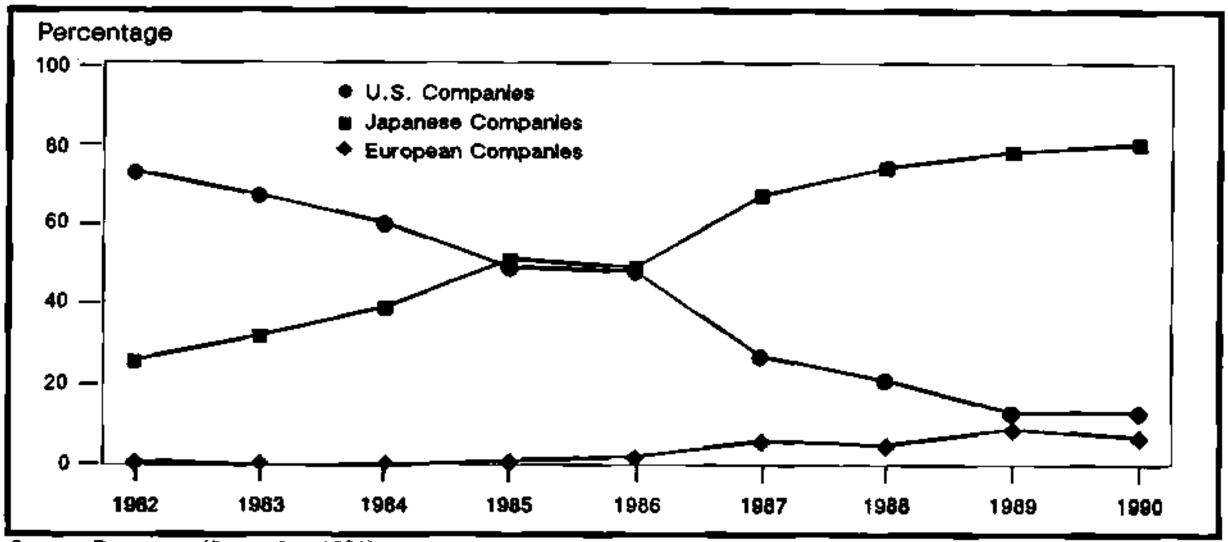
As of October 1990, member companies believed that 70 percent (40) of the projects were on schedule or were no more than two months behind and that 30 percent (17 projects) had slipped two to five and a half months. Of these 17 projects, 10 are rated as high priority. The member companies are generally satisfied with progress on the projects and believe that they are under good control. SEMATECH's top management has a strong commitment to its members to deliver results on schedule. This commitment is reflected in the fact that 70 percent of all projects are basically on schedule.

Lithography Stepper Projects

The report focuses on one key thrust area—lithography stepper development—and notes that it is experiencing some delays. Two particular projects experiencing delays are GCA's XLS stepper improvement program and SVGL's step-and-scan exposure system improvement program. The GCA project focuses on improving the performance of GCA's AUTOSTEP 200 i-line stepper; the SVGL project focuses on improving the performance and reliability of this advanced lithography system. One member company executive noted that because SVGL is developing a fundamentally different technology, it may provide the United States with a leader even if GCA does not succeed.

The report also states that member companies noted the competitive strength of foreign lithography equipment companies, and were uncertain whether either company will generate sufficient equipment sales to become competitive in the world market. As Figure 1 illustrates, it took the Japanese several years to dominate the lithography market. Only time will tell if GCA and SVGL will be able to regain a competitive advantage. This cannot be judged for at least another three to four years. However, an immediate result of SEMATECH equipment

Figure 1
Worldwide Stepper Unit Shipment Market Share



Source: Dataquest (September 1991)

improvement programs is that member companies are already considering purchasing more equipment from U.S. suppliers than they have bought in the past.

Dataquest Perspective

SEMATECH is helping U.S. semiconductor equipment suppliers by infusing funds to help with the large capital requirements needed to sustain new product development and introduction. However, many other factors must be considered, especially when trying to recover lost market share. The equipment business is particularly risky because large sums must be invested for unrecoverable up-front R&D.

SEMATECH seems to be having a positive impact on the U.S. semiconductor industry, specifically the equipment industry and its ability to deal with the forces mentioned earlier.

One factor that must be considered when attempting to recover market share is switching costs. Japanese equipment manufacturers have a large installed base, and semiconductor manufacturers have developed their processes on these tools. As a result, switching suppliers may result in additional costs for technical help, costs and time in testing and qualifying the new tool, and cost for employee training. Another consideration is the rivalry among the equipment suppliers. Some suppliers have a reputation of placing great importance on achieving success in order to further other corporate objectives. In this case, suppliers may resort to behavior that involves potential willingness to sacrifice profitability.

SEMATECH seems to be having a positive impact on the U.S. semiconductor industry, specifically the equipment industry and its ability to deal with the forces mentioned earlier. Intangible benefits derived from SEMATECH include a national awareness of supplier partnering and a spirit of cooperation among member companies that, until SEMATECH's existence, were typically unwilling to share technology and other developments with their competitors. As technology complexity increases and the resources required to transfer this technology into manufacturing increase, partnering and other cooperative forms will be required to survive. SEMATECH is facilitating this process in the United States in an effort to ensure that U.S. semiconductor manufacturers will have access to leading-edge, state-of-the-art equipment. So in the final analysis, what grade does SEMATECH get for overall performance? How about a B. ■

By Jeff Seerley

News and Views

Bechtel Opens Regional Office in Oregon

The Pacific Northwest has become a center of significant new fab activity: Fujitsu in Gresham, Oregon, and Intel's new R&D facility in Aloha, Oregon, are the two most recent examples of the region's burgeoning semiconductor muscle. We believe that there will be more to come—both Oki Electric and Toshiba have been rumored to be considering new fabs in Oregon in the near future.

In a move to support the growth of the semiconductor industry in the Pacific Northwest, Bechtel recently announced that it has opened a regional office in Portland, Oregon. Bechtel thus joins clean room architectural and engineering companies and clean room construction companies such as IDC, RUST, Harris Group, Lepco, and CRS Sirrine, which already have offices in the area. Bechtel's Portland office will be headed by John Henri, who was the project director responsible for the building of Fujitsu's new fab.

By George Burns

In Future Issues

Watch for the following topics in future issues of *Dataquest Perspective:*

- More News and Views

Errata

We recently discovered errors in Table 1 of the Semiconductor Equipment, Manufacturing, and Materials *Dataquest Perspective* Volume 1, Number 7 article entitled "Five-Year Capital Spending Forecast: More Stable Growth Than in the Past." A corrected version of the table follows.

Table 1
Regional Capital Spending Forecast
(Millions of Dollars)

Region	1990	1991	1992	1993	1994	1995	CAGR (%) 1990-1995
United States	4,088	4,194	5,075	6,278	6,660	7,153	12
Percent Change	5	3	21	24	6	7	
Japan	5,425	6,216	7,221	8,748	9,157	9,734	12
Percent Change	-1	15	16	21	5	6	
Europe	1,512	1,759	1,934	2,798	2,978	3,092	15
Percent Change	25	16	10	45	6	4	
Asia/Pacific-ROW	1,495	1,954	2,564	3,312	3,741	3,849	21
Percent Change	-22	31	31	29	13	3	
Worldwide	12,519	14,123	16,794	21,136	22,536	23,829	14
Percent Change	0	13	19	26	7	6	

Source: Dataquest (September 1991)

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Dataquest Perspective

Semiconductor Equipment, Manufacturing, and Materials

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Market Analysis

Will 4Mb DRAMs Have a Short Life?

Introduction

When plummeting 64Kb and 256Kb DRAM prices in the 1985 semiconductor recession caused major chipmakers to restrain capital investment, only Toshiba continued aggressive investment in 1Mb DRAMs; later, it dominated the market. Now Dataquest sees more competition in the 4Mb DRAM market. Hitachi has a slight lead, closely followed by Toshiba, NEC, Mitsubishi Electric, and Fujitsu. Slow growth of 4Mb demand appears to help narrow the difference. Empirical evidence shows that chipmakers that dominated the DRAM market invariably enjoyed a significant growth in semiconductor revenue, and in order to recover their gigantic investment, 4Mb chipmakers are engaged in a serious race for survival.

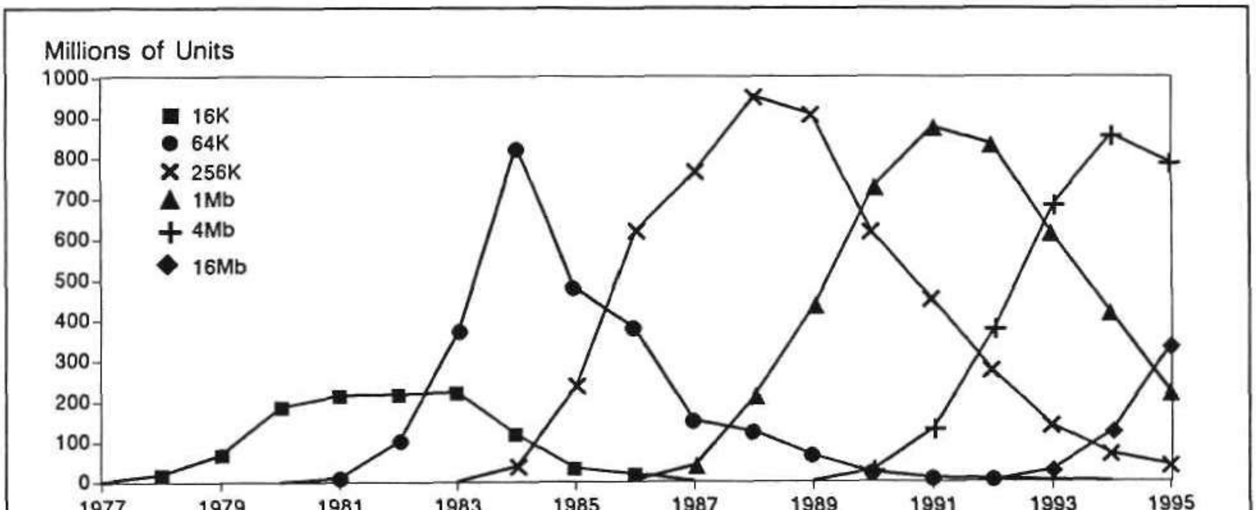
This year is supposed to be the year for 4Mb DRAMs. However, with volume production of 16Mb DRAMs scheduled in 1992 and as development of 64Mb DRAMs is accelerated, some say that 4Mb DRAMs may have a short life. If so, it would certainly be a life-and-death matter for DRAM suppliers that are behind in 16Mb development. A short life for 4Mb DRAMs would cause some companies to withdraw from the DRAM business. This article examines the potential life of 4Mb DRAMs.

The 4Mb DRAM Life Cycle

Since the birth of 16Kb DRAMs in 1977, the semiconductor industry has introduced a new generation to the market every three years. Although this technological tradition is expected to continue up to the 64Mb DRAM generation, the pace of volume production growth has slowed steadily from one generation to the next (see Figure 1). In particular, the initial growth of 4Mb production has obviously lost the momentum seen in past generations.

Dataquest looks at the peak of DRAM production in each generation. Assuming that a new generation of DRAMs is introduced every three years and production peaks every four years, the life cycle becomes longer for later generations. If applied to 4Mb DRAMs, production will reach a peak level between 1994 and 1995, at which time more than two generations will be in the market. Dataquest believes that this situation is likely because DRAMs, the demand of which has previously been governed by computer market growth (e.g., PC booms in 1984 and 1988) will find a wide range of applications including facsimiles, telephones, automobiles, VCRs, and TVs; therefore, consumption of DRAMs with smaller storage capacity will continue in the foreseeable future. Coexistence of several generations is already seen in non-DRAM memories, and DRAMs are not likely to be an exception to such a trend.

Figure 1
DRAM Life Cycle
(Millions of Units)



Source: Dataquest (August 1991)

PC Evolution and DRAM Consumption

The PC market absorbs one-half of DRAM supply. Based on shipment data, peak production exceeded that of the previous generation up to 256Kb DRAMs, but was down in 1Mb DRAMs (see Figure 1). A probable cause is that the increase in DRAM storage capacity has outpaced that of PC memory capacity, leading to a slowdown in DRAM consumption. PCs use main memories with 1 or 2MB (see Figure 2), which can be satisfied by much cheaper 1Mb DRAMs. Nevertheless, with main memory capacity expected to increase with wider use of Windows and other factors, the shift to 4Mb is likely to be accelerated. This is further evident in several types of laptops recently introduced to the market.

Another factor to consider in increasing memory capacity is the constant increase in data volume handled by large general-purpose computers and PC-application programs. Because the maximum capacity of PC main memories is largely governed by the operating system and CPU architecture, the relationship between the average capacity of PC main memories and OS has been examined by the industry in general. In 1983, the wide use of DOS 2.0 boosted the average memory capacity to 512KB, consuming a large amount of 64Kb DRAMs. Then in 1985, emergence of DOS 3.0 pushed main memory capacity up to 640KB and spurred consumption of 256Kb DRAMs. Today, the average memory capacity is 1.5MB, using 1Mb DRAMs. However, current OS will limit the increase in the main memory capacity, driven by the upgrading of OS versions and improvement of application software from 2MB to 3MB until 1993. Although OS/2, which is capable of handling a 16MB address space, is expected to drive a significant increase in main memory capacity, it will take more than three years before the new OS becomes widely used. Until then, Dataquest believes that 4Mb DRAMs will be the mainstream device, and the shift to 16Mb will take place after 1994.

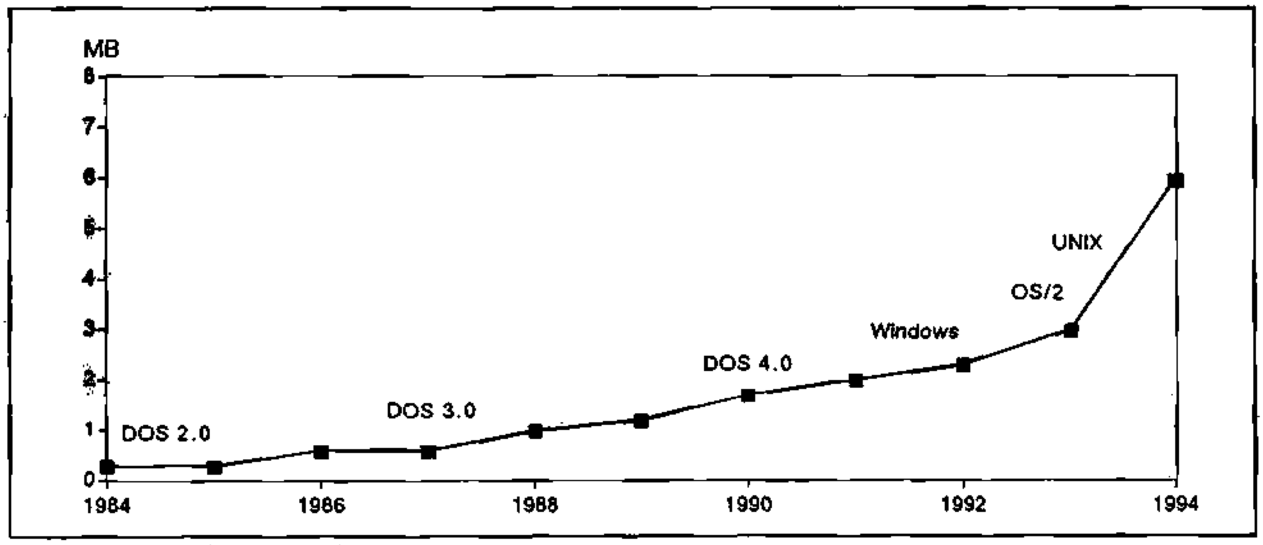
Improvement of CPU performance is also an important factor in determining the direction of DRAM consumption. Currently, 32-bit CPUs are at the leading edge and will be the mainstay of PCs for upcoming years, ending the CPU evolution from 4- to 8- to 16- to 32-bit devices. This evolution will affect DRAM consumption, which has been growing with CPU performance improvement. Dataquest therefore concludes that current needs are satisfied by 4Mb DRAMs, and consumption is not likely to grow significantly in the next few years.

Diversification of 4Mb DRAMs

DRAM makers have to provide many types of DRAMs including different packaging, different speed, and different organization because of diversified applications.

Although the computer main memory capacity will continue to increase in the future, it does

Figure 2
PC Main Memory
(Megabytes)



Source: Dataquest (August 1991)

not necessarily mean that all systems require such large memory. Dataquest expects consumption of x4, x8, and x16/18 types of DRAMs to grow rapidly (see Figure 3); if 4Mbx1 versions are used for the main memory of a 16-bit PC, 16 units of 4Mbx1 DRAM are required, and 32 units in case of a 32-bit CPU-based PC. A 16-bit PC using a 1Mbx4 DRAM would require 4 units of 1Mbx4 DRAM. A 16-bit PC using a 256Kbx8 DRAM would require 2 units of 256Kbx8 DRAM. Dataquest anticipates that about two-thirds of 4Mb DRAMs will be x4 versions and x8, x16/18 versions. These wide-bit DRAMs minimize the need for replacement with 16Mb DRAMs in order to save space.

16Mb DRAMs and 4Mb Shrink Versions

The 16Mb DRAM will be initially marketed as x1 and x4 versions in a 475-mil package. Dataquest believes that the market will not be ready to accept these products because the high price and large package are likely to discourage users from replacing 4Mb DRAMs just because of quadrupled storage capacity. The industry has experienced this phenomenon with the 350-mil SOJ package of 4Mb DRAMs; the full-fledged 16Mb DRAM market will likely have to wait until the second-generation version of 400-mil SOJ is introduced.

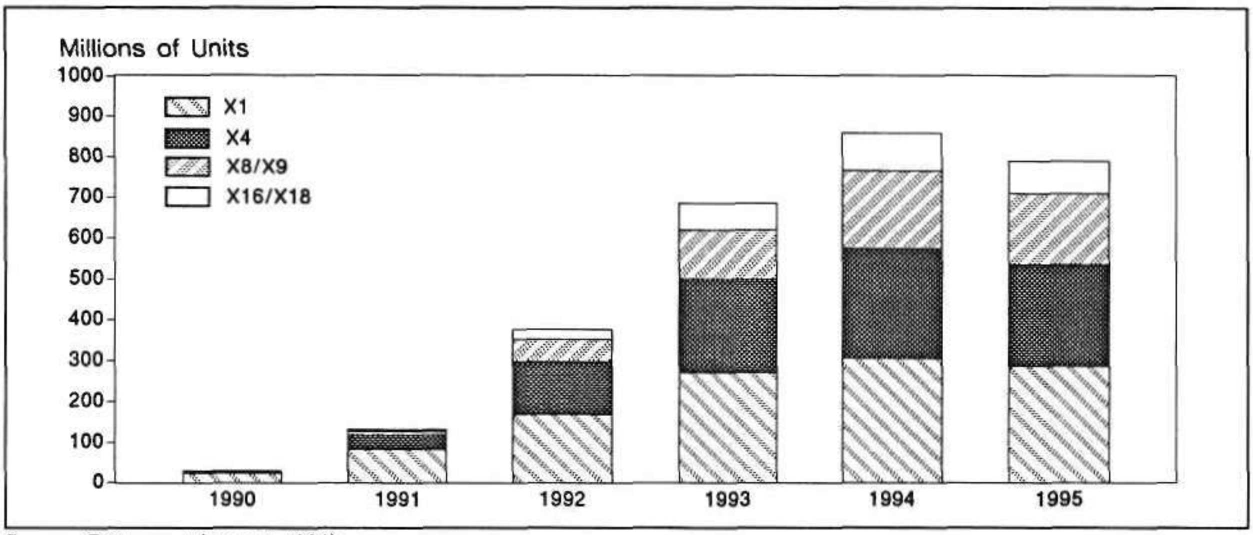
With the current cycle of introducing x1 commodity products with higher integration every three years, the available memory capacity may exceed the growth of per-bit demand for DRAMs by system products, leading to production decrease. This problem cannot be avoided if DRAMs continue to rely on being used in computers. Thus, the industry must explore other uses for DRAMs or reduce production costs to improve profitability.

One solution is to manufacture 4Mb shrink versions by using 16Mb DRAM technology; chipmakers plan to introduce this shrink-version device as their third-generation version. By using a 0.5-micron process, the chip size can be made one-half the size of the first-generation versions, reducing the price significantly and using smaller packaging. Many chipmakers anticipate that, by operating the 16Mb DRAM production line for 4Mb shrink versions, they can offer favorable foreign market values (FMVs) once 16Mb production begins to dominate the market. This intention is clearly reflected in aggressive investment by leading DRAM chipmakers on 16Mb facilities. In this sense, 4Mb DRAMs play a key role in surviving the next-generation DRAM market.

DRAM Price Trends

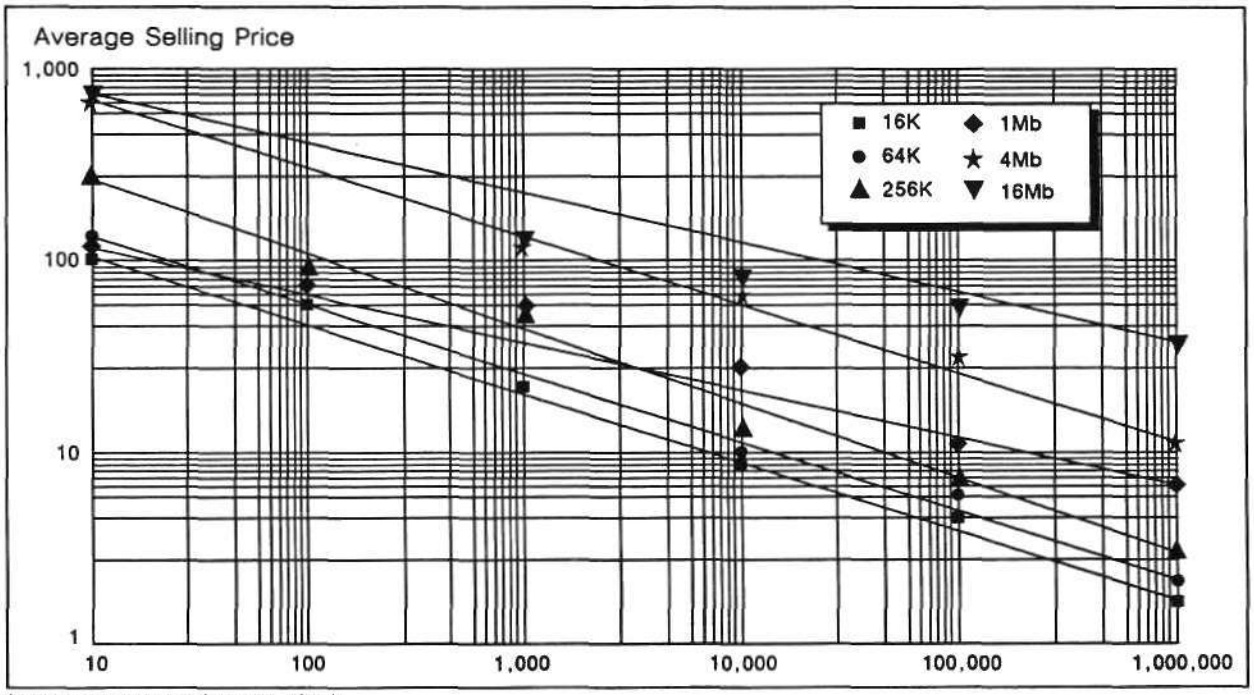
DRAM price trends, from market introduction to total shipments of 1 billion units, are examined for each generation. Although prices declined in a similar pattern from the 16Kb to the 256Kb generation, the rate of price decline became moderate for the 1Mb and 16Mb generations (see Figure 4). Prices for the 1Mb DRAM remained at a high level in 1989 and declined relatively late. However, our analysis suggests that 16Mb prices are likely to follow a similar pattern.

Figure 3
4Mb DRAM Demand Forecast



Source: Dataquest (August 1991)

Figure 4
Price Learning-Curve Comparison



Source: Dataquest (August 1991)

Now that the pace of increase in memory capacity of memory ICs has exceeded that of memory capacity of system products, users will shift their focus of interest from space-saving merit to price advantage. As long as 16Mb prices are high, the life of 4Mb DRAMs will be prolonged accordingly.

Dataquest believes that 16Mb prices will not fall as much as users expect and thus will not follow the learning curves experienced in 256Kb and older products for the following reasons:

- The increase in the number of processes will increase the influence of particles and contamination on slowing the pace of yield improvement.
- DRAM makers are delaying the shift to wafer processing from 6 to 8 inches.
- Increase in development costs will create a diverse product mix.
- The increase in product line will make it difficult to achieve cost reduction through volume production of a small product line.
- Value-added products including low voltage, low power consumption, and high speed will increase.
- Capital spending will continue to increase (see Figure 5).

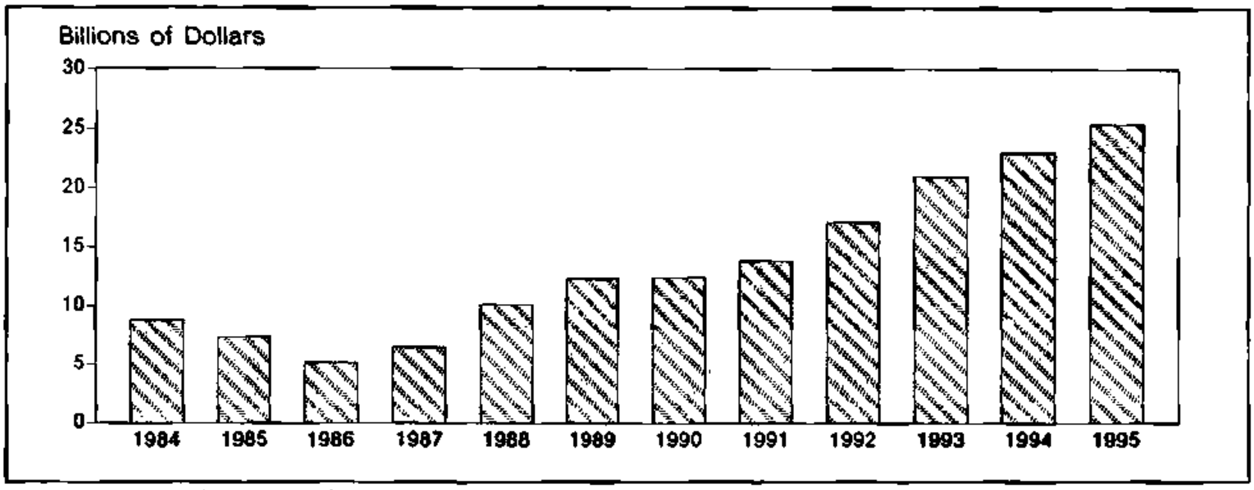
All of these factors will work to fend off the shift from 4Mb to 16Mb devices.

Dataquest Perspective

From an analysis of the factors affecting 4Mb DRAM consumption, Dataquest draws the following conclusions:

- In terms of life cycles, 4Mb, 16Mb, and later generations are expected to have a longer product life.

Figure 5
Worldwide Capital Spending
(Billions of Dollars)



Source: Dataquest (August 1991)

- 4Mb prices will decline at a faster pace than 16Mb prices.
- Increasing applications will keep products in the market longer, where a few generations of products will coincide.
- 4Mb DRAMs will dominate the PC market, with main memory capacity up to 6Mb.
- Increasing use of Windows and OS/2 will boost main memory capacity to serving as a momentum for the shift to 4Mb DRAMs.
- Various technological hurdles must be cleared before volume production of 16Mb DRAMs begins.
- 4Mb shrink versions will be used for early recovery of investment on 16Mb production facilities while acting as a spearhead for exploring the 16Mb market.

Dataquest believes that these findings indicate a long life for 4Mb DRAMs. ■

By Akira Minamikawa

U.S. Gas Vendors Close Rank on Price Hikes

The major industrial gas vendors in the United States—Air Liquide, Air Products, Airco, and Linde—have all announced price increases for liquid/bulk gases. Prices for nitrogen, oxygen, argon, hydrogen, and helium will be impacted. Average price increases are in the 7 to 10 percent range.

Linde led the industry in the announcement of the price hike, and the rest of the vendors quickly followed suit. Dataquest believes that prices for atmospheric products have fallen well below the level at which companies can recover their plant costs.

The question is how well vendors can make the price hikes stick. There will be pressures among the vendors to break rank in certain regions of the country where plant loading is very light. Dataquest estimates that air separation plant utilization on average is running just over 80 percent.

The North American industrial gas business has been very competitive over the last five years. For instance, Airco had been pursuing a low-cost producer strategy since the early 1980s, causing downward pressure on prices. However, under new management, it appears to have abandoned this strategy.

A longer-term threat to the profitability of the bulk industrial gas business is changes in on-site technology. New on-site technology threatens to make it more cost-effective for low-volume end users to convert to on-site generation. If this technology is widely adopted, bulk plant loading will suffer, and margins on liquid products may well collapse.

In this environment, industrial gas companies are expected to be very cautious about any investment. As an example, Air Liquide has just announced a new 750-ton-per-day plant in the Los Angeles area; however, the company is retiring two older plants so net capacity is not expected to change.

Dataquest Perspective

The success of the current price increase will ultimately depend on the discipline of the gas vendors. Competitive market pressures—capacity utilization, market share strategies—suggest that this price hike will be marginally successful. However, the current prices for bulk products point to a bleak profitability picture, and consequently, industrial gas companies may show more discipline than they have in the past. ■

By Mark FitzGerald

Semiconductor Manufacturing

A New Sword to Cut the Cost of Capital and R&D: TI's Harmonization Program

Texas Instruments has developed a method of product development that has revolutionary implications. TI's new method of product development is called harmonization. Rather than design just one product for manufacturability, the goal of TI's harmonization program is to design several different product families with a high degree of compatibility in equipment sets and process recipes. The result of this compatibility would be that each different family can be manufactured on the same equipment set in the same fab.

If this program is successful (and the company believes that it has already achieved success), TI believes that fab lifetimes would be doubled, product development costs cut 25 to 35 percent, and its factories loaded much more efficiently.

Harmonization: The Next Step?

TI's developmental program is similar in one regard to those of many state-of-the-art semiconductor manufacturers: It is focused on designing products for manufacturability. Manufacturability is a method of product and process development that gained currency in the late 1980s. It owes a great deal to Japanese manufacturers.

Essential to the concept of manufacturability is the idea that products be designed so that they can be easily and efficiently manufactured in volume production. Before the concept of manufacturability, many semiconductor products were designed without much thought given to how they would be produced in volume. Production of working devices in a developmental lab was thought to be sufficient.

Many semiconductor manufacturers today focus on designing one product family at a time for manufacture in a fab that was specifically designed and equipped for that product family (e.g., DRAMs). TI, however, is taking manufacturability to the proverbial next step. It is now designing several product families (e.g., DRAMs, logic, NV flash memory) so that they can be manufactured in the same fab on the same equipment with common process recipes.

Harmonization: How It Works

TI has a near-term goal of having its DRAMs, logic, and NV memory manufactured on an almost identical equipment set—an equipment set that has a compatibility of at least 95 percent.

Process recipes refer to changes in process parameters such as gas pressures in deposition or dosages in implantation. TI claims that its process recipes for a given technology generation (e.g., 0.8 micron, 0.5 micron, 0.35 micron) are now 60 to 65 percent compatible. This is in marked contrast to what has gone before: Before harmonization, the process recipes for DRAMs, logic, and NV memory were only 10 to 15 percent compatible.

TI has also found that although process engineers would add "individualistic" changes to process recipes, these changes would not be justified by increased device performance. TI concluded that at least one-half of the devices that it designed did not need different recipes.

Benefits of Harmonization

The benefits of harmonization include increased yields, especially for lower-volume products; a lengthening of a fab's productive lifetime; more efficient loading of a fab; and major reductions in product and process development costs.

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Yield Benefits

TI has seen yield increases in its low-volume products. For example, the 1Mb DRAM was brought up in one of TI's Dallas fabs. This fab is now producing digital signal processing (DSP) chips and graphics processors on the same line that produced the 1Mb DRAMs. TI reports that the initial yields of these DSP and graphics processors were three to five times higher than initial yields of similar devices brought up in nonharmonized fabs.

The learning-curve (sometimes known as experience-curve) theory postulates that as more units of a product are produced over time, a manufacturer learns to produce that product more efficiently. In producing semiconductors, this efficiency means higher yields. The increase in DSP chips' and graphics processors' yields is due to learning-curve benefits because of harmonization: The equipment and process compatibility between the two product families was such that TI's 1Mb DRAM learning-curve experience was transferable to the low-volume DSP production.

Dataquest notes that the high degree of compatibility between high- and low-volume products should also cause increased yields for TI's high-volume products. Production of lower-volume devices will count as part of the same learning-curve experience that affects high-volume production.

Fab Cost Benefits

Many companies run older-generation products through their older fabs. This extends a fab's lifetime and thereby reduces manufacturing overhead costs. However, these older-generation products are not usually designed for the fab in which they are running: The fab is reconfigured for these products.

With harmonization, products will be planned and designed for timed production release into the same fab. Thus, for example, TI plans to begin running advanced logic in a fab one year after the fab has started the latest-generation DRAM. Then, one additional year later, it plans to fabricate dense NV flash EPROMs in the same fab. Both the advanced logic and NV flash EPROMs will have been designed to be fabricated on essentially the same process—the latest-generation DRAM process. TI believes that this ability to quickly and easily add new product families to an existing fab can double the fab's lifetime.

An additional benefit of the harmonization program is flexibility, which will also cut the cost of manufacturing overhead. Because a wider mix of products are capable of production in the same fab, a company will be able to respond to the ebbs and flows of supply and demand and still be able to load its fab efficiently.

Product Development Benefits

TI no longer just develops a product; it develops what it calls a technology "node." Examples of technology nodes are 0.8-micron, 0.5-micron, and 0.35-micron products. Each node is developed for several product families (e.g., DRAMs, logic, NV memory). Because a very high degree of compatibility exists between the different products within a node, duplication of efforts and expenses for the development of the different products will be eliminated. TI estimates that its product development costs will be reduced by as much as 25 to 35 percent because of its harmonization program.

Dataquest Perspective

The semiconductor industry is one of the most R&D-intensive industries in the world. Currently, U.S. merchant semiconductor companies spend 14 percent of their revenue on R&D. Harmonization, by taking manufacturability from a one-product concept to a concept that embraces diverse product families, appears to be the logical next step in the evolution of the product development process. If TI's estimates of a 25 to 35 percent developmental cost reduction are accurate, R&D costs could fall to as low as 10 percent of revenue. For U.S. merchants, a 4 percent decline in R&D costs would be a savings of almost $1 billion. These substantial savings will go straight to the merchants' bottom line.

Dataquest notes that in addition to being one of the most R&D-intensive industries in the world, the semiconductor industry is also one of the most capital intensive in the world. Worldwide semiconductor capital spending is now 20 percent of semiconductor revenue—and growing. Because of this high degree of capital intensity, depreciation is a major expense in semiconductor manufacturing (e.g., as much as

30 percent of wafer manufacturing costs for advanced products). By extending fab lifetimes and allowing the fab to be fully loaded during that lifetime, harmonization will reduce depreciation costs.

Harmonization will also reduce depreciation in another way: by reducing capital spending. Separate product families that were once produced in separate product fabs on separate equipment sets will now be produced in one "harmonized" fab on one set of equipment. This one fab will have fewer pieces of equipment than did the formerly separate product fabs. The result will be a reduction in capital spending.

Reducing the number of equipment sets that a company buys may have an additional effect on the industry besides reducing capital spending. It may also work to reduce the number of preferred equipment vendors from which a semiconductor company chooses.

Harmonization is, thus, not only a sword that can cut deeply into the high costs of capital and R&D. It may also further trim the industry's list of preferred equipment vendors. ■

By George Burns

Company Analysis

A Quick Look at Cypress Semiconductor

This article provides a quick look at Cypress Semiconductor's semiconductor capital spending, R&D spending, capacity by line geometry, and recent company highlights as related to semiconductor manufacturing. This article is part of the "Quick Look" series of articles from Dataquest's Semiconductor Equipment, Manufacturing, and Materials service.

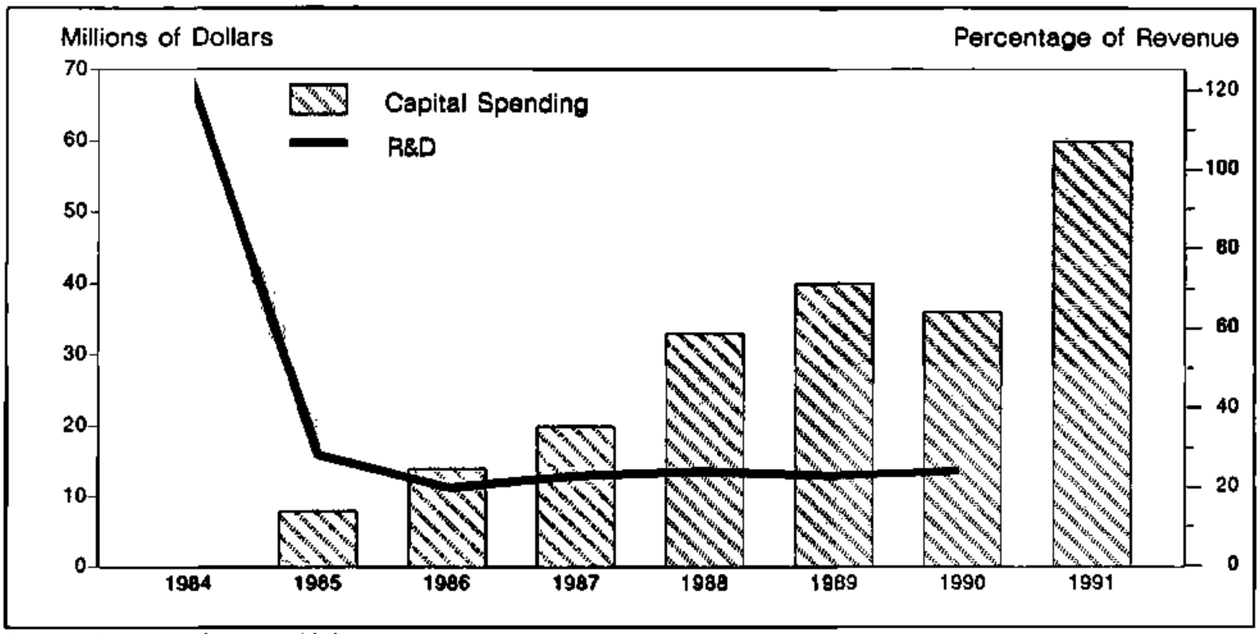
Semiconductor Capital Spending and R&D Spending

Figure 1 graphically illustrates Cypress' semiconductor capital spending and semiconductor R&D spending expressed as a percentage of semiconductor revenue by year from 1985 through 1990.

Manufacturing Facilities

Table 1 lists Cypress' existing and planned manufacturing facilities. Figure 2 illustrates the percentage distribution of Cypress' existing semiconductor capacity by line geometries.

Figure 1
Cypress Semiconductor—Semiconductor Capital Spending and R&D Spending by Year



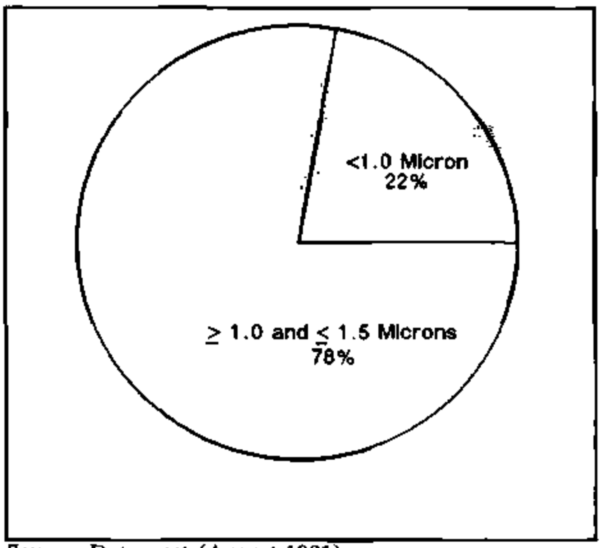
Source: Dataquest (August 1991)

Table 1
Cypress Semiconductor—Existing and Planned Facilities (1984 to 1994)

Location	Product	Wafer Size	Year
San Jose, California	SRAMs, MPUs	5-inch	1984
Round Rock, Texas	SRAMs, PLDs, RISCs, MPU	6-inch	1987
Round Rock, Texas	SRAMs	6-inch	1991
Bloomington, Minnesota	SRAMs	6-inch	1991
Round Rock, Texas	SRAMs	6-inch	1994

Source: Dataquest (August 1991)

Figure 2
Cypress Semiconductor—Existing Capacity by Line Geometry



Source: Dataquest (August 1991)

Company Highlights

The following discussion highlights significant events for Cypress Semiconductor:

- In January 1991, Cypress announced the purchase of VTC's fab from Control Data Corporation. Cypress paid $11.5 million for the property, plant, and equipment valued at $26.5 million. Cypress will also purchase leased equipment, which originally cost $32 million, for $3.2 million. This fab is now being run as an independent subsidiary called Cypress Minnesota Inc. (CMI), and the operation is expected to be profitable by the third quarter of this year. First-year revenue from this fab is projected to be $36 million. The fab has a production capacity of 8,000 wafers per month.

- In February 1991, Cypress issued a purchase order for a Novellus Concept One-W tungsten chemical vapor deposition (CVD) system and a Lam Rainbow etcher. This deal defeated an Applied Materials proposal for an Applied Precision 5000 CVD Tungsten system.

- In April 1991, Cypress and National Semiconductor came to a licensing agreement allowing Cypress to build and market National's 2Kbx9-bit ECL SRAMs. This deal enabled National to exit the ECL SRAM market while still giving customers a source for the proprietary device.

- In May 1991, Cypress purchased a Hampshire Instruments Series 3500 X-ray wafer stepper. The stepper has a throughput of 20 to 40 wafers per hour. Cypress plans to take delivery in 1992 and install the stepper in Cypress' San Jose fab.

- In August 1991, Cypress ordered two PAS 2500 steppers from ASM lithography. These steppers will be used to upgrade SRAM production capacity at CMI. Cypress plans to use the ASM steppers for 64K SRAMs through 1 megabit. Cypress already has an installed base of ASM steppers in both San Jose, California, and Round Rock, Texas. ■

News and Views

A Ticking Time Bomb for Photoresist Vendors

Dispense volumes for photoresist are falling, and it is going to cut hardest into the demand for i-line and advanced resists. Track vendors are developing pump systems with more precise and repeatable dispense volumes, enabling smaller volumes to be used. Most of these new systems are being sold into submicron fabs, which will use i-line and advanced resists.

The current dispense volume for an i-line resist on a 150mm wafer is 2.7 to 3.0cc and on a 200mm wafer, 3.3 to 4.0cc (see Table 1). The range of the dispense volume for each wafer diameter reflects the viscosity of the resist. The initial dispense volume for an i-line resist on a 200mm wafer was 5.0cc, so track vendors have made headway in reducing dispense volumes in just the past year.

As pump technology improves, Dataquest expects dispense volumes to decline further. We estimate that by 1995, leading-edge track equipment will deliver 1.5cc of i-line resist to a 150mm wafer and 2.5cc to a 200mm wafer. The net result is that i-line dispense volumes per mask level will not mirror g-line resist volumes per mask level.

Further compounding the problem is the trend among device makers to reduce material waste. Fabs are installing equipment that will permit the entire resist bottle to be drained. These efficiencies will be partially offset by increasing mask levels.

Table 1
Current Dispense Volumes—Positive I-Line Resist
(Units cc)

Wafer Type	I-line	G-line
150mm	2.7-3.0	2.8-3.5
200mm	3.3-4.0	NA

NA = Not available
Source: Dataquest (August 1991)

Resist vendors will need to recover their investments in i-line and advanced resist products. Consequently, Dataquest believes that prices for i-line and advanced resists will remain well above prices for traditional positive g-line resists. ■

By Mark FitzGerald

Nippon Sanso Gas Cabinet Update

Following the publication of Dataquest's 1990 gas cabinet market share (see *Dataquest Perspective* Vol. 1, No. 6, dated July 29, 1991) Nippon Sanso responded to our survey. The survey numbers are materially different from our previous estimate. Previously, we had estimated that Nippon Sanso's 1990 sales of gas cabinets totaled $17 million. Nippon Sanso has since reported 1990 sales of ¥1,260 million or $8.75 million. Using these updated sales, the total 1990 Japanese market for gas cabinets is now $20.4 million. ■

By Mark FitzGerald

In Future Issues

The following topic will be featured in a future issue of Semiconductor Equipment, Manufacturing, and Materials *Dataquest Perspective*:

- Point-of-use purifiers

The topics covered by SEMMS newsletters are selected for their general interest to SEMMS clients, which include wafer fab equipment suppliers, semiconductor materials companies, and semiconductor device manufacturers. The topics selected indicate the broad range of research that is conducted in the SEMMS group. Clients, however, often have specific information requirements that either go beyond the level of detail contained in the newsletters or beyond the scope of what is normally published in the newsletters. In order to provide complete decision support to our clients, Dataquest has a consulting service available to handle these additional information needs. Please call Stan Bruederle at (408) 437-8272 or Joe Grenier at (408) 437-8206 to discuss your custom requirements.

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Dataquest Perspective

Semiconductor Equipment, Manufacturing, and Materials

Vol. 1, No. 7 August 12, 1991

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Semiconductor Manufacturing

Five-Year Capital Spending Forecast: More Stable Growth than in the Past

Summary

Our January 1991 capital spending forecast was made just before the outbreak of hostilities in the Persian Gulf and at the beginning of an economic recession in the United States. Now that the war is over and the economic outlook has cleared somewhat, we are revising our earlier forecast. Capital spending should be up by 13 percent worldwide (see Table 1). Our January forecast had predicted 11 percent growth in 1991.

Our long-term worldwide forecast through 1995 has been modified downward, but only slightly. We had previously forecast capital spending to be $25.3 billion in 1995. We now expect capital spending to be $23.8 billion in 1995. The compound annual growth rate (CAGR) of our earlier forecast was 15 percent; the CAGR of our current forecast is 14 percent.

There are two reasons for the downward revision. First, because of better capacity planning, we do not expect as much of a capital spending binge in 1992 through 1994 as we did previously. Second, we do not expect the Asia/Pacific companies in Taiwan and Korea to expand at the "supernova" rates that they have in the past; however, Asia/Pacific-ROW will still be the world's fastest-growing region for capital spending.

In general, semiconductor capital spending will grow because the industry needs additional capacity over the next five years to support a 13 percent CAGR for semiconductor production. Globalization will also be a major factor in the growth of semiconductor capital spending, as will the continuing emergence of Asia/Pacific as a manufacturing center.

We are also witnessing the beginning of the 16Mb DRAM cycle, and this will have a strong effect on the demand for state-of-the-art equipment. The 16Mb DRAM devices are currently being sampled, and new fabs are being built to support volume production of these devices.

As in our previous forecast, Japan and the United States will continue to be the dominant regions of capital spending, although Europe and Asia/Pacific-ROW will experience the fastest growth.

Growth: Less Binges, More Stability

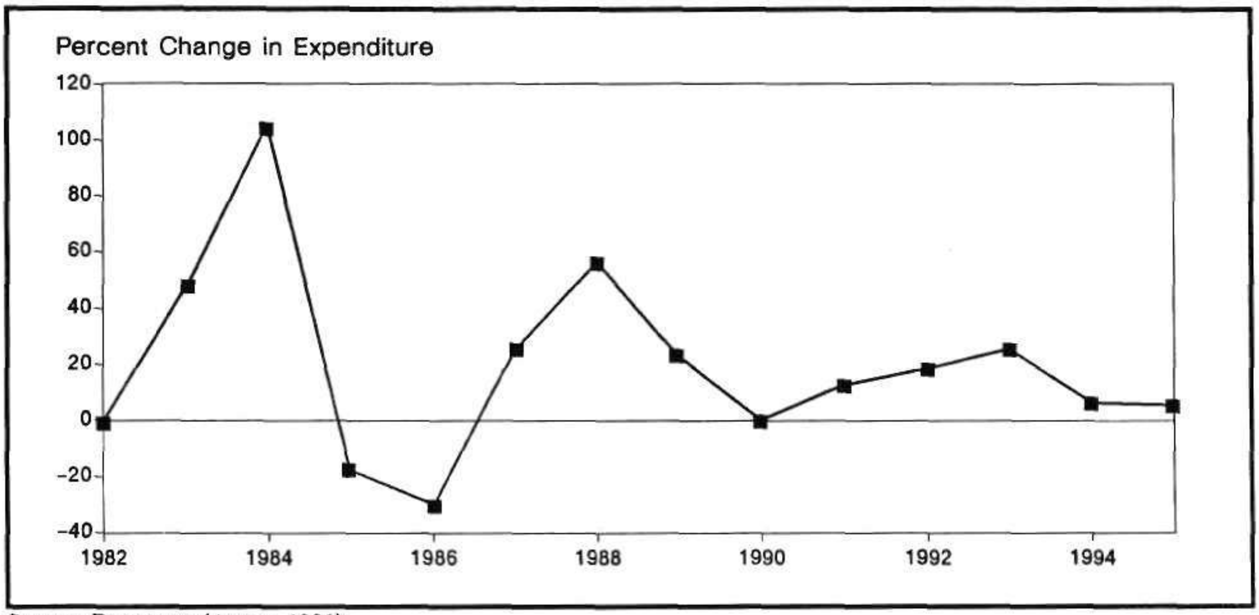
Semiconductor capital spending for the industry as a whole, although continuing to grow at a robust rate, will grow in a much more stable and programmatic manner, and spending plans will no longer be subject to sudden stops and starts as they have been in the past (see Figure 1).

Table 1
Regional Capital Spending Forecast
(Millions of Dollars)

Region	1990	1991	1992	1993	1994	1995	CAGR (%) 1990-1995
United States	4,088	4,194	5,075	6,278	6,660	7,153	12
Percent Change	-1	3	3	3	3	3	
Japan	5,425	6,216	7,221	8,748	9,157	9,734	12
Percent Change	5	3	3	3	3	3	
Europe	1,512	1,759	1,934	2,798	2,978	3,092	15
Percent Change	25	3	3	3	3	3	
Asia/Pacific-ROW	1,495	1,954	2,564	3,312	3,741	3,849	21
Percent Change	-22	3	3	3	3	3	
Worldwide	12,519	14,123	16,794	21,136	22,536	23,829	14
Percent Change	0	13	19	26	7	6	

Source: Dataquest (August 1991)

Figure 1
Semiconductor Capital Spending Patterns—1982-1995



Source: Dataquest (August 1991)

The reason for this stability is, in part, due to the size of individual companies' capital budgets. Each company in the top 10 capital spending ranking in 1991 has an annual semiconductor capital budget of over $500 million (see Table 2). Investment sums of this magnitude need to be planned well in advance and, increasingly, they need to be coordinated with the plans of other companies. For example, IBM and Siemens now have a joint-production agreement for equipping a 16Mb DRAM facility in Corbeil-Essonnes, France. AT&T and NEC have a joint-development agreement for a 0.35-micron CMOS process and are discussing the possibility of joint production. Texas Instruments has joint-production arrangements with several different companies: Kobe Steel in Japan, the Acer Group in Taiwan, and Canon and Hewlett-Packard in Singapore. Toshiba and Motorola (Tohoku Semiconductor) and LSI Logic and Kawasaki Steel (Nihon Semiconductor) are additional examples of joint-venture manufacturing.

These joint-production agreements are a direct result of the high capital costs associated with building and equipping a submicron facility. (For additional information on this subject, see SEMMS November 1990 Research Newsletter entitled "Technology Trends and Fab Costs: An Overview.") Joint-production facilities allow companies to share the burden and the risks associated with such large expenditures. The magnitude of such projects dictate a large degree of coordination and forward planning between the partner companies. Dataquest believes that the degree of coordination and planning provides greater stability in the growth of capital expenditure.

Table 2
Semiconductor Capital Spending:
The Top 10
(Millions of Dollars)

Company	Amount
Intel	900
NEC	822
Fujitsu	799
Texas Instruments*	790
Toshiba	747
Hitachi	747
IBM	733
Mitsubishi	650
Motorola	640
Matsushita	553
Total	7,380

*Total includes $330 million in non-TI funded joint ventures.
Source: Dataquest (August 1991)

In addition to contributing to the stability of the capital-spending environment, joint development and production has one further effect that is worth mentioning: Joint venture semiconductor partners will agree on a list of vendor companies to equip their joint-venture fab. Dataquest believes that equipment vendors that qualify for the joint-venture fab will become preferred vendors to both of the partner companies. Vendors that do not make the preferred list at the joint-venture fab may lose their preferred status in the individual partner companies.

Regional Markets

Japan

Japan continues to be the region where the largest amount of capital spending takes place. Spending by all companies in Japan, regardless of the region of ownership, was $5.4 billion in 1990. Dataquest anticipates that capital spending will reach $6.2 billion in 1991. A significant portion of this growth will be due to the construction and equipping of new 16Mb DRAM production facilities. Significant joint-venture activity is also under way in Japan: LSI Logic and Kawasaki Steel (Nihon Semiconductor) and Texas Instruments and Kobe Steel (KTI Semiconductor) are currently building new facilities.

Capital spending in Japan is expected to grow at a CAGR of 12 percent and reach $9.7 billion in 1995. This growth rate is not as high as the anticipated growth rate for Europe and Asia/Pacific-ROW, and it is much lower than the historical growth rate for capital spending in Japan. One of the main reasons for this slowdown in Japan's capital spending growth rate is that Japanese companies are globalizing their manufacturing operations. Both Europe and the United States will see additional Japanese fabs between now and 1995.

United States

U.S. spending in 1990 was $4 billion. This level is expected to increase to $4.2 billion in 1991—a relatively modest increase of 2.5 percent. The CAGR of expenditure in the United States from 1990 to 1995 is estimated to be 12 percent, with capital spending reaching $7.1 billion in 1995. This growth rate is less than that of Asia/Pacific-ROW and Europe. As in the case of Japan, this relatively low growth rate is in part due to the continued movement of U.S. manufacturers to establish facilities overseas. U.S. companies already have substantial investment in Europe and Japan, and, with Texas Instruments' recent joint-venture activity in Taiwan and in Singapore, they will soon have a significant presence in the Asia/Pacific region as well.

Asia/Pacific-ROW

Asia/Pacific-ROW, which includes Korea, Taiwan, and Southeast Asia, is the fastest-growing region for capital spending. Spending in Asia/Pacific-ROW was $1.5 billion in 1990 and is forecast to have a five-year CAGR of 21 percent to reach $3.8 billion in 1995.

This growth will be the result of several different factors: 16Mb DRAM investments, especially in Korea; the continued growth of Taiwanese companies such as TSMC; and the emergence of Singapore as a center for semiconductor manufacturing.

It is interesting to note that although Singapore is a relatively small nation in terms of geography, it is now rapidly gaining stature on the economic map of the semiconductor world. Singapore can now boast of fab lines by SGS-Thomson and Chartered Semiconductor and a new joint venture by Texas Instruments, Canon, Hewlett-Packard, and the Singapore Development Agency.

Europe

Capital spending in Europe by all companies reached $1.5 billion in 1990 and is expected to grow to $1.8 billion in 1991. By 1995, capital spending in Europe should reach $3.1 billion, representing a five-year CAGR of 15 percent between 1990 and 1995.

This growth will, to a large extent, be due to offshore manufacturers building fabs in Europe—particularly Japanese companies. Currently Fujitsu, Hitachi, Mitsubishi, and NEC either have production fabs in Europe or will be building production fabs in 1991. Dataquest anticipates that other Japanese companies, and possibly an Asia/Pacific company, will locate in Europe before 1995.

U.S. manufacturers already have a strong presence in Europe and are expected to increase their activity. Texas Instruments, for example, currently plans to begin the second phase of its fab at Avezzano, Italy, in the next two years.

One of the most intriguing joint ventures to be announced will take place in France. IBM and Siemens have announced that they will jointly upgrade IBM's facility at Corbeil-Essonnes to produce 16Mb DRAMs.

Overall, the growth of capital spending in Europe will be fueled by the general economic growth. This growth will be the result of the integration of the EC and the desire of major non-European manufacturers to have a fab line close to their customers. A secondary reason for locating in Europe, but one expected to gain in importance by the mid-1990s, is proximity to potential markets in Eastern Europe.

Dataquest Perspective

In a year that started out with war and recession, Dataquest still anticipates that capital spending will grow by almost 13 percent. This is reasonably healthy growth, considering the economic uncertainty that existed at the beginning of the year, and to some extent, lingers still. The growth in 1991 and throughout our forecast period will be spurred on by the need to upgrade technology for the next generation of devices and by the need for new capacity to support the expected growth of semiconductor production. Globalization strategies and the emergence of Asia/Pacific also continue to be major factors in the growth of semiconductor capital spending.

One aspect of globalization is the development of technology and manufacturing joint ventures by semiconductor companies from different regions of the world. One important reason for joint-production ventures is to minimize the magnitude of the huge financial investment required to build an advanced submicron production facility.

Dataquest expects growth in capital spending to continue at a healthy rate and be more stable than it has been in the past. However, with globalization strategies and the emergence of joint-production ventures, we anticipate a continuing reduction in the number of preferred vendors. ■

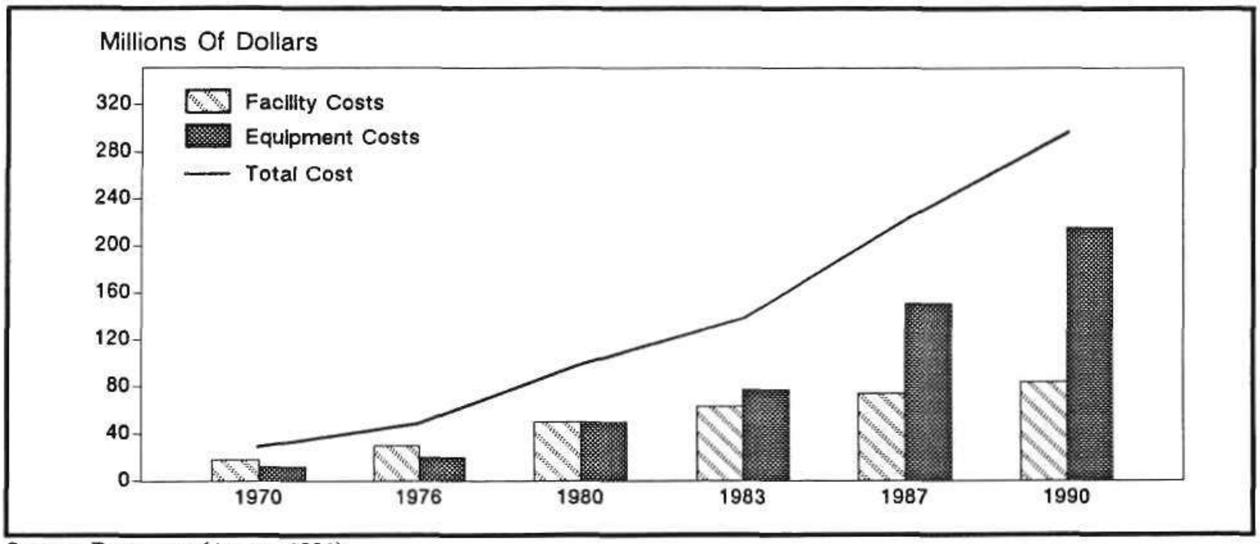
By George Burns

A Macro View of Microenvironments

Summary

As semiconductor technology advances, the cost of building a new fab also increases. Figure 1 shows the cost trend for building and equipping a state-of-the-art fab. In 1970, the initial cost of building and equipping a high-volume, state-of-the-art fab was $30 million. By 1990, this cost had risen to $300 million. As line geometries shrink and process steps increase, the cost to build and equip a fab will continue to increase. The clean room cost represents a significant portion of the total cost to construct a fab. Alternative clean room procedures are being developed to lower clean room costs and increase contamination control. One such alternative is microenvironments.

Figure 1
Building and Equipment Costs for a High-Volume Fab Line



Source: Dataquest (August 1991)

Definition of a Microenvironment

A microenvironment is defined as a relatively small volume of controlled space surrounding and isolating wafers from contamination sources both in the process tool and the room in general. Different processes and material-handling mechanisms require different microenvironment solutions.

Microenvironment Suppliers

Three North American companies are aggressively perusing microenvironment market share. They are Asyst Technologies Inc., Briner/Yeaman Engineering Inc., and Intelligent Enclosures Corporation.

Asyst Technologies

Asyst Technologies is located in Milpitas, California. The company manufactures and markets a product line designed around a standard mechanical interface (SMIF). The SMIF product line includes a sealed wafer carrier (SMIF pods), robotic transfer mechanisms (SMIF arms), and custom enclosures. A list of semiconductor manufacturers with SMIF installations follows:

- AMI
- Cypress Minnesota
- EM Microelectronics
- Harris
- Hewlett-Packard
- IBM
- Intel
- LSI Logic
- NCR
- Philips
- Siemens
- TSMC
- UMC

It is interesting to note that some level of SMIF has been installed in every region of the world—North America, Japan, Europe, and Rest of World.

Briner/Yeaman Engineering

Briner/Yeaman Engineering is located in Santa Clara, California. It markets manual, SMIF, and automation-compatible microenvironments. Microenvironments produced by Briner/Yeaman Engineering achieve 10 to 100 times better contamination control than that of Class 1. In addition to microenvironment design and manufacturing, Briner/Yeaman performs wafer fab layout, design, process equipment selection, manufacturing simulation, and facility fitup/hookup design. Semiconductor manufacturers with microenvironments installed by Briner/Yeaman include Fortrend, LSI Logic, Motorola, NEC, and Pace.

Intelligent Enclosures

Intelligent Enclosures is located in Norcross, Georgia. The company manufactures and markets minienvironments. "Minienvironment" is its term for microenvironment. The minienvironment enclosures are modular and reusable, and they can accommodate tool clustering as well as a wide range of material-handling methods including manual load, SMIF pod/arm, or robotic automation. Intelligent Enclosures is a second-source supplier of minienvironments for IBM. It is currently working with a company that has had a 10 percent increase in product yield with the implementation of its minienvironments. Bookings for projects in 1990 totaled more than $1 million, and the company expects business to quadruple in 1991.

Types of Microenvironments

The following paragraphs discuss four different types of microenvironments.

Tool-Integrated Microenvironment

This type of microenvironment is the most efficient because it represents the minimum in enclosure volume. It is also the most difficult to design because of the needs of integrating the normal equipment access requirements necessary for normal operation and maintenance. Some tools that have traditionally used integrated microenvironments are reduction wafer steppers, which need precise control of temperature, humidity, and particulates. Equipment companies that are proactive with respect to providing microenvironment control with their tool will opt for the tool-integrated solution.

Tool-Enclosing Microenvironment

The entire tool, with its own contamination generating portions, is enclosed. The volume of enclosed space is larger than the tool-integrated enclosures, but some of the design and integration difficulties are avoided.

Cassette-Enclosing Microenvironment

Run boxes are microenvironments for cassette enclosing that have been used for many years and are supplied by Fluoroware. This style of microenvironment is compatible with both manual and automated methods of microenvironment access. More recently, the SMIF pod was developed as a SMIF-style cassette-enclosed microenvironment.

Robotic-Enclosing Microenvironment

Robots are used in semiconductor manufacturing to move product in a repeatable, controlled manner. Microenvironments are used with robotics to isolate the product from contamination sources during transport and to keep the automation-generated particles away from the product. Automated diffusion furnace loading, implanter end stations, automated stockers, and enclosed robots on rails are examples of this type of microenvironment in which manual operations have been replaced with automated mechanisms for transporting wafers and cassettes of wafers.

Access Between Microenvironments

As microenvironments become more prevalent in the semiconductor industry, one of the key issues will be how material is moved between these microenvironments while minimizing contamination. The material can be accessed manually or moved with automation.

Manual access is the most cost effective, and it is also the easiest to implement. The microenvironments are engineered to allow a clean load area for opening the cassette carrier and for cassette placement on the tool. Maintenance access is easier, and no tool modifications are required. Briner/Yeaman Engineering has developed a manual access port that interfaces easily to a tool-integrated microenvironment and allows for the manual, contamination-free transfer of cassettes from a Fluoroware-type run box to the equipment.

Several companies provide automation compatible with microenvironments. These companies include Accufab, Asyst Technologies, Daifuku, Precision Robots Inc., Proconics, and Programmation. The Asyst-SMIF system uses clean-isolation technology to protect the integrity of wafers during processing, storage, and transportation within the facility. Wafers are isolated in sealed, ultraclean cassette containers, and specialized robotic arms transfer the sealed wafers into and out of enclosures.

Advantages of Microenvironments

One of the major advantages of a microenvironment is that, fundamentally, a small volume is easier to control than a large volume. More precise control and better economies are both possible. In the traditional clean room environment, a zone of control is established for a relatively large volume, enclosing multiple process tools along with manufacturing personnel.

Some of the specific relative advantages of microenvironments over the traditional clean room are better contamination control, less initial and operating costs, reduced clean room protocol, elimination of cross-contamination, allowance for different control set points, facilities flexibility, and ease of major upgrades.

Dataquest Perspective

Dataquest believes that demand for microenvironments will increase, especially with the growing number of 5- to 10-year-old fabs that will require upgrades to manufacture semiconductors with competitive yields. Today, semiconductor manufacturers can easily and inexpensively add this new level of contamination control. For the average cost of about $12,000 per tool, a custom manual microenvironment can be engineered, built, and installed with minimal interruptions to production.

Considering that the only other options for increased contamination control are to construct a cleaner facility with increased contamination control or shut down the existing facility for renovation, microenvironments are definitely a viable alternative to achieving increased contamination control. (This article was written by Jeff Seerley in conjunction with Don Briner of Briner/Yeaman Engineering Inc. For further information, please contact Jeff Seerley.) ■

By Jeff Seerley
Don Briner

Market Analysis

Wafer Fab Equipment Forecast Revisited—Only Modest Changes

July Forecast

Dataquest recently revised its January 1991 wafer fabrication equipment forecast. Our latest forecast (dated July 1991) reflects only modest changes in our expectations for overall growth in the wafer fabrication equipment industry during the next five years (see Table 1). One of the changes in our July forecast is an adjustment of the 1990 base year from our preliminary estimate in January to a final market total based on detailed survey input. The modest changes in our year-to-year growth rate for wafer fab equipment are tied to changes in the capital spending environment as discussed in the featured article of this *Dataquest Perspective*.

Individual equipment category forecasts, in general, reflect these modest changes. One exception, however, is the category of maskmaking lithography equipment. Dataquest's January 1991 forecast reflected aggressive growth for this category of equipment. This forecast was fueled by our expectation for the maskmaking community to retool facilities in the next several years in order to meet the mask requirements for advanced lithographic processing. Although we still maintain that this retooling will occur, we have downsized our previous maskmaking lithography forecast to reflect a less-aggressive ramp. (Please refer to the *Semiconductor Equipment, Manufacturing, and Materials Forecast—July 1991* booklet for individual equipment category forecasts.)

Dataquest is forecasting overall growth of 9 percent in the worldwide wafer fab equipment market in 1991. We believe that this growth rate, while on the upper side of market expectations, is clearly achievable in today's market environment. We recognize that some companies in the industry may judge this forecast to be overly optimistic, based on their own year-to-date 1991 financial performance.

Growing Gap in Company Performance

One of the key trends in the wafer fab equipment industry over the past several years has been a growing gap in company performance. In 1984, a year when the wafer fab equipment market grew 66 percent, only a handful of companies (6 percent) experienced negative growth in equipment revenue. Essentially all companies enjoyed the surge in the 1984 equipment market. In 1988, another significant year of high growth in the wafer fab equipment industry, the worldwide market grew 59 percent over its 1987 level. However, in this peak year of the equipment buying cycle, close to 20 percent of all companies had negative growth in revenue and thus did not experience the benefits of a healthy market environment. Dataquest contends that the gap in company performance is continuing to grow.

The growing gap in performance among companies in the wafer fab equipment industry is due to a number of factors. Japan accounts for over one-half of the worldwide wafer fab equipment industry. Companies that do not have a global presence, and in particular do not participate in the Japanese market, significantly reduce their opportunities for new business. Companies with older-generation technology face the challenge of investing precious R&D dollars in those areas of advanced technology development that will hopefully produce the most lucrative return for their money.

Table 1
Comparison of July 1991 and January 1991 Wafer Fabrication Equipment Forecasts (Millions of Dollars)

	1990	1991	1992	1993	1994	1995	CAGR (%) 1990-1995
July 1991 Forecast	5,818	6,353	7,704	9,707	10,848	11,189	14.0
Percent Change	-3	9	21	26	12	3	
January 1991 Forecast	5,562	6,211	7,689	9,483	10,416	10,902	14.4
Percent Change	-6	12	24	23	10	5	

Source: Dataquest (August 1991)

Sophisticated advanced equipment technology has dictated that service and support become a key component of the equipment purchase. Finally, the wafer fab equipment market is a highly competitive arena. Few companies enjoy the luxury of establishing and maintaining a successful market niche with little or no competition. These factors affect a company's vision of its future market opportunities.

Dataquest Perspective

Fabrication equipment technology continues to advance dramatically to meet the process requirements of advanced submicron devices. Lithography, deposition, and etch/clean equipment continue to be technology drivers that fuel the wafer fabrication equipment industry's growth. Future equipment market growth is based on two key factors: unit shipment increases to support new device production and capacity expansions, and increased average selling prices of equipment driven by increased process complexity.

Dataquest anticipates that modest growth in 1991 will be followed by two strong years of 20-percent-plus growth in the wafer fab equipment industry. Companies well positioned from a technical and global perspective will continue to increase the performance gap relative to their competitors during this next upswing in the business cycle. ■

By Peggy Marie Wood

Midyear Review of the Silicon Wafer Forecast

Introduction

Dataquest has updated its forecast of silicon wafer consumption. The most prominent change in the updated July 1991 forecast (see Table 1) versus the earlier January 1991 forecast (see Table 2) is a downward revision in European and Asia/Pacific silicon consumption.

Consumption of silicon wafers in Europe is now expected to grow at an 8.6 percent compound annual growth rate (CAGR) from 1990 to 1995. The earlier forecast predicted that silicon consumption in Europe would have a 12.8 percent CAGR. Dataquest is also cutting back the Asia/Pacific-ROW silicon growth rate. The current five-year CAGR is 15.3 percent versus the earlier forecast rate of 19.8 percent.

Regional Overviews

Europe

The near-term economic outlook for Europe is weak through the first quarter of 1992. Germany is experiencing difficulties due to an economic slowdown in the western part of the country and a recession in the eastern part. The Bundesbank is expected to drive interest rates higher over the next several quarters in response to inflationary pressures. The annual inflation rate is currently 4.5 percent versus last year's rate of 2.7 percent, according to data released by the German central bank.

Great Britain is in the middle of a recession, and gross national product is expected to decrease 1.6 percent in 1991 according to The Dun & Bradstreet Corporation. Both France and Italy have lost momentum in the first half of the year, and both countries' GNP is forecast to grow less than 2 percent in 1991.

The current economic downturn in Europe has cut into the domestic production of semiconductors. In real terms (discounting currency exchange rates), device production is expected to grow an anemic 4 percent in 1991.

The fabs of the major Europe-based companies, which account for roughly 80 percent of device production in Europe, are cutting back. Production of memory devices and MOS logic is expected to be down at Philips. In September 1990, Philips announced its departure from the SRAM business. Dataquest believes that device sales at Siemens are also suffering because of exposure to the weak European and U.S. markets. Because all of Siemens' IC production takes place in Europe, Dataquest believes that output at its European fabs is slowing. Moreover, Siemens has announced the closure of its Perlach fab, which manufactures 4Mb DRAMs.

The net result is that Dataquest expects silicon consumption in Europe to be down in 1991. However, the market should improve moderately in 1992. Silicon consumption, driven by a more favorable economic climate, is expected to increase 8.6 percent in 1992. Starting in 1993, we expect the growth of silicon wafers in the European market to pick up pace as a small number of new Japanese and U.S. fabs begin ramping production (see Table 3).

Over the longer term, we have reduced our five-year growth rate for the European market. Dataquest now estimates the five-year CAGR for silicon to be 8.6 percent versus the previous forecast of 12.8 percent. The previous forecast

Table 1
July 1991 Silicon Consumption Forecast
(Millions of Square Inches)

	1990	1991	1992	1993	1994	1995	CAGR (%) 1990-1995
United States	648	687	731	807	894	921	7.3
Percent Growth	11.4	6.0	6.4	10.4	10.8	3.0	
Japan	1,017	1,102	1,230	1,389	1,498	1,572	9.1
Percent Growth	10.1	8.4	11.6	12.9	7.8	4.9	
Europe	227	224	244	272	312	343	8.6
Percent Growth	-1.7	-1.4	8.9	11.5	14.7	9.9	
Asia/Pacific-ROW	145	168	196	231	271	295	15.3
Percent Growth	27.0	16.1	16.7	17.9	17.3	8.9	
Total	2,037	2,181	2,401	2,699	2,975	3,131	9.0
Percent Growth	10.1	7.0	10.1	12.4	10.2	5.2	

Source: Dataquest (August 1991)

Table 2
January 1991 Silicon Consumption Forecast
(Millions of Square Inches)

	1990	1991	1992	1993	1994	1995	CAGR (%) 1990-1995
United States	620	662	733	847	861	855	6.6
Percent Growth	10.7	6.8	10.7	15.5	1.7	-0.7	
Japan	1,022	1,101	1,221	1,400	1,434	1,447	7.2
Percent Growth	12.5	7.7	10.9	14.7	2.4	0.9	
Europe	217	244	285	343	368	395	12.8
Percent Growth	0.1	12.6	17.0	20.2	7.4	7.3	
Asia/Pacific-ROW	169	221	273	338	389	417	19.8
Percent Growth	32.8	30.6	23.6	23.9	15.1	7.0	
Total	2,028	2,228	2,512	2,928	3,053	3,114	9.0
Percent Growth	11.9	9.9	12.8	16.6	4.3	2.0	

Source: Dataquest (August 1991)

was too heavily influenced by the promotion surrounding Europe 1992.

As the deadline looms closer, the importance of setting up shop in Europe for semiconductor manufacturers is receding. Harris Semiconductor has canceled its plans to expand into Europe, and Samsung is currently reviewing its plans for building a fab in Europe. Moreover, Japan-based device manufacturers have not been as aggressive in announcing new fabs in Europe as we originally estimated.

Asia/Pacific-ROW

The countries of the Asia/Pacific-ROW region are experiencing a slowing of their economies because of their reliance on exports to the industrial West. GNP in the newly industrialized countries—Korea, Taiwan, and Hong Kong—will range from 6 to 9 percent according to The Dun & Bradstreet Corporation. These growth rates are very strong relative to the other regions of the world, although they are lower than the double-digit growth that overtook these economies in the latter half of the 1980s.

Dataquest is forecasting silicon consumption in Asia/Pacific-ROW to have a 15.3 percent CAGR between 1990 and 1995. Our previous forecast projected the five-year silicon CAGR to be at 19.8 percent. Dataquest is lowering the growth

Table 3
Planned European Fabs by Company

Company	City	Country	Fab Type	Target Production Date
Fujitsu	Newton Aycliffe	England	Production	1992
				1993
				1994
Hitachi	Landshut	Germany	Production	1992
IBM	Sindelfingen	Germany	Production	1991
ITT	Freiburg	Germany	Production	1991
Intel	Leixlip, Kildare	Ireland	Production	1993
Mitsubishi	Alsdorf	Germany	Production	1992
NEC	Livingston	Scotland	Production	1991
Qudos	South Yorkshire	England	Quick Turn	1991
SGS-Thomson	Agrate	Italy	R&D	1991
Sharp	Oxford	England	R&D	1991
Siemens	Regensburg	Germany	Production	1991
Texas Instruments	Avezzano	Italy	Production	1992

Source: Dataquest (August 1991)

rate for silicon because Korea- and Taiwan-based companies are expected to delay investments in new plants.

Delays are attributed to price erosion in memory products and the declines in local capital markets, which makes it increasingly more difficult to justify new plants. The Vitelic/Hualon facility is on hold indefinitely. Hualon has also canceled plans for a fab in Malaysia, and Taiwan Semiconductor Manufacturing Company has stopped doing DRAM foundry work for Intel.

Long term, Dataquest believes that Asia/Pacific-ROW will remain the fastest-growing region in the world. The only potential dark cloud on the horizon is the fragile political stability of the nascent democracies in this region.

Japan

Dataquest is slightly raising the near-term and long-term forecasts of silicon consumption in Japan. Silicon consumption is expected to grow 8.4 percent in 1991; our earlier estimate was 7.7 percent. The adjustment for 1991 can be attributed to the minimal impact of the mideast crisis on the Japanese economy and the continued resilience of the Japanese economic expansion, which is entering its 57th month.

The aggressiveness with which Japanese manufacturers are investing in 8-inch fabs also bodes well for the five-year forecast. Economic problems in the other regions of the world are not curtailing the investment in new 16Mb and 64Mb lines. This investment will benefit silicon consumption beginning in 1992 when 16Mb production begins to ramp.

United States

Dataquest has cut its near term outlook for the U.S. market. The forecast for 1991 is slightly lower from the earlier forecast, but, more important, we do not see a strong recovery in the U.S. economy in 1992. As a result, we are now estimating that silicon consumption will grow only 6.4 percent compared with our previous estimate of 10.7 percent.

We have increased the five-year CAGR for the U.S. market to 7.3 percent from the January forecast of 6.6 percent. We expect the United States to benefit from cheaper capital costs, which we view as a long-term trend. Cheaper capital costs are expected to bolster the ability of semiconductor companies to invest in new plants in the United States.

Dataquest Perspective

Silicon consumption, on a global basis, is forecast to have a 9 percent CAGR over the next five years. By 1995, consumption will total 3,131 million square inches. Japan will account for 50.2 percent of the total worldwide consumption; the United States, 29.4 percent; Europe, 11.0 percent; and Asia/Pacific-ROW, 9.4 percent.

The huge investment in front-end production facilities in Japan by both Japanese and foreign semiconductor companies will guarantee that this country will lead all other regions in the consumption of silicon, well past the end of this decade. ■

By Mark FitzGerald

News and Views

Armistice in the Epi Reactor Wars

Applied Materials and Moore Technologies have settled the patent infringement litigation surrounding Moore's epi expansion kit. The expansion kit enables epi wafer manufacturers to upgrade Applied Materials' 7800 series epi reactors. The upgrade increases the throughput of the 7800 series reactor up to 50 percent.

The settlement calls for Moore to pay royalties to Applied Materials for each system sold. The agreement also permits Applied to market the kits, although Dataquest believes that Applied will not actively pursue this option.

The resolution is expected to open the market for the expansion kit. Many 7800 reactor owners delayed decisions to purchase expansion kits because of the litigation. To date, Dataquest estimates that 45 expansion kits were sold. Total market for the expansion kit is the installed base of Applied 7800 series reactors, which is estimated worldwide to be 375 systems.

The settlement reflects the depth and breadth of Applied's patent position in the epi equipment market. Epi equipment was the original product line that carried Applied Materials through its early days as an equipment vendor. The company dominates the market with about 1,100 reactors sold worldwide The next-closest competitor is Lam Research, with just over 200 systems sold worldwide. Parenthetically, Applied Materials also has filed a patent infringement suit against ASM Epitaxy, manufacturer of a single-wafer epi reactor. ■

By Mark FitzGerald

Lam Makes Tantalum Pentoxide Breakthrough

Lam Research announced a breakthrough in the development of a proprietary tantalum pentoxide chemical vapor deposition (CVD) process. This process is being developed on Lam's Integrity CVD platform, will be commercially released next year, and is targeted at future-generation DRAM manufacturing requirements.

Dataquest Perspective

Previously, the problem with using tantalum pentoxide was its inability to maintain thickness, strength, and breakdown voltages. However, the tantalum pentoxide results achieved at Lam so far include uniformity +/-1.5 percent one-sigma over a series of 150mm wafer runs and conformality greater than 95 percent with the films fully stoichiometric.

The dielectric constant of tantalum pentoxide ranges from 20 to 24. In contrast, the oxide/nitride/oxide films in use today have a dielectric constant of 4. This fivefold increase in dielectric constant of tantalum pentoxide may solve the problem of obtaining high conductivity as line geometries shrink. For example, tantalum pentoxide may help DRAM manufacturers achieve the high conductivity needed to effectively build density necessary for 256Mb DRAMs. ■

By Jeff Seerley

In Future Issues

The following topic will be featured in a future issue of *Dataquest Perspective:*

- Investment in Europe

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Market Analysis

The Fragmentation of Knowledge and the Failure of Established Firms

Dataquest is pleased to publish an invited article by Dr. Rebecca Henderson, Assistant Professor, Sloan School of Management, Massachusetts Institute of Technology. In this article, Dr. Henderson analyzes the failure of established firms to recognize the impact of architectural innovation in new product development, a situation that Dr. Henderson concludes is a serious contributing factor to subsequent loss of market leadership. Although Dr. Henderson's article is based on her research of the photolithography equipment industry, Dataquest believes that her conclusions have clear ramifications throughout all high-technology industry sectors.

Peggy Marie Wood

Introduction

Dramatic commercial success is too often a precursor to equally dramatic failure. In a wide range of industries, well-established firms with a track record of financial and technological success have been unable to respond to subtle shifts in their environment that have been better exploited by faster-moving entrants. In the computer industry, IBM has been a longtime leader in mainframes and personal computers, not in minicomputers or workstations, and Digital Equipment Corporation has yet to duplicate its success in minicomputers in the personal computer arena. In the semiconductor industry, a handful of once-dominant U.S. companies now face significant competition from all corners of the globe. A three-year study of the optical photolithography aligner industry suggests that the reasons behind an erosion in market leadership are often pervasive, critical, and *under managerial control.*

Architectural Innovation

Research conducted for a doctoral dissertation (Henderson, 1988) suggests that successful firms erode their standing in the market through a failure to respond to "architectural" innovation—innovation that changes the ways in which the elements of a product are integrated together while leaving the core design concepts on which the product is based untouched. Architectural innovation is particularly difficult to react to effectively because of the way that a company's technology base and the customer's requirements are managed inside the majority of companies. A history of success with one generation of the technology leads firms to fragment their technical knowledge and their understanding of their customer's needs, placing undue reliance on information filters, problem solving strategies, and communication channels that reflect an increasingly obsolete understanding of the technology and industry. In the photolithography equipment industry, established firms attempted to push architectural innovation such as the scanner and the second generation of steppers back into the frameworks with which they were familiar, refusing or failing to understand the dimensions along which they could offer customers very real performance improvements.

This concept of innovation can be clarified if one thinks of a product as consisting of a series of components integrated together to form the final product. Innovation can then take the following four forms:

- "Incremental" innovation improves the performance of individual components but leaves the relationships between components untouched. Think, for example, of the steady stream of improvements in lens size and power that characterize each generation of stepper.
- "Radical" innovation introduces an entirely new set of components and, hence, of relationships between them. The use of direct-write electron beam machines in mainline production is an example of this type of radical innovation.
- In "modular" innovation, some of the core concepts of the design are changed while the links between them remain stable: The replacement of analog with digital control in some instruments is an example of this type of innovation.
- "Architectural" innovation is intermediate in character between incremental and radical innovation: Much of the knowledge that a firm has accumulated in its experience with incremental innovation remains relevant, but its architectural knowledge—its knowledge about the relationship between components—becomes obsolete.

Architectural innovation in photolithography—the introduction first of the proximity printer and then of the scanner, the stepper, and the second generation of stepper—created enormous problems for established firms because they had allowed their architectural knowledge to become embedded in the tacit knowledge of the organization—in their communication channels, information filters, and problem-solving strategies—where it became difficult to observe and almost impossible to change.

The Case of Kasper Instruments

The case of Kasper Instruments and its response to Canon's introduction of the proximity printer illustrates some of these problems. Kasper Instruments was founded in 1968 and by 1973 was a small but profitable firm supplying approximately half of the market for contact aligners. In 1973, Kasper introduced the first contact aligner to be equipped with proximity capability. Although nearly half of all the aligners that the firm sold from 1974 onward had this capability, Kasper aligners were only rarely used in proximity mode, and sales declined steadily until the company left the industry in 1981. The widespread use of proximity aligners only occurred with the introduction and general adoption of Canon's proximity aligner in the late 1970s.

Canon's aligner was superficially very similar to Kasper's. It incorporated the same components and performed the same functions, but it performed them much more effectively because it incorporated a much more sophisticated understanding of the technical interrelationships that are fundamental to successful proximity alignment. Kasper failed to develop the particular component knowledge that would have enabled it to match Canon's design. More importantly, the architectural knowledge that Kasper had developed through its experience with the contact aligner had the effect of focusing its attention away from the new problems whose solution was critical to the design of a successful proximity aligner.

Kasper conceived of the proximity aligner as a modified contact aligner. Like the incremental improvements to the contact aligner before it, design of the proximity aligner was managed as a routine extension to the product line. In particular, the gap-setting mechanism that was used in the contact aligner to align the mask and wafer with each other was slightly modified, and the new aligner was offered on the market. As a result, Kasper's proximity aligner did not perform well. The gap-setting mechanism was not sufficiently accurate or stable to ensure adequate performance, and the aligner was rarely used in its proximity mode. Kasper's failure to understand the obsolescence of its architectural knowledge is demonstrated graphically by two incidents.

The first incident was the firm's interpretation of early complaints about the accuracy of its gap-setting mechanism. In proximity alignment, misalignment of the mask and the wafer can be caused both by inaccuracies or instability in the gap-setting mechanism and by distortions introduced during processing. Kasper attributed many of the problems that users of its proximity equipment were experiencing to processing error, because it believed that processing error had been the primary source of problems with its contact aligner. The firm "knew" that its gap-setting mechanism was entirely adequate and, as a result, devoted very little time to improving its performance. In retrospect, this may seem like a wanton misuse of information, but it represented no more than a continued reliance on an information filter that had served the firm well historically.

The second illustration is provided by Kasper's response to Canon's initial introduction of a proximity aligner. The Canon aligner was evaluated by a team at Kasper and pronounced to be a copy of a Kasper machine. Kasper evaluated it against the criteria that it used for evaluating its own aligners—criteria that had been developed during its experience with contact aligners. The technical features that made Canon's aligner a significant advance, particularly the redesigned gap mechanism, were not observed because they were not considered important. The Canon aligner was pronounced to be "merely a copy" of the Kasper aligner.

Further Examples in the Photolithography Industry

Similar problems show up in other episodes of architectural innovation in the industry's history. In one company, the engineers evaluating a new technology—an architectural innovation—accurately forecast the progress of individual components in the new system but failed to see how new interactions in component development—including better resist systems and improvements in lens design—would give the new technology a decisive advantage.

Similarly, in another company, engineers were organized by component, and cross-department communication channels were all structured around the architecture of the first-generation system. Although the engineers were able to push the limits of the component technology, they had great difficulty understanding the roots of the superior performance achieved by the next generation of equipment. A successful entrant in the market changed aspects of the design—particularly the ways in which the optical system was integrated with the rest of the aligner—of which the established firm's engineers had only limited understanding. Moreover, because these changes dealt with component interactions, there were few engineers responsible for developing this understanding. As a result, the older firm's second-generation machines did not deliver the kind of performance that the market demanded. In both of these cases, other factors also played a role in the subsequent loss of market share for the older companies, but a failure to respond effectively to architectural innovation was of critical importance.

Conclusions

Is the concept of architectural innovation useful in thinking about the issues facing high-technology industries today? The answer is a resounding yes. Continuing research to support this premise in the aerospace, pharmaceutical, and electronic instrument industries is currently under way at MIT. The key to managing architectural innovation successfully in all of these areas seems to be the explicit recognition that a firm cannot afford to let the knowledge of its design team become fragmented and bounded by information filters or communication channels that reflect only the factors that have made the firm successful historically. Design teams that manage to survive architectural innovation actively seek to reintegrate the knowledge of their designers through strong, integrative team management; extensive cross training; and a focus on the goals of the group as a whole rather than the goals of any particular discipline. As semiconductor technology becomes increasingly complex and architectural innovation becomes more pervasive, the firms that survive will be those that have learned this lesson. ■

By Rebecca Henderson, Ph.D.
Assistant Professor
Sloan School of Management
Massachusetts Institute of Technology

Semiconductor Materials: The 1990 Japanese Photoresist Market

In 1990, Japan remained the largest regional market for photoresist with sales of ¥18,406 million ($126.9 million) or 517,300 gallons. The consumption of photoresist in front-end semiconductor processing grew 6.4 percent in volume from 1989 to 1990.

Growth in the Japanese market occurred exclusively in positive-type resists (see Figure 1). The consumption of positive resist totaled 328,100 gallons, an increase of 12.4 percent (see Table 1). This growth parallels the regional increase in semiconductor capacity requiring the tighter performance of positive-type resists.

The market for negative-type resists totaled 189,200 gallons in 1990, a decrease of 2.5 percent on a year-to-year basis (see Table 2). Negative resists are sold primarily into lower-end technology applications (i.e., discrete device manufacture, which experienced little growth).

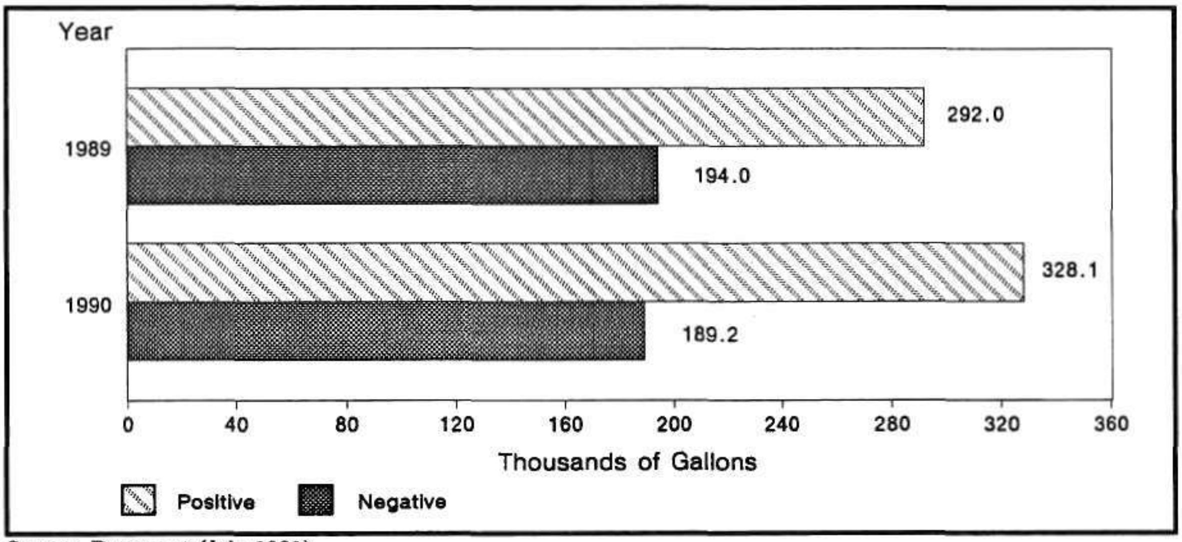
The major beneficiaries of the positive resist growth were Japan-based companies, whose share of the market totaled 85.6 percent in 1990. Tokyo Ohka's (TOK's) shipment of positive resists totaled 202,000 gallons. TOK continued to dominate the Japanese positive resist market with market share of 61.6 percent.

One other Japanese vendor, Japan Synthetic Rubber (JSR) and a joint-venture company, Fuji-Hunt, ranked second and third, respectively, although both have significantly smaller market share than does TOK. Among the smaller players, JSR and Sumitomo Kagaku are notable because both are currently supplying i-line-type resists, which have had excellent market acceptance. However, i-line photoresist still accounts for only 1,300 gallons or 0.4 percent of the total Japanese positive resist market in 1990.

Dataquest anticipates that both JSR and Sumitomo Kagaku will increase their market share as the demand for i-line resist grows rapidly through the rest of the decade. Most of the i-line resist consumed in Japan in 1990 was used to manufacture 4Mb DRAMs. The main lithography tool for the 4Mb DRAM is g-line steppers; i-line steppers are used only for critical layers, thus accounting for the small volume of i-line resist consumed.

Mitsubishi Kasei's total market share changed little in 1990, but Dataquest believes that the company benefited from its strategy of focusing on the high-grade photoresists mainly used for

Figure 1
Japanese Optical Photoresist Market
(Thousands of Gallons)



Source: Dataquest (July 1991)

Table 1
1990 Japanese Optical Photoresist Market—Positive Resist
(Thousands of Gallons)

Company	Volume	Millions of Yen	Millions of Dollars	Percent Volume
North American Companies				
Nagase & Co.[1]	7.5	350	2.4	2.3
Shipley	11.6	570	4.0	3.5
Subtotal	19.1	920	6.4	5.8
Japanese Companies				
Japan Synthetic Rubber	48.0	2,460	17.1	14.6
Tokyo Ohka	202.0	10,100	70.1	61.6
Mitsubishi Kasei	17.0	836	5.8	5.2
Sumitomo Kagaku	10.6	510	3.5	3.2
Others	3.2	140	1.0	1.0
Subtotal	280.8	14,046	96.6	85.6
European Companies				
Hoechst[2]	5.2	230	1.6	1.6
Joint-Venture Companies				
Fuji-Hunt[3]	23.0	1,100	7.6	7.0
Total	328.1	16,296	112.2	100.0

[1]KTI Chemical in the United States
[2]AZ Photoresist in the United States
[3]Olin-Hunt in the United States
Source: Dataquest (July 1991)

Table 2
1990 Japanese Optical Photoresist Market—Negative Resist (Thousands of Gallons)

Company	Volume	Millions of Yen	Millions of Dollars	Percent Volume
North American Companies				
Nagase & Co.[1]	9.6	125	0.9	5.1
Japanese Companies				
Japan Synthetic Rubber	43.0	565	3.9	22.7
Tokyo Ohka	120.0	1,230	8.5	63.4
Others	7.0	65	0.5	3.7
Subtotal	170.0	1,860	12.9	89.9
Joint-Venture Companies				
Fuji-Hunt[2]	9.6	125	0.9	5.1
Total	189.2	2,110	14.7	100.0

[1]KTI Chemical in the United States
[2]Olin-Hunt in the United States
Source: Dataquest (July 1991)

Exchange Rate: ¥144/US$1

1Mb and 4Mb DRAMs. Their product mix is believed to have shifted in favor of these higher-purity, higher-priced products.

The negative resist market totaled 189,200 gallons (see Table 2). Dataquest expects little growth in demand for negative-type resists for device applications, and volumes may well decrease as device manufacturers install track equipment, which provides more efficient dispense volumes. Market shares for companies participating in this segment are not likely to shift significantly.

Dataquest believes that negative i-line resists will be used in phase-shift mask applications. However, no significant volumes of negative i-line resists will be required for this application before 1992. This time frame may also be pushed out further because few device makers are familiar with negative resist processing.

In Japan, the liquid crystal display (LCD) industry is a large, developing market for photoresist. In 1990, Dataquest estimated that photoresist use in thin film transistor LCD processing was roughly 2 percent of the total Japanese semiconductor photoresist market, or about 10,000 gallons. (This study excludes photoresist used for the manufacture of LCDs.) Photoresist use in this market should grow rapidly in the next five to seven years.

Dataquest Perspective

In the next few years, Dataquest expects new resist formulations, deep UV, and X-ray resists to be required for production of 64Mb devices. Chemical systems for these types of resists will require extensive characterization studies by device manufacturers. The photoresist vendors that win these battles will be positioning themselves for strong growth in the second half of the decade as demand for these new resists ramps up. ■

By Mark FitzGerald (San Jose)
Kunio Achiwa (Tokyo)

Semiconductor Manufacturing

IBM and Siemens Sign Agreement to Manufacture 16Mb DRAMs

Summary

On July 4, 1991, IBM and Siemens signed an agreement to manufacture 16Mb DRAMs at IBM's fab in Corbeil-Essonnes (France). This agreement will capitalize on the technology of both companies and enable them to implement the latest semiconductor manufacturing technology in Europe. This agreement is part of an ongoing effort to strengthen an independent European electronics industry, and it will also allow both companies to transfer this technology to other manufacturing sites.

In 1990, both companies introduced 16Mb DRAM samples. However, as a result of this agreement, 16Mb DRAMs with increased functionality will be developed at a Siemens facility in Munich. Dataquest estimates that

Siemens will contribute between $400 million and $600 million for design and equipment, and IBM will contribute the manufacturing process technology and fab. This is IBM's biggest joint-manufacturing agreement and exemplifies the action that major semiconductor manufacturers are taking to reduce the risk and cost associated with a new submicron state-of-the-art fab.

Manufacturing Plans

Manufacturing will begin by the end of this year with shipments scheduled to begin in the second half of 1992. An existing IBM facility is being upgraded to handle the strict contamination control required to manufacture these devices. The upgrade is based on Dr. Ohmi's ultraclean technology. A Dr. Ohmi-specified fab includes a Class 1 clean room, electrostatic discharge control, and high-purity chemical, gas, and DI water delivery systems. Dataquest estimates that a Dr. Ohmi-specified clean room costs about $2,900 per square foot. When fully operational, the facility will employ a total of 600 people, roughly 300 from each company.

The manufacturing process is based on existing IBM process technology developed at Corbeil-Essonnes. Dataquest estimates that between 375 and 525 process steps are required to manufacture a 16Mb DRAM. The manufacturing test vehicle used to bring up the line will be an IBM device. However, this device was designed for mainframe computer applications. Therefore, after the line is up and running, the newly designed Siemens 16Mb DRAM with increased functionality will be manufactured. When fully equipped, the fab will have the capacity to start 12,000 8-inch wafers per month. The fab will also have the capability to produce ASIC products that feature linewidths of 0.5 micron.

Where the Chips Are Going

IBM plans to retain the chips for captive use, and Siemens plans to sell the chips on the merchant market. This strategy will enhance Siemens' product line and guarantee its customers DRAM availability. If excess capacity is available, participation by other companies will be allowed in this agreement.

Last year, IBM and Siemens also entered into a 64Mb DRAM agreement. This agreement is of strategic importance to both companies; the following section analyzes its strategic importance.

Last Year's 64Mb DRAM Agreement

On January 23, 1990, IBM and Siemens signed an agreement to develop 64Mb DRAMs. This agreement focused on process-technology development and chip design. Both IBM and Siemens decided that the cost of developing the new process technology required to make leading-edge DRAMs is too risky and costly to do alone. As a result, IBM and Siemens entered into an agreement in which they would share equally in 64Mb DRAM technology development costs. They each dedicated 100 engineers to this project. No financial transaction took place between the two companies. The goal of the agreement is to introduce a 64Mb DRAM into volume production in about 1995. Before this agreement, Siemens' goal was to complete 64Mb DRAM development by 1995. With IBM's help, this goal could be achieved one year early, which is of strategic importance because time to market is critical in today's environment. In the DRAM market, the best profit margins occur during the first year a chip is in volume production. This is the point at which demand is strong and supply is tight.

As a starting point for this agreement, each company disclosed its strengths and weaknesses as they relate to DRAM production. Although a common process and product are being developed, each company will manufacture and market the 64Mb DRAMs separately. IBM plans to manufacture the 64Mb DRAMs in Essex Junction, Vermont, and Siemens plans to manufacture in Munich and Regensburg, Germany. As with the 16Mb DRAM agreement, IBM will use the chips for captive purposes and Siemens will expand its device product line offering.

IBM and Siemens both use a trench capacitor for the 64Mb DRAM process rather than the stack capacitor process. The trench capacitor will most likely be used for higher-density designs. This deal is not a technology-transfer arrangement but a codevelopment arrangement that will give both companies equal ownership in the process and base product.

Joint Ventures—A Way of Life

Dataquest believes that the 1990s will bring a substantial amount of joint-venture activity. This increase in activity is being driven by escalating fab and equipment costs. Even the giant semiconductor manufacturers are managing their financial resources more carefully than in the past. This section briefly describes two other unrelated recently announced joint ventures that illustrate this point.

A significant joint venture was announced in April 1991. Texas Instruments, Hewlett-Packard, Canon, and the Singapore Economic Development Board announced that they will form a venture that will use submicron CMOS manufacturing technology to manufacture DRAMs. The fab being constructed for this venture will also have the capability to manufacture advanced logic if market demand shifts.

Also in April, a joint-development agreement was reached between AT&T Microelectronics and NEC that will have a positive impact on U.S.-Japan trade relations. The purpose of this agreement is to reduce the risks and costs associated with developing a 0.35-micron process. Twenty-six research teams were assembled to carry out this agreement. AT&T plans to incorporate the results of this agreement into its new fab in Orlando, Florida, which will incorporate microenvironments. The most important aspect of this agreement is that AT&T and NEC will have the same process and tool set, which means that they can second-source each other's products. This is truly second-sourcing for ASIC customers.

In 1990, Dataquest ranked NEC number 1 with semiconductor revenue of $5 billion, and AT&T was ranked number 20 with semiconductor revenue of $830 million. It is evident that if these financially sound companies are entering into agreements to reduce cost and risk, the others will have to follow.

Dataquest Perspective

The Siemens/IBM 16Mb DRAM agreement increases the chances of Siemens remaining a contender in the fiercely competitive DRAM market. This is of strategic importance because Europe does not want to become dependent on foreign sources for its DRAMs. However, before this agreement, it was questionable if Siemens would have survived in the DRAM market by itself.

As semiconductor manufacturing complexity increases, agreements of this nature are mandatory to survival. Forces that make these agreements mandatory include the mammoth R&D investment required to design a chip such as the 16Mb DRAM, the huge initial capital investment required for manufacturing equipment and facilities, and the cost of capital. ■

By Jeff Seerley

Fab Database Series: Regional Migration of Wafer Production and Pilot Lines in the United States

Is it all gloom and doom for construction of new wafer fabrication facilities in specific regions of the United States? On the surface, the number of wafer fabrication production and pilot lines in the United States has remained relatively stable at 375 in 1986 and at 372 in 1991. Yet there is a dynamic undercurrent of fab migration from one state to another, leaving many with the following impression:

The Last One to Leave . . . Remember to Turn Off the HEPA Filters

This sentiment is possibly the strongest in California. Table 1 presents the number of pilot and production lines by state in 1986 and 1991. In both years, California had the largest number of lines of any state, with 165 in 1986 and 147 in 1991. Nevertheless, California experienced a combined net loss of 18 production and pilot lines during this period. Figure 1 shows wafer fabrication production and pilot line shifts for 6 key states. Dataquest estimates reflect all announced lines to date and assume no closures of existing lines.

Between 1986 and 1991, Dataquest estimates that in the United States, a combined total of 79 production and pilot lines were closed. We categorize a closed line as a line where production has ceased or where expansion of an adjacent line has cannibalized another line. Of these 79 closures, 38 occurred in California. Thus, in California, 20 new lines were constructed during this period to achieve the 147 lines. In addition, Dataquest has identified 6 new pilot and production lines announced to begin operation in California in the next few years. Dataquest views future growth in California to be tempered because of numerous economic variables inducing semiconductor manufacturers to locate new wafer fabs in other regions of the country.

Regions to Watch

Figure 2 provides a regional view of fab migration. The Northwest is prospering: Oregon

Table 1
Number of U.S. Production and Pilot Semiconductor Lines by State 1986—1991*

Region	State	1986	1991	Change 1986-1991
California	California	165	147	-18
Midwest	Illinois	3	4	1
	Indiana	4	4	0
	Michigan	1	0	-1
	Minnesota	5	2	-3
	Missouri	3	3	0
	Ohio	3	3	0
	Wisconsin	1	0	-1
Northeast	Maine	3	2	-1
	Maryland	3	6	3
	Massachusetts	24	23	-1
	New Hampshire	4	2	-2
	New Jersey	3	5	2
	New York	13	16	3
	Pennsylvania	12	17	5
	Rhode Island	1	1	0
	Vermont	2	7	5
Northwest	Idaho	6	7	1
	Oregon	8	11	3
	Washington	3	5	2
Southeast	Florida	9	12	3
	North Carolina	3	3	0
	Virginia	1	2	1
Southwest	Arizona	27	26	-1
	Colorado	16	15	-1
	New Mexico	3	7	4
	Utah	6	4	-2
Texas	Texas	43	38	-5
Total		375	372	-3

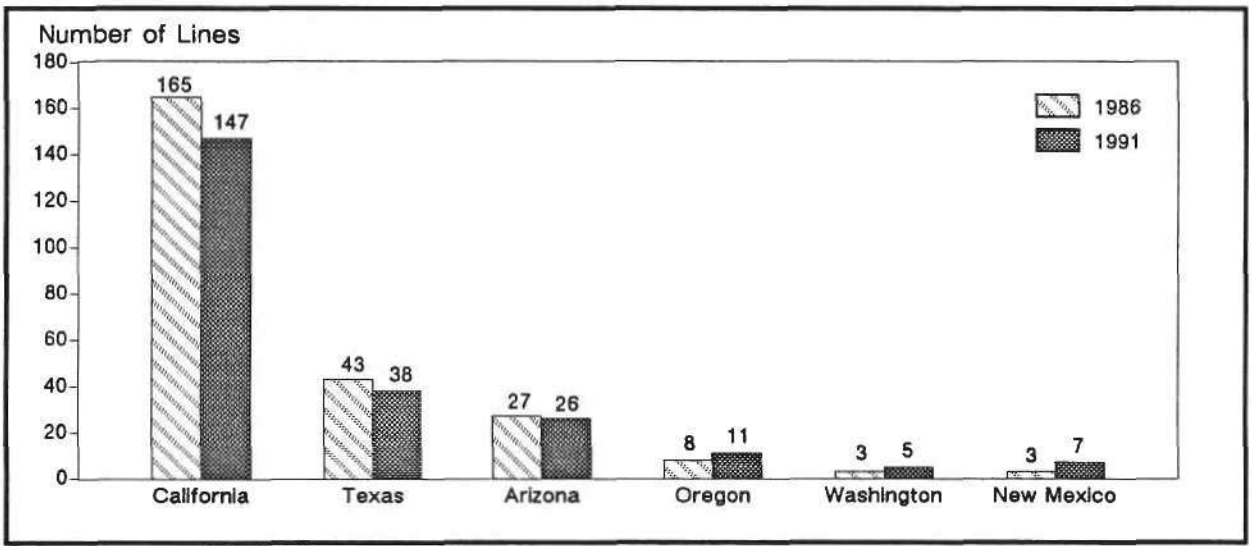
*Including facilities slated to begin operation in 1991.
Source: Dataquest (July 1991)

and Washington are supporting the area with burgeoning fab construction. Dataquest foresees this trend to continue, with four fab lines expected to be constructed in the near future. Intel, Hewlett-Packard, and Oki have all announced new facilities to be built in Oregon, and Micron Technology, depending on future capacity requirements, may build an additional line in Idaho.

The Southwest has clearly been an active region. New Mexico, in the vicinity of Albuquerque, has experienced a windfall of new production lines. Intel, which in the 1986 time frame had one production line in New Mexico, has since constructed two more with the potential for an added two lines in the next few years. Signetics, which also had one New Mexico production facility in 1986, has erected two more lines in Albuquerque. Signetics is currently in the process of phasing out production at one of its older Sunnyvale, California, lines and shifting production to New Mexico.

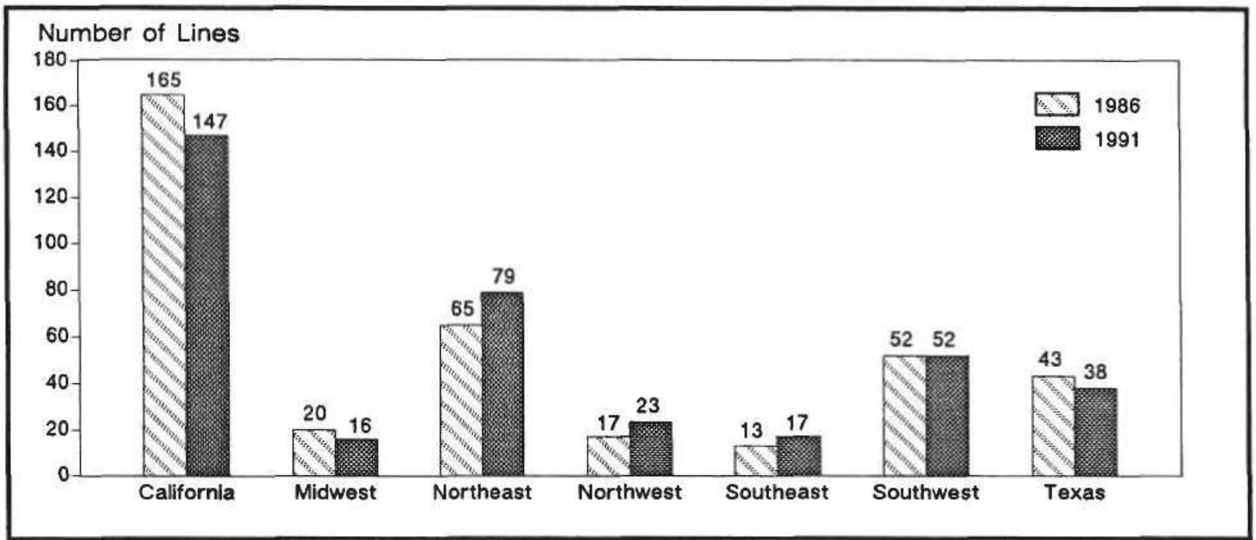
Texas lost a total of five production or pilot lines between 1986 and 1991. This drop in the number of pilot and production lines can be directly attributed to Texas Instruments' (TI's) upgrade and expansion of existing lines. Dataquest anticipates a promising fab construction market in Texas, with 10 new lines slated to begin production in the near term. AMD, Hitachi, Motorola, TI, and VLSI are considering plans for new production or pilot lines in Texas.

Figure 1
Distribution of U.S. Pilot and Production Semiconductor Lines by Key States



Source: Dataquest (July 1991)

Figure 2
Distribution of U.S. Pilot and Production Semiconductor Lines by Region



Source: Dataquest (July 1991)

Dataquest Perspective

The construction of a fab line is, in part, driven by technological factors. Also, strong financial incentives propel semiconductor manufacturers to shift their lines from high- to low-cost areas of the country. The drive toward smaller feature sizes in many devices has definitely been a contributing factor to new facility construction. Needless to say, many factors must be considered when locating new wafer fabrication lines. Semiconductor manufacturers must deal with a myriad of issues ranging from the fixed costs of land and equipment and the opportunity cost of potential delays of construction completion to the variable costs of a qualified employee pool and materials associated with the manufacturing process. *Dataquest believes that semiconductor manufacturers are "voting with their feet."* In other words, they are and will continue to locate the bulk of new lines in states where they can minimize costs—from groundbreaking to shipment of final product.

By Rebecca E. Burr

News and Views

Air Products Capitalizes on Confusion at SemiGas

Worldwide gas cabinet sales totaled $92.3 million in 1990, a 2.8 percent increase over 1989 (see Table 1). Although there was little growth in the total market, Air Products managed to grab a larger share than it had last year, partly because of the drawn-out legal battle in which SemiGas, the market share leader, was embroiled during the past year.

SemiGas was acquired by Nippon Sanso in April 1991 after a Federal District Court blocked an attempt by the Justice Department to prevent the sale of U.S.-based SemiGas to Japan-based Nippon Sanso. The Justice Department argued that foreign companies should be prevented from buying American high-technology companies deemed crucial to the nation's economic security.

The acquisition took over a year to receive court approval. In the meantime, SemiGas experienced a serious exiting of personnel throughout most of 1990. SemiGas' sales force was hit especially hard. The turmoil caused by the acquisition stalled SemiGas' historically fast-paced growth.

Table 1
1990 Worldwide Market Share for Gas Cabinets by Company (Millions of Dollars)

	1989	1990
North America-Based Companies		
SemiGas Systems	16.9	17.0
Air Products/APCI-Europe	12.8	14.6
Veriflow	2.8	1.5
Union Carbide/Flopure/Linde-Germany	2.7	2.7
Process & Cryogenics	1.5	1.2
SCI	1.1	1.0
Matheson/Nippon Sanso	1.0	1.2
Scott Specialty Gases	0.6	0.5
Stainless Steel Design	0.4	0.5
VSM	0.4	0.4
Creative Pathways	0.3	0.2
SILSCO	0.3	0.2
MG Scientific Gases	0.2	0
Total North America	40.9	41.0
Percentage of Total	45.6	44.4
Japan-Based Companies		
Tanaka/Nippon Sanso	14.0	17.0
Taiyo-Sanso	3.0	2.5
Toyoko	2.0	2.3
Ueki Gas Systems	2.0	2.1
Tomoe	2.0	2.2
Suski Shokan	1.5	1.6
Daido Sanso	1.2	0.9
Total Japan	25.7	28.6
Percentage of Total	28.6	31.0
Europe-Based Companies		
BOC/Osaka Sanso/Airco	4.9	3.4
Air Liquide/Labeille/ASGT/Teisan	10.4	10.9
Messer-Gresheim	1.4	1.5
Druva/AGA—30%	1.3	1.4
P.K. Mueller	1.3	1.1

(Continued)

Table 1 (Continued)
1990 Worldwide Market Share for Gas Cabinets by Company (Millions of Dollars)

	1989	1990
Draegger	0	0.2
UCAR	2.0	1.6
Cedeux	0.4	0.5
Total Europe	21.7	20.6
Percentage of Total	24.2	22.3
ROW Production		
Hanyang	1.5	2.1
Percentage of Total	1.7	2.3
Worldwide Total	89.8	92.3

Source: Dataquest (July 1991)

However, the acquisition is expected to provide SemiGas better access to Japanese semiconductor manufacturers because of Nippon Sanso's dominance of the Japanese industrial gas market. Considering the level of capital spending planned by the major Japanese semiconductor manufacturers, SemiGas may well return to its historical growth pattern in the near future. ■

By Mark FitzGerald

Micro Linear Announces New Fab

Micro Linear announced that it will build a 14,000-square-foot Class 10 fabrication facility in San Jose, California, to manufacture mixed-signal and analog integrated circuits. Micro Linear had used foundries up to this point to handle its manufacturing requirements. By having its own fab, Micro Linear plans to shorten delivery time to its customers and decrease development time on its next generation of chips. The fab will contain an 8,000-square-foot clean room and run an 0.8-micron BiCMOS process. The total cost for Phase 1 will be $16 million. Micro Linear plans to start production with 200 6-inch wafer starts per week and eventually ramp to 600 wafers per week. Micro Linear plans to produce prototype devices by the first quarter of 1992, and full production is expected in the middle of 1992. Quasar Engineering (Santa Clara, California) was selected to do the architectural design and construction. ■

By Jeff Seerley

In Future Issues

The following topic will be featured in an upcoming issue of *Dataquest Perspective:*

- Capital spending forecast by region

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Dataquest Perspective

Special Edition

July 22, 1991

Market Analysis

Dataquest's 1990 Electronics Industry Market Shares

Every year, Dataquest surveys both vendors and users in most major high-technology industries to collect market share and market sizing data. This article presents a summary of the 1990 market share results and is designed to provide an overview of the major players and major events of 1990 in the high-technology markets of telecommunications; semiconductor equipment, manufacturing, and materials; semiconductor devices; business and technical systems; personal computers; software; document imaging systems; CAD/CAM/CAE; computer storage; display terminals; electronic printers; and plain paper copiers.
By Jeremy Duke

Dataquest's 1991 Electronics Industry Forecast

The electronics industry will continue to experience basic structural changes as we progress into the 1990s. These fundamental structural changes are being driven by globalization of telecommunication networks, maturation of sectors of the computer industry, ongoing expansion in the Asia/Pacific region, and continued company consolidations and alliances.
By Jeremy Duke

Market Analysis

Dataquest's 1990 Electronics Industry Market Shares

Every year, Dataquest surveys both vendors and users in most major high-technology industries to collect market share and market sizing data. This article presents a summary of the 1990 market share results and is designed to provide an overview of the major players and major events of 1990 in the high-technology markets of telecommunications; semiconductor equipment, manufacturing, and materials; semiconductor devices; business and technical computer systems; personal computers; software; document imaging systems; CAD/CAM/CAE; computer storage; display terminals; electronic printers; and plain paper copiers.

The Markets

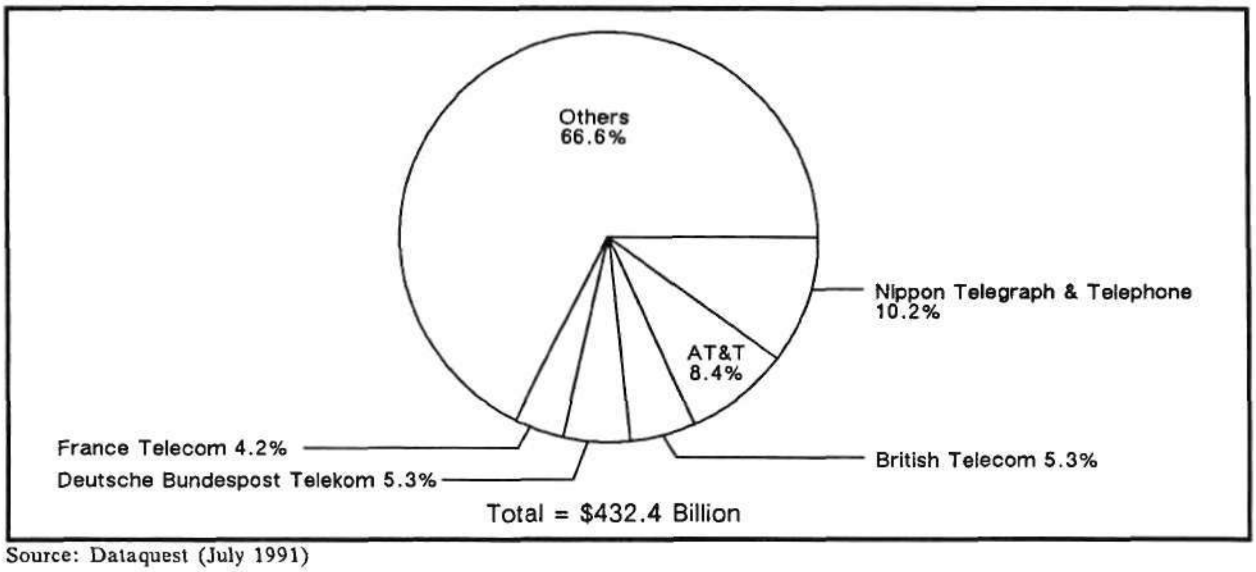
Telecommunications

The revenue market shares shown in Figure 1 reflect the total telecommunications market, including network services and equipment sales. The total available market for telecommunications was $432.4 billion in 1990. As is typical in this industry, the vast majority (more than 78 percent) of revenue is attributed to network services such as local, long distance, and international telephone calls. Because of this revenue imbalance, the market share leaders are representative of network providers—postal, telegraph, and telephone organizations (PTTs)—and not equipment manufacturers. As a point of comparison, the top five equipment providers (in alphabetical order: Alcatel, AT&T, NEC, Northern Telecom, and Siemens) have a combined equipment-related revenue of slightly more than $44 billion, which is almost exactly the total telecommunications-related revenue of NTT (see Figure 2).

The staggering size of the telecommunications market, combined with the necessity for communications standards and network capability, highlights the international character of this industry, which therefore demands a global perspective. Of the five companies shown in Figure 1, five countries are represented as worldwide leaders. Expanding the list to the top ten, the RBOCs start appearing along with Alcatel and Bell Canada (which includes Northern Telecom). Then seven different countries are represented in the top ten market leaders.

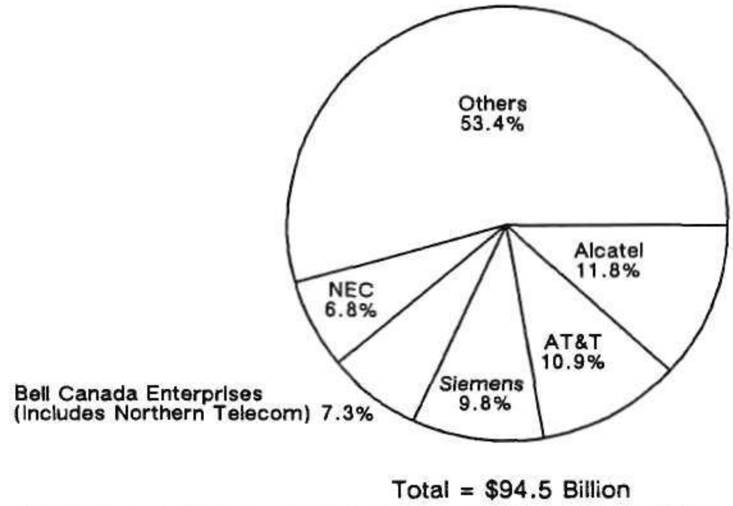
The 1990s will be an exciting time for the telecommunications industry, especially in the area of personal communications. The continuing globalization of the industry, utilization of communications standards such as ISDN, and

Figure 1
Estimated 1990 Worldwide Telecommunications Equipment and Services Revenue



Source: Dataquest (July 1991)

Figure 2
Estimated 1990 Worldwide Telecommunications Equipment Revenue



Source: Dataquest (July 1991)

ongoing mergers and acquisitions set the stage for an intense and dynamic business environment.

Semiconductor Equipment, Manufacturing, and Materials

In 1990, the worldwide market for semiconductor wafer fab equipment was $5.8 billion, down 3 percent from its 1989 level of $5,996 million. Figure 3 displays the top five participants by percent of market share in 1990.

In 1990, four of the top five players in the semiconductor equipment market were of Japanese origin. Applied Materials, a U.S. company that ranked number two with revenue of $462 million, was the only non-Japanese company in the top five. In the 1960s and 1970s, the wafer fab equipment market was dominated by U.S. companies. As the industry matured in the 1980s, however, one of the major trends that emerged was a steady gain in worldwide market share for Japanese equipment companies. The steady gain was due to the growth of a vigorous domestic semiconductor device manufacturing industry in Japan. In 1990, this industry accounted for $2.9 billion of a $5.8 billion worldwide wafer fab equipment market.

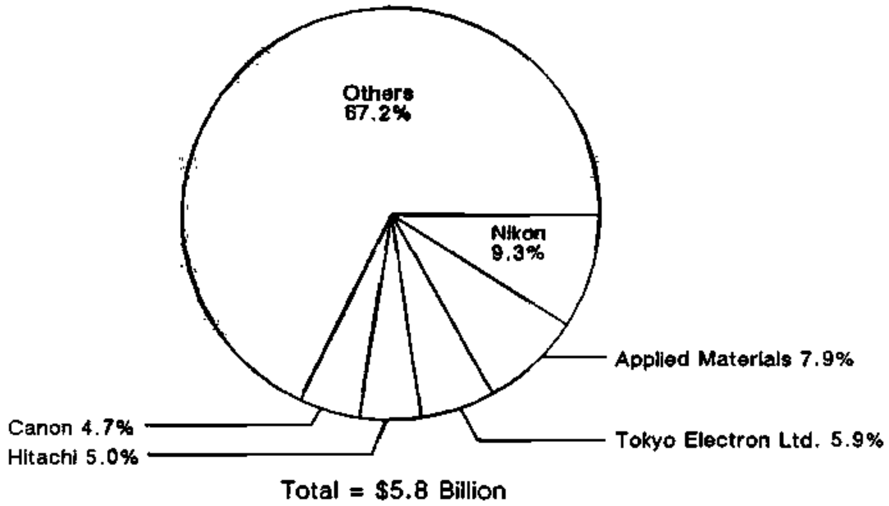
Semiconductor Devices

The number one rule of the semiconductor game asserted itself forcefully in 1990: What goes up must come down. Companies that derive large portions of their revenue from highly volatile commodity products eventually will see their business decline and their market share decrease as rapidly as they had previously grown. A case in point is MOS memory, which was responsible for much of the semiconductor industry's growth in 1988 and 1989. The market share gains made by memory suppliers in those years fell by the wayside (in most cases), allowing other companies to move up in the ranking list (see Figure 4).

Although the memory market did not disappear in 1990, steep price declines made it an unpleasant market to be in. The top three semiconductor vendors in 1990—NEC, Toshiba, and Hitachi—each derived 35 percent or more of their 1989 semiconductor revenue from MOS memory products. In 1990, this ratio slipped 3 to 6 percentage points. Although the same effect can be seen for the fourth- and fifth-ranked companies—Motorola and Intel—these companies received only 12 and 18 percent, respectively, of their 1989 revenue from MOS memory.

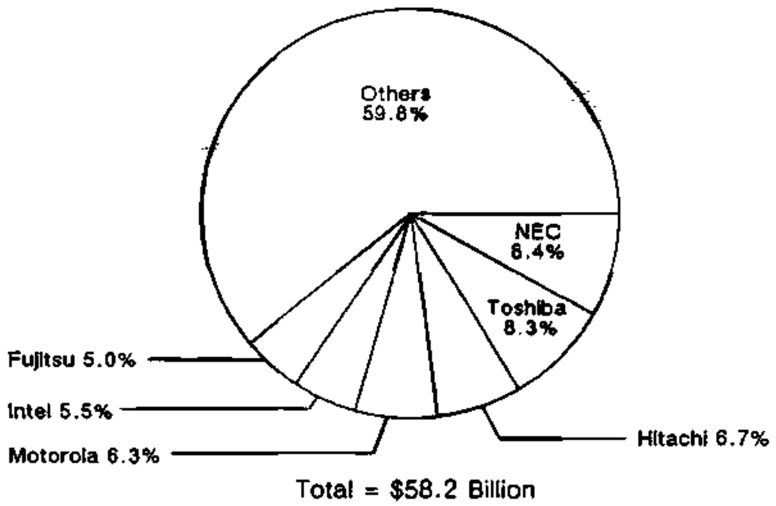
In 1990, these top five companies increased the percentage of total semiconductor revenue from MOS microcomponents. In the case of Intel, which went up in the rankings from number eight to number five, the portion of total semiconductor revenue that came from microcomponents grew from 79 to 86 percent. If it were not for the dramatic growth of microcomponents, the semiconductor industry would have

Figure 3
Estimated 1990 Total Semiconductor Equipment, Manufacturing, and Materials Factory Revenue



Source: Dataquest (July 1991)

Figure 4
Estimated 1990 Total Semiconductor Factory Revenue



Source: Dataquest (July1991)

declined by 2 percent in 1990, rather than having grown by 2 percent.

It is very clear that vastly different product strategies are being followed by each regional grouping of companies. The largest portion of North American companies' 1990 revenue—27 percent—came from microcomponents, while the largest portions of Japanese companies' revenue were from MOS memory (28 percent) and the combined grouping of bipolar digital, discrete, and optoelectronics (29 percent). European companies, on the other hand, are heavily dependent on bipolar digital, discrete, and optoelectronics (36 percent) and analog (30 percent); their revenue from the fastest-growing segments (in the long term) of the semiconductor industry—MOS memory and microcomponents—totaled only 21 percent of their semiconductor revenue. The Asia/Pacific companies' revenue was very heavily skewed in favor of memory, with 63 percent of their revenue coming from that product category.

The memory market eventually will recover, and companies with major commitments in this market will have a chance to regain semiconductor market share. However, in 1990, Dataquest saw that a strong marketing strategy in other product areas can pay off handsomely. We continue to believe that companies with balanced product portfolios in conjunction with volatile commodity exposure will gain market share over the long term.

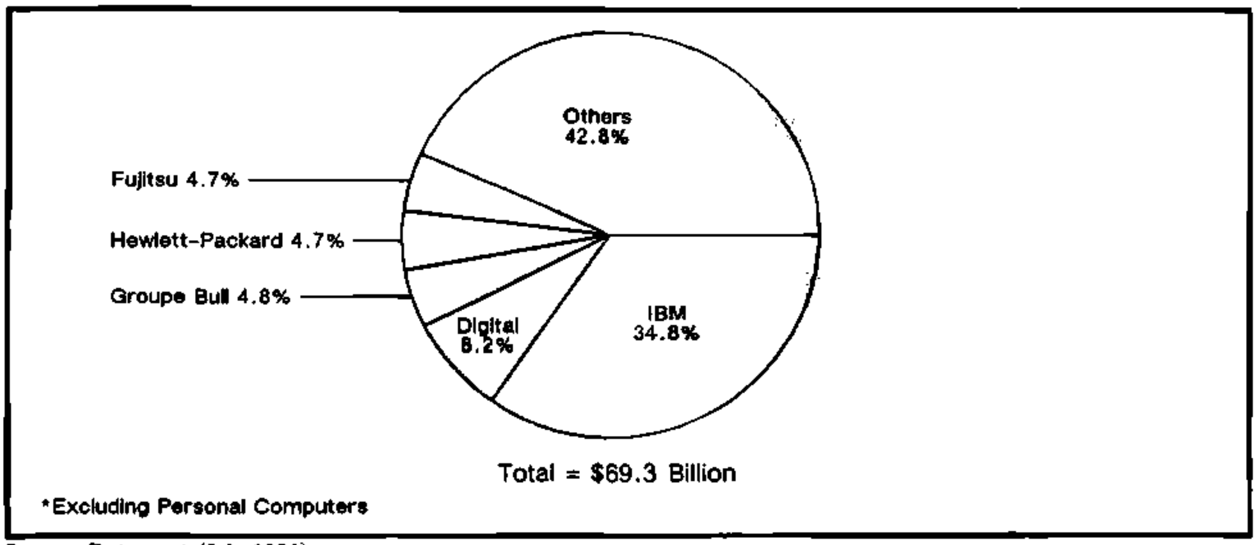
Business and Technical Computer Systems

The year 1990 was a tough one for the computer systems industry. The economic downturn in the United States and the threat of war in the Middle East combined with economic slowing in all regions of the world to slow the worldwide computer systems market growth. In total, the market grew only 6.4 percent over 1989, a rate lower than the 7.9 percent forecast for 1990.

The top five vendors' estimated 1990 factory revenue and market share are shown in Figure 5. IBM continued to hold the lead but lost about 1.4 percent in market share over 1989. With many major vendors having flat or declining revenue for the year, a number of the top vendors lost market share. Although remaining in the second-ranked position, traditional minicomputer vendor Digital Equipment Corporation has seen its share fall from 9.0 percent in 1989 to 8.2 percent in 1990. Digital struggled to maintain the traditionally profitable proprietary VAX line while transitioning to more open UNIX-based systems that have much narrower margins.

Of the top five vendors, only Hewlett-Packard and Fujitsu increased their market share from 1989 to 1990. Fujitsu went from 4.5 percent in 1989 to 4.7 percent in 1990. If the acquisition of ICL had been completed in 1990, Fujitsu's total computer systems revenue would have been $4.0 billion, moving Fujitsu into third place with a 5.8 percent market share. Other vendors making gains in 1990 were Hitachi and Sun Microsystems. Hitachi's gain was fueled by growth in the mainframe product segment. From 1989 to 1990, Hitachi's mainframe revenue increased 12.5 percent (including revenue from HDS in both 1989 and 1990). Sun Microsystems' move into the top ten has been based on the strength of virtually a single product line—workstations. The workstation product segment has been the hottest segment of the market for a number years, and Sun has been at the top of the workstation market for the last several years.

Figure 5
Estimated 1990 Worldwide Business and Technical Computer Systems Factory Revenue



Source: Dataquest (July 1991)

Personal Computers

In 1990, the Notebook PC gained notoriety. At COMDEX/Fall '90, 37 vendors introduced "notebook" computers. Also in 1990, prices fell the fastest in the shortest period of time. See Figure 6 for a display of the market leaders in 1990.

As 1990 came to a close, the market was left with an unstable pricing structure, shaky margins for vendors and dealers, and an economy struggling to stay on the positive side of growth.

HP validated the hand-held computer market with a bang. In April, the HP 95LX was introduced; Dataquest estimates that 300,000 could be sold by year-end. Pen-based PCs are the newest interest, with GRiD expanding the GRiDPad line and NCR entering the market. Operating systems are fueling the excitement with GO Corporation introducing the PenPoint operating system and Microsoft introducing PenWindows. By the end of the year, Dataquest expects several more entrants as PC vendors scramble for positioning in this potentially large market.

The desktop PC market is expected to crest in the United States, as portables eat into an already sluggish market and replacement sales continue to decrease.

The notebook PC market should be the most difficult market this year, as intense competition and obsolescence are precariously balanced. The 80386SL microprocessor will rapidly replace the 80386SX in the notebook segment. Vendors must balance demands for today's notebook sales with the risk of holding warehouses of 80306SX-based notebooks when the 80386SL-based notebook PC is available in volume.

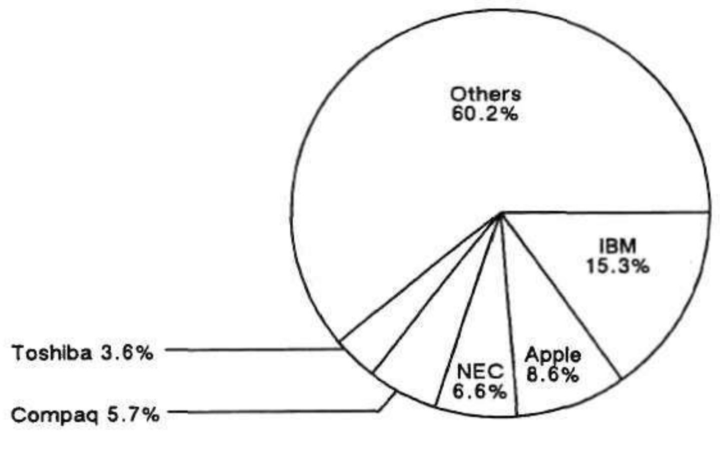
In the laptop DC and notebook segments, entropy is growing, causing further price confusion.

Dataquest expects Apple to increase its market share by units with new, lower-priced PCs and Compaq to increase market share with its notebook and high-end PCs. We also expect HP to increase market share with its new hand-held PC, IBM to increase market share with its assault on distribution channels, and Zenith Data Systems (a company of Groupe Bull) to increase market share as it emerges from a sleepy 1990 with new, well-designed laptop and notebook PCs.

Software

Windows was the star of the show in 1990, grabbing the attention of users and driving vendors to provide Windows products. Also monumental in that year was IBM and Microsoft's fight over the fate of operating software. IBM was intent on providing its own Presentation Manager (PM), not using Windows as the ubiquitous graphical user interface. It is interesting to note that while Microsoft is

Figure 6
Estimated 1990 Worldwide Personal Computer Factory Revenue



Source: Dataquest (July 1991)

aggressively promoting Windows over PM and implementing a strategy of cross-platform availability, it is still actively maintaining its present relationship with IBM. See Figure 7 for a display of the major players in 1990.

In 1990, Borland embarked on an aggressive marketing campaign in the spreadsheet market that successfully wooed a large part of the Lotus 1-2-3 installed base to Borland's QuattroPro. Through its dynamic marketing actions, Borland changed the competitive etiquette of this market, catching Lotus completely off guard. To no one's surprise, Lotus lost significant market share as a result. Also, Borland applied its new marketing techniques to Paradox, its relational database, with success. Other companies are copying Borland's style.

Also on the cutting edge of change, Borland broke away from traditional methods of selling products in this market. The company continued to sell products via the two-tier channel, while concentrating on direct sales through an aggressive direct-mail marketing campaign. Borland's innovation proved fruitful.

Of all the important events in 1990, Dataquest believes that Windows 3.0 will have the most significant effect on PC software for years to come. PC software as a market will be impacted by Borland International's product design and marketing innovations. The increasing growth of the direct market indicates that PC software is becoming more of a commodity.

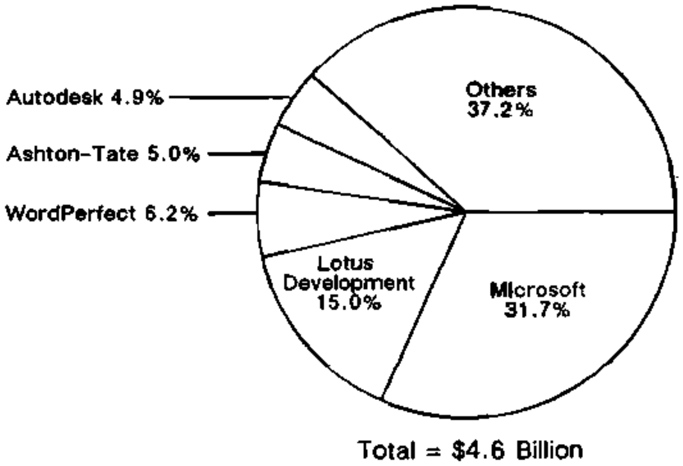
Document Imaging Systems

Dataquest defines document image management systems (DIMS) as computer systems that convert paper documents into digital images via scanning that can be viewed at a workstation, stored on random-access media, transmitted across networks, and printed. During tight times such as these, when many businesses must make cuts in budget and staff to stay afloat, DIMS seem to offer a viable way to be more productive using fewer resources. In the business document imaging system market, several key vendors' introduction of software enabling PCs to run document imaging applications promises to extend image management capabilities deeper into organizations.

To date, only IBM, Digital Equipment, and Wang Laboratories among the computer systems vendors have had measurable success in document imaging. Others, such as Bull, Hewlett-Packard, NCR, and Unisys, are moving slowly but steadily. FileNet, a company that specializes in providing document imaging systems, ranked second in terms of DIMS revenue in 1990 (see Figure 8).

Technical document image management systems (TDIMS) are used to image wide-format drawings and documents. TDIMS shipments grew by nearly 14 percent between 1989 and 1990, and revenue skyrocketed by 46 percent. The top five market leaders in this marketplace are Optigraphics, Intergraph, GTX, Litton/Integrated Automation, and FormTek (see Figure 9).

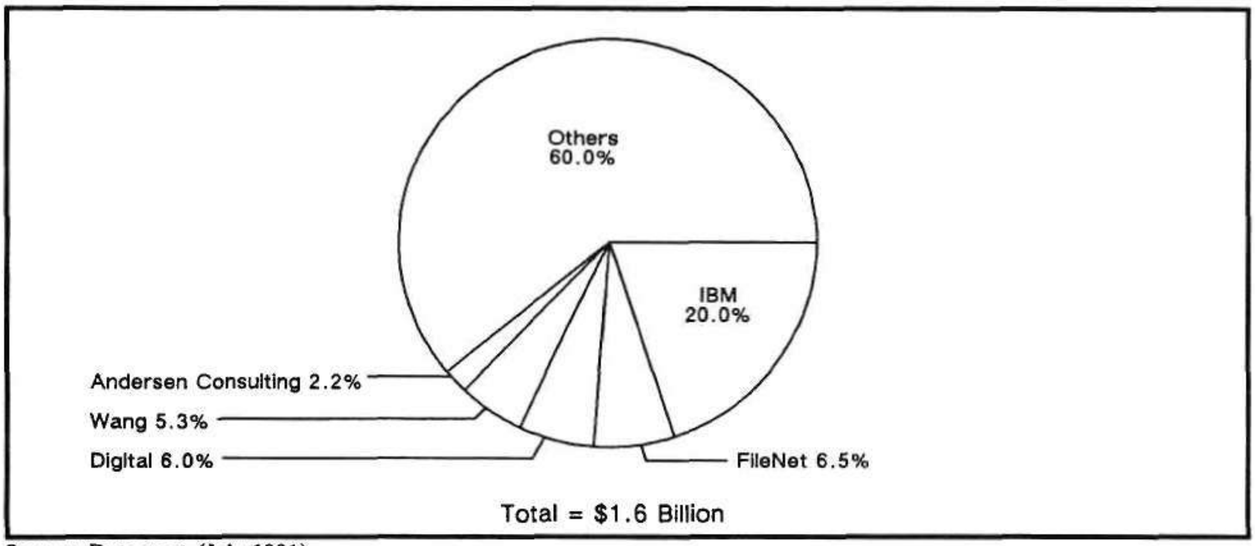
Figure 7
Estimated 1990 Worldwide PC Software Factory Revenue*



* Includes only shrink-wrapped single-user revenue

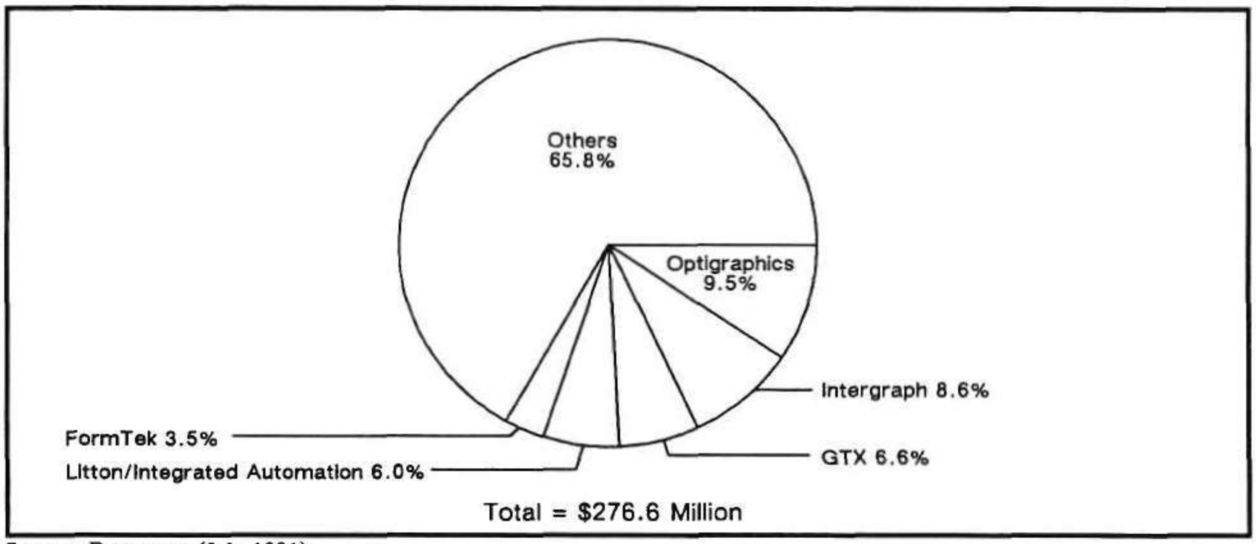
Source: Dataquest (July 1991)

Figure 8
Estimated 1990 Vendor Revenue—Business Document Image Management Systems



Source: Dataquest (July 1991)

Figure 9
Estimated 1990 Vendor Revenue—Technical Document Image Management Systems



Source: Dataquest (July 1991)

Although some of the industries served by TDIMS are experiencing hard times, this enabling technology continues to make inroads into engineering and document management groups across a broad number of industries.

Despite a year that was slower than expected in terms of overall TDIMS shipments, revenue was much higher than anticipated, and the TDIMS market continues to build momentum. This is a time when most TDIMS vendors and integrators are still getting it together—learning from pilot installations, building second-generation products, continuing to improve enabling technologies such as raster-to-vector conversion, and building a systems-implementation knowledge base.

CAD/CAM/CAE

In 1990, the CAD/CAM/CAE market grew 14.6 percent to $14.4 billion. The biggest gains in this market went either to vendors that had established CAD/CAM/CAE market share or to vendors that were very innovative. The biggest CAD/CAM/CAE vendors benefited from the growing importance placed by users on long-term supplier viability; buyers were willing to commit to using more design tools, but not without strategic alliances with leading vendors. The year was not a study in big vendors getting bigger, however. Users were also active in testing and buying some of the newest technology from all vendor sources, big and small. See Figure 10 for the major TDIMS vendors' 1990 market share.

The fastest-growing and best niche vendors in this maturing market reaped the rewards of developing joint marketing agreements with the top systems integration vendors. Products that enhance design, analysis, and quality control functions grew particularly well.

Instability in the electronic design automation (EDA) industry continued to create market uncertainty that affected growth. Several major players in the EDA industry weathered significant product transitions, others began to attack new markets, and many are being forced to revamp their business models.

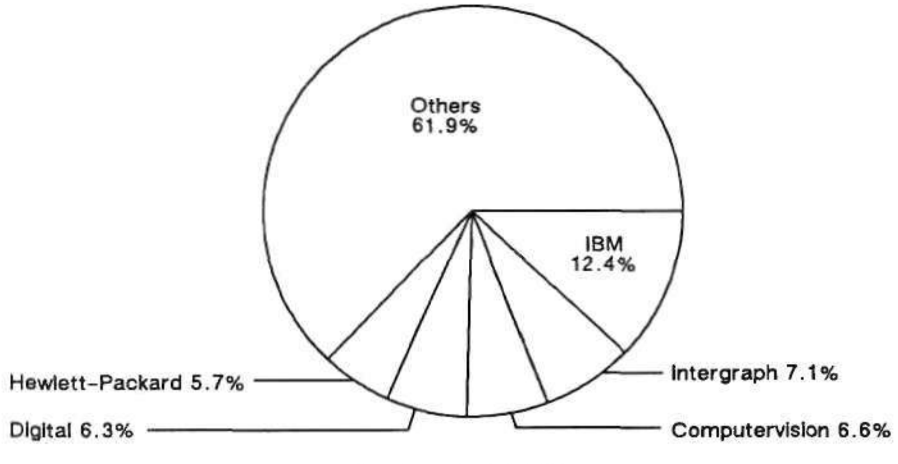
The European market continued to grow faster than expected, and it should continue to grow faster than the worldwide average. Opportunities for CAD/CAM/CAE in Eastern Europe will grow as the area moves to a Western-style, market-driven economy. Opportunities include both sales to existing companies for design of products to satisfy the enlarged domestic market and tool sales to Eastern European companies to assist their drive toward greater productivity and competitiveness.

Computer Storage

The computer storage market ended the year ahead of our previous projections. Worldwide factory revenue grew to $21.1 billion, an increase of 18 percent. Sales of 3.5-inch rigid disk drives (RDD) exploded beyond expectations, driving 1990 revenue in this segment to $5.6 billion, up 78 percent over 1989 revenue. The 3.5-inch RDD segment is the largest segment of the computer storage market and also the fastest growing.

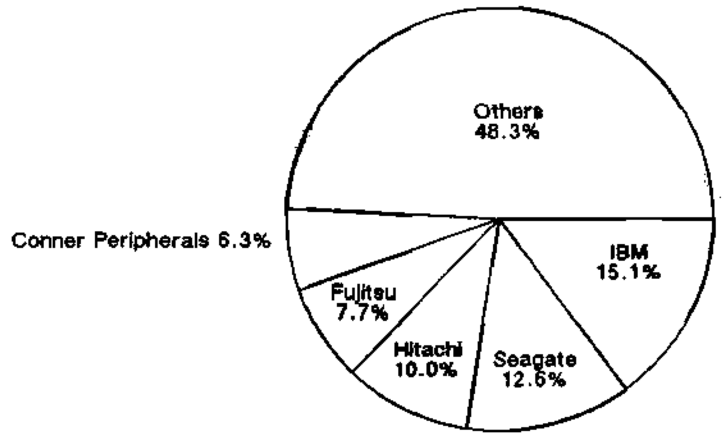
Figure 11 shows the estimated 1990 computer storage market shares. The top five companies are the same as in 1989; however, significant changes occurred during 1990. IBM remained in first place, albeit with a lower share than the previous year because of a large portion of its sales in the slower-growing high-end markets. Seagate overtook Hitachi for the number two spot, largely due to the growth of the 3.5-inch

Figure 10
Estimated 1990 CAD/CAM/CAE Worldwide Market Shares



Source: Dataquest (July 1991)

Figure 11
Estimated 1990 Worldwide Computer Storage Factory Revenue



Source: Dataquest (July 1991)

RDD market and an increased share of the 5.25-inch RDD market. Fujitsu does not participate in the 3.5-inch RDD market and lost market share during 1990. Conner Peripherals grew from 4 percent market share in 1989 to 6.3 percent in 1990.

Dataquest expects the 3.5-inch RDD segment to grow from its current 27 percent of the computer storage market to nearly 55 percent by 1995 and to greatly influence future total computer storage market shares. The key players in the 3.5-inch RDD segment are Conner, IBM, Maxtor, Quantum, Seagate, and Western Digital (in alphabetical order). The list of key players for 1991 will show the same names, but the positions will vary again.

Display Terminals

The top five leading worldwide display terminal vendors captured 52.3 percent of the total market (see Figure 12). IBM led this market with 22.6 percent market share, resulting from the continued success of its AS/400 product lines and the growth of its ANSI terminal business. Wyse, together with its subsidiary Link Technologies, maintained its leadership position in the still growing ASCII/ANSI/PC sector of the display terminal market.

Dataquest believes that the ASCII/ANSI/PC sector will continue to grow in market share. Color will play an increasingly significant role in the IBM 3270 and 5250 markets, but only a minor role in the ASCII/ANSI/PC market. The total ASCII/ANSI/PC market is expected to have a 5.9 percent compound annual growth rate (CAGR) through 1995.

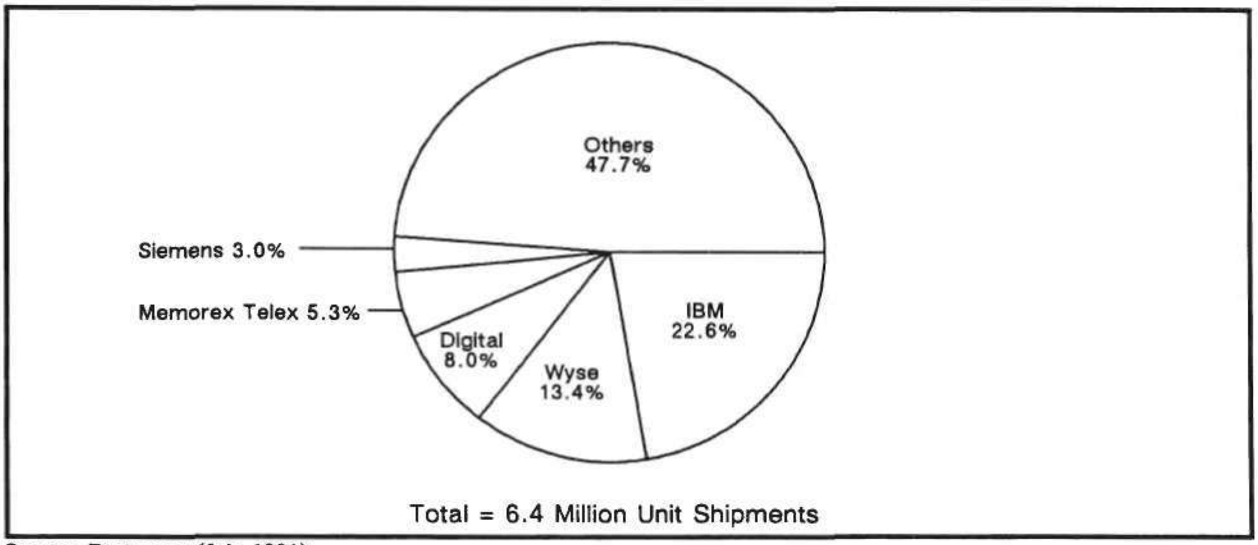
Electronic Printers

In some respects, the 1990 North American electronic printer market was a mirror image of 1989. There was only a slight growth in total factory revenue, and the market leaders and their rankings remained the same as in 1989. Figure 13 shows factory revenue of the major vendors of electronic printers.

In other respects, 1990 was a pivotal point in the market. It demonstrated Dataquest's previous assessments of the market. The serial printer market leveled off—serial dot matrix printers were being replaced by serial ink jet printers. Serial printers (which dominated the market in the 1980s) were being replaced by page printers. Page printers have become the dominant force in the printer market because they enable the user to advance to faster and higher-quality printing.

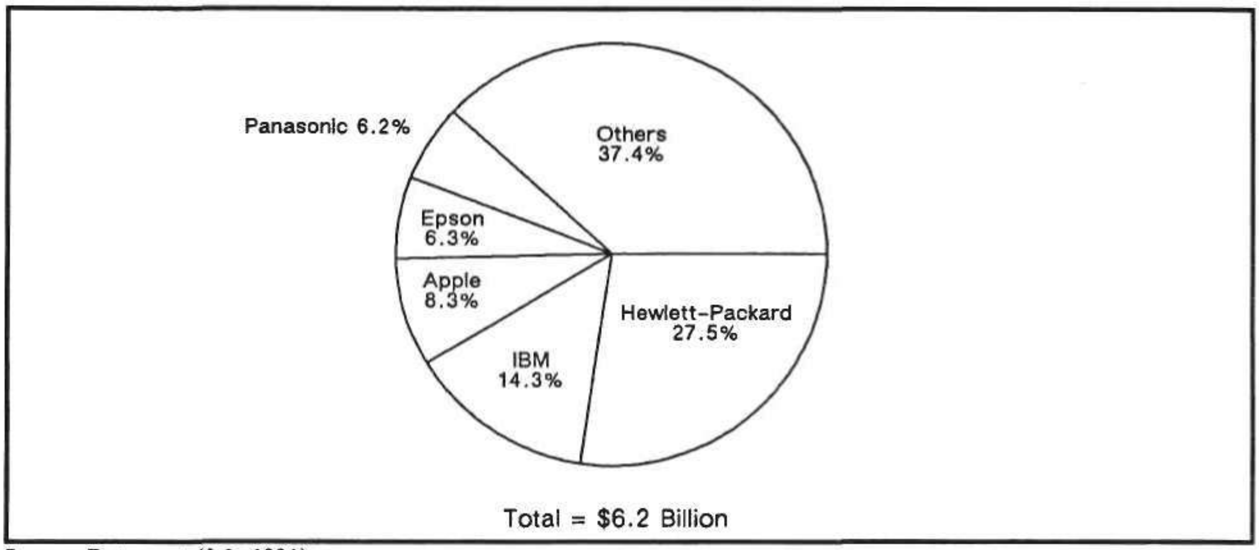
During 1990, page printers surpassed the 50 percent mark of total North American market revenue, and our projections are that this portion will expand to 60 percent by 1995. The

Figure 12
Estimated 1990 Worldwide Display Terminal Shipments



Source: Dataquest (July 1991)

Figure 13
Estimated 1990 North American Electronic Printer Factory Revenue



Source: Dataquest (July 1991)

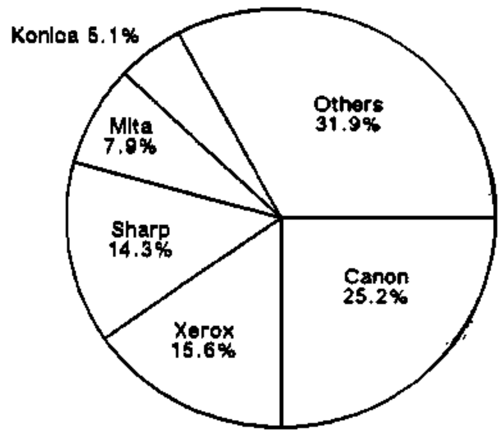
top three players in the total market (HP, IBM, and Apple) were also the market leaders in the page printer market—with 70 percent of that market.

Again in 1990, HP was clearly the winner in market share. HP had the dominant market share in both the ink jet and page printer markets, the fastest-growing segments of the electronic printer market.

Plain Paper Copiers

Once again, the clear winner in unit placements/shipments was Canon, followed by Xerox and Sharp. Canon's strength has traditionally been in the very low end of the copier market,

Figure 14
Estimated 1990 U.S. Plain Paper Copier (Placements)



Source: Dataquest (July 1991)

but the company is making a pronounced transition into a powerhouse in the midrange and upper end of the market. Xerox posted its seventh straight year of market share improvement. Although this improvement averages only about 1 percent per year, it does indicate a company that has made a remarkable turnaround in improvement of its market position. Sharp, which traditionally has had a good reputation in the low end of the market, expanded its capabilities in the midrange of the copier market. Figure 14 shows Dataquest's estimates of the 1990 U.S. market shares.

Although it is a relatively mature marketplace, there are still a number of dramatic changes taking place in the copier market. In the high end of the market, digital front ends that can be networked as output devices are being incorporated in order to improve the economies/efficiencies of the way documents are produced in high volume. This charge is being led by Xerox and Kodak.

In the midrange segments, traditionally dominated by independent dealers, we see increased competition as these dealers try to maintain their viability in the market. In the low end (a commodity market with little or no hardware differentiation), severe price cutting has led to margin erosion, with the result that dealers are giving less emphasis to this segment.

Dataquest's 1991 Electronics Industry Forecast

The electronics industry will continue to experience basic structural changes as we progress into the 1990s. These fundamental structural changes are being driven by globalization of telecommunication networks, maturation of sectors of the computer industry, ongoing expansion in the Asia/Pacific region, and continued company consolidations and alliances.

Although the 1990s started slowly with a burdening recession and war in the Persian Gulf, things are appearing to pick up according to significant indicators. Dataquest believes that the recession has hit rock bottom and is bouncing upward to recovery. This optimistic outlook is supported by the following U.S. government announcements of economic and business activity for the month of May:

- Industrial production is up 0.5 percent, the second consecutive monthly increase.
- Capacity utilization is up 0.2 percentage points to 78.7 percent.
- Nonfarm payrolls are up 58,000, which is the first increase in 11 months.
- Housing starts are up 0.1 percent.

- Retail sales are up 1.0 percent.
- Consumer borrowing is up 2.8 percent.

According to The Dun & Bradstreet Corporation, real gross national product (GNP) is expected to grow at only 0.2 percent in 1991, down from 1 percent in 1990. However, to get a true picture of 1991 GNP growth, we need to examine the quarterly data. The Gulf War was the major culprit in the first quarter, forcing first-quarter GNP growth to decline by 2.6 percent. However, things should begin to heat up in the remaining quarters: 1.5 percent for the second quarter, 3.8 percent for the third quarter, and 3.6 percent for the fourth quarter. Furthermore, real GNP will increase to 3.4 percent in 1992, the highest it has been in the past three years. A recovering GNP should lead to reduced inflation rates, a decline in unemployment, and increased consumer confidence.

In addition, government reports have suggested that the housing market is beginning to recover (housing starts were up 0.1 percent in May), companies are planning more hiring activities, and factory orders are beginning to build momentum. Also, according to the federal government, there is a steady drop in the number of people who are seeking unemployment benefits. This fact implies that new hires are beginning to offset layoffs.

In 1991, according to Dun & Bradstreet, capital equipment spending growth over 1990, as a percentage of GNP, is forecast to be a negative 0.8 percent. However, a closer examination of this figure is also needed to get an accurate picture. Growth for the first quarter was negative 18.2 percent; second quarter, 2.8 percent; third quarter, 7.5 percent; and fourth quarter, 10.1 percent. Apart from the strong dip in the first quarter, these figures clearly display the building momentum of capital equipment spending. This positive trend will continue; equipment spending is forecast to jump up to 8.3 percent for 1992.

The Markets

Telecommunications

Whether it be voice, text, or data, communication is key to business as we know it; therefore, by association, so is the telecommunications industry. Irrespective of international boundaries, the companies positioned to fulfill both the continuing and newly emerging demands for telecommunications will prosper well into the next century.

Forecast growth for the telecommunications industry as a whole remains mixed. Overall, the telecommunications market should grow at a compound annual growth rate (CAGR) of 7.1 percent until 1995 (see Table 1). The greatest influence on this market's growth is attributed to local and long distance calling services. In 1991, this segment will generate $150.6 billion, accounting for 86 percent of all North American telecommunications revenue. Although smaller, the equipment side of this market will grow more rapidly at a CAGR of 8.6 percent. Of this segment, customer premises equipment will grow faster than public equipment, at a CAGR of 14.8 percent compared with 4.1 percent. In Europe, total telecommunications sales are expected to parallel the U.S. rate. Also, equipment revenue growth is expected to be about half that of the United States.

The primary factors driving the telecommunications industry include globalization of worldwide networks, markets, and standards; rapid movement to a digital telecommunications network; transition from an engineering perspective to a marketing focus; and continued consolidations and alliances.

In the last decade, the telecommunications landscape was altered drastically: It became truly international. The ramifications of recent events taking place in Europe, alone, are monumental. Meeting the needs of these dynamic markets

Table 1
Worldwide Telecommunications Forecast by Region (End-User Revenue in Millions of Dollars)

	1990	1991	1995	CAGR (%) 1990-1995
North America	207,431	220,932	285,387	6.6
Europe	110,066	118,652	157,274	7.4
Japan	56,853	60,407	77,458	6.4
Asia/Pacific-ROW	58,019	63,076	90,331	9.3
Total Worldwide	432,370	463,067	610,450	7.1

Source: Dataquest (July 1991)

will require the globalization of networks and standards. Dataquest believes that outstanding opportunities exist for expansion in Europe and the Pacific Rim regions.

Furthermore, digitization of the networks creates strong opportunities. As a result of a digital network, bandwidth (data-carrying capability) will no longer be an issue or constraint. Simultaneous video, data, and voice transmission sharing the same medium will become a reality once the needed standards are passed and in place.

The acceptance of the Integrated Services Digital Network (ISDN) has been slower than anticipated. However, its use is expected to increase at a steady pace from the existing 206,000 access lines in service in 1991 to 1.1 million lines in service in 1995, representing a CAGR of 52 percent. ISDN is broadly supported by the industry, all critical standards have been implemented, field trials are presently being conducted in selected locations, and initial "pockets" of local services are currently available.

As we move into the new decade, the telecommunications industry will continue to shift its engineering focus to a more predominant marketing focus. The elements of success will be determined by customer service and support, solution-based applications, personal communications, strategic distribution, and account management.

Further mergers, acquisitions, and alliances will continue in the 1990s. These consolidations will occur partly as a result of competition, but also as a result of globalization.

Semiconductor Equipment, Manufacturing, and Materials

For the wafer fabrication equipment market, Dataquest is cautiously optimistic about the near-term outlook. The short-term outlook is clouded by the current worldwide macroeconomic and political uncertainties. However, in the long term, Dataquest believes that the wafer fabrication equipment market will enjoy healthy growth through 1995. Wafer fabrication equipment companies with global presence, financial muscle, and innovative customer-driven technology solutions can be optimistic about their long-term future in an increasingly chip-pervasive world.

Japan is the largest regional wafer fabrication equipment market in the world. In 1990, the market for wafer fab equipment in Japan was $2.94 billion, up 5 percent from its 1989 level of $2.80 billion. Japan represents the leading production region for high-volume advanced devices such as 4Mb DRAMs, 1Mb SRAMs, gate arrays, and embedded microcontrollers for Japan's burgeoning equipment industry. Hence, the Japanese wafer fab equipment market drives the requirements of high throughput and leading-edge process technology. Through sheer size and momentum, the Japanese wafer fabrication equipment market is expected to continue to prevail as the largest during the next five years, although it will grow at the slowest rate among the four major geographical markets.

North America as a region did not add many large production fabs in 1990. The 1990 wafer fab market in North America was $1.60 billion, down 4 percent from its 1989 level of $1.64 billion. Fab capacity expansion, upgrades, and offshore Japanese fabs in North America accounted for the bulk of the 1990 market. The United States is expected to continue to be the second largest wafer fab equipment market in the world.

In 1990, the wafer fab equipment market in Europe was $758 million, up 5 percent from the 1989 market of $720 million. In 1990, most of the wafer fab equipment market activities revolved around offshore Japanese and North American fabs locating in Europe to better serve their customer base and to position themselves as potential partners for 1992. These offshore European fabs were typically clones of parent North American and Japanese fabs. The European wafer fab equipment market will enjoy healthy growth during the next five years as Japanese, U.S., and Asian semiconductor companies set up Europe-based fabs to cater to a unified European market as well as large blocs of countries in Eastern Europe.

Semiconductor Devices

Dataquest believes that the long-term trend toward slower growth will continue for the semiconductor market in the 1990s. We are forecasting a worldwide CAGR of 12.6 percent from 1990 to 1995 (see Table 2). In addition, we believe that the cyclicality of the industry, although still in evidence, will abate considerably in magnitude. We do not foresee annual growth approaching even the 25 to 30 percent range in any one year. Key events and assumptions driving our short- and long-term forecasts are based on the following factors:

- Memories, microcomponents, and MOS logic are leading the industry recovery in 1991.

Table 2
Worldwide Semiconductor Consumption Forecast by Region
(Factory Revenue in Millions of Dollars)

	1990	1991	1995	CAGR (%) 1990-1995
North America	17,386	18,761	28,001	10
Europe	10,661	12,274	20,764	14.3
Japan	22,508	26,354	40,762	12.6
Asia/Pacific-ROW	7,670	8,834	16,004	15.8
Total Worldwide	58,225	66,223	105,531	12.6

Source: Dataquest (July 1991)

- Fluctuations against the U.S. dollar are skewing 1991 dollar growth upward.
- The European and Asian semiconductor markets are the hotbeds of activity for both the near and long term.
- As electronic equipment becomes an ever-larger component of the worldwide economy, semiconductor growth rates are slowing.
- The historical cyclicality of the industry, while still visible, has moderated.

Dataquest expects the next market peak to occur in 1992 or 1993, in keeping with historical cyclicality and the traditional market drivers of U.S. presidential elections and the Olympic games. We believe that the market will soften slightly in 1994 and 1995. Although semiconductor penetration is expected to increase in electronic equipment, the overall electronic equipment market is maturing and experiencing slower growth, and relationships between semiconductor suppliers and users are smoothing out the traditional volatility in the demand curve.

Throughout the forecast period, we expect Europe and Asia/Pacific-Rest of World (ROW) to consistently outperform North America and Japan. Europe and Asia will be driven by growing economies, communications standardization, and both new industrialization and reindustrialization. The applications with greatest opportunity will be personal communications, personal data processing equipment (such as laptop and palmtop PCs, and personal faxes), workstations, and—particularly in Europe—transportation.

Competitive pressure in the semiconductor industry is increasing as well. More and more microprocessors have become proprietary, with only a few vendors producing state-of-the-art devices.

Business and Technical Computer Systems

In the near term, the computer systems industry is not expected to perform much better than it did in 1990. Dataquest believes that Europe will not continue to experience the explosive market growth that it did in the recent past. However, we expect Japan to grow at a slightly higher rate than North America and Europe, fueled by the workstation and supercomputer product segments. Over the next five years, we believe that the market will grow at a 5.3 percent CAGR (see Table 3).

The supercomputer segment will show the second highest growth rate of any product segment, with a CAGR of 12.0 percent. Supercomputers will remain a small portion of the total market, with growth most likely fueled by a flow of systems into Eastern Europe assisted by U.S. and Japanese government subsidiaries.

The workstation segment will show the most growth over the next five-year period, with a CAGR of 25.8 percent. The gain in this segment will be apparent in both the technical and commercial markets. Growth in the commercial workstation market is projected at 62.4 percent over the next five years. However, this growth is dependent on the availability of applications and development of distribution channels. Workstations will continue to face stiff competition from PCs as PC functionality increases, forcing workstation prices even lower.

The mainframe market is expected to decline by the end of 1995, with a CAGR of negative 1.1 percent. Dataquest believes that big-ticket purchases will continue to be postponed and even canceled. Many users instead will be opting for lower-cost solutions such as PCs and workstations.

The midrange segment will continue to grow slowly, with a 3.0 percent CAGR over the five-

Table 3
Worldwide Business and Technical Computer Systems* Market Forecast by Region (Factory Revenue in Millions of Dollars)

	1990	1991	1995	CAGR (%) 1990-1995
North America	29,350	29,860	36,851	4.7
Europe	24,479	25,106	31,354	5.1
Japan	13,245	13,547	17,145	5.3
Asia/Pacific-ROW	2,272	2,577	4,350	13.9
Total Worldwide	69,346	71,090	89,700	5.3

*Excluding personal computers
Source: Dataquest (July 1991)

year period. Within the midrange market, we expect to continue to see falling ASPs. This segment is being squeezed by both workstations and networked PCs. As the large midrange suppliers—namely Digital and Hewlett-Packard—transition their product lines from the older proprietary systems to the newer open systems, margins will become ever smaller.

Software

Over the course of the last year, several hardware vendors—among them Digital Equipment Corporation, Wang Laboratories, and Apple Computer—have stated that they are repositioning themselves as software companies. Yet other vendors—including Sun Microsystems and Compaq—are looking to reduce their reliance on hardware products. A surge in software activity, often in the form of alliances with existing software vendors, has begun.

Another significant trend that has increased the impetus of the course of the last year has been the development of strategic software architectures. Ranging from relatively proprietary initiatives like SAA within IBM to much more open and esoteric strategies like that from Patriot Partners, software architectures have the potential to significantly impact the software industry. Particularly when they encompass object management capabilities, these software architectures will revolutionize the way that software is written and, as a consequence, vastly increase the number of software packages that are developed.

Dataquest primarily focuses on two specific segments of the software market: Personal Computer Software and Office Software. Personal computer software is utilized by more individuals than any other group of software products. Office software is highly strategic to the end-user community that implements it and to the vendor community that supplies it.

PC Software

In 1990, Windows grabbed the attention of the market, compelling major vendors to provide Windows products. Dataquest expects Windows-based DOS to exceed character-based DOS in worldwide unit sales after 1993. Windows 3.0 will have the most effect on PC software technology in the years to come.

Microsoft has reached a point where it believes that it can position itself in direct conflict with IBM's intentions. IBM wants the Presentation Manager (PM), not Windows, to be the graphical user interface used on every desktop. Although Microsoft is still facilitating a relationship with IBM, it is at the same time aggressively promoting Windows over the PM and is implementing a strategy of cross-platform availability. Dataquest believes that Microsoft will be successful. Through the mechanism of OS/2, Microsoft 3.0 will place the Windows interface on any computing environment that comes into use, whether it be its own or another vendor's.

Ashton-Tate, the Torrance, California-based publisher of dBASE IV, was recently purchased by arch-rival Borland International. Ashton-Tate used to be the market leader in relational database software, but release of a malfunctioning dBASE IV in late 1988 caused several bad quarters for the company. Though in the process of recovery, Ashton-Tate was still ripe for purchase. Borland acquired not only the dBASE product line, but more importantly, the dBASE customer list, which will serve Borland well in the 1990s.

Office Software

Overall, 1990 was a good year for office software. Dataquest expects this healthy trend to continue. The total worldwide office software market will grow to $2.9 billion in 1995 from $1.4 billion in 1990, representing a CAGR of 15.6 percent (see Table 4).

However, manufacturer-based office software is on the decline. Still lagging behind the PC independent software vendors (ISVs) in terms of features of productivity tools—specifically, the standalone variety—the systems vendors dominating this market have relied on their expertise in integration and enterprise-solution orientation to remain competitive. Although this may prove to be the case in the longer term, current trends indicate that neither end users nor vendors believe that systems vendors have the monopoly on enterprise solutions.

Although UNIX experienced high growth in 1990, the UNIX-based segment ultimately remains vulnerable to the fact that UNIX does not equate to open systems. Although this segment is expected to continue its healthy growth, vendors operating in this segment need to provide substantial added value, at least equal to that provided by vendors in the other segments, in order to continue to entice users to the UNIX platform. Business-solution orientation and increased penetration of large accounts would be among the highest imperatives, ensuring continued strength.

As for PC LAN-based office software, this segment remains the dark horse. Although this segment must be a critical component of all office software vendors' strategies, the segment is awaiting impetus from the PC ISVs' entry. Ultimately, office software will be dominated by connected LANs.

Document Imaging Systems

In 1990, the document imaging industry experienced a good year; the overall value of the worldwide document imaging market was $1.8 billion. Revenue for sales of document imaging systems into business and commercial markets grew by nearly 29 percent, and technical document imaging systems revenue increased 45.6 percent.

Dataquest defines document image management systems (DIMS) as computer systems that convert paper documents into digital (bit-map/raster) images that can be viewed at a workstation, stored on random-access media, transmitted across networks, and printed.

Dataquest's overall forecast for the worldwide document imaging industry is growth to $7 billion by 1995 (see Table 5). We expect business document imaging systems to account for roughly 76 percent of the market and technical systems to make up the remaining 24 percent.

Table 4
Worldwide Office Software Forecast by Region
(If-Sold License Revenue in Millions of Dollars)

	1990	1991	1995	CAGR (%) 1990-1995
United States	808	892	1,587	14.5
Europe	491	586	1,066	16.8
ROW	108	130	245	17.8
Total Worldwide	1,407	1,608	2,899	15.6

Source: Dataquest (July 1991)

Table 5
Worldwide Document Imaging Systems Forecast by Region
(Factory Revenue in Millions of Dollars)

	1990	1991	1995	CAGR (%) 1990-1995
United States	1,007	1,441	3,467	28
Europe	406	517	1,350	27.1
ROW	173	230	506	23.9
Total Worldwide	1,586	2,188	5,323	27.4

Source: Dataquest (July 1991)

Factors driving growth in this market include the following:

- The entry of almost all U.S. computer systems companies into the market has legitimized it, driven development forward, and raised user awareness of the technology's potential.
- The growing use of industry-standard PCs as desktop imaging platforms will bring the power of document imaging to more users throughout the decade.
- The focus of providing software solutions to paper storage and retrieval problems will make systems continually more useful.
- The increasingly popular client/server computing model is an ideal architecture for department-size imaging systems, the fastest-growing segment.
- Advances in enabling technologies, such as LAN, compression/decompression, work flow software, optical storage, optical character recognition, full-text retrieval, bar coding, and hand-print character recognition will move document imaging forward.
- Strategic alliances between business and technical document imaging vendors will produce systems capable of managing both small- and wide-format documents and drawings from a common database. The rise of multimedia computing will blend images as a common data element into all of the work that people do on computers by the end of the decade.

CAD/CAM/CAE

The worldwide CAD/CAM/CAE market will maintain consistent, steady growth over the next five years at a CAGR of 12.9 percent. Please refer to Table 6 for further information.

The market will be driven by the following factors:

- CAD/CAM/CAE systems will continue to give buyers a competitive edge. As time-to-market requirements shrink, demand for design automation tools will also increase.
- Market demand will be limited by vendors' inability to fully meet the demand for integrated systems; no vendor will completely solve the systems integration puzzle. Successful vendors will need to invest in systems integration, ensuring that hardware and software work together.
- Incremental progress in delivering open systems and standards to this market will also constrain market demand. When more open systems arrive on the market, the value of CAD tools to many users will become more pronounced. Standards will fuel growth in this market and also encourage third-party software suppliers to enter the market.
- The "late majority" for CAD/CAM/CAE will be coming to the market over the next five years, driving additional growth. However, conservative buyers will favor market leaders. These conservative buyers are the late majority buyers who do not buy until the weight of the majority seems to legitimize the product. Therefore, for vendors, the value of having high market share as well as financial clout will increase.

Computer Storage

Worldwide computer storage factory revenue grew to $21.1 billion during 1990, representing an increase of nearly 18 percent. The market grew more than expected, primarily as a result of increased demand for 3.5-inch rigid disk drives. Rigid disk drive revenue grew to 80 percent of total computer storage revenue during 1990. Within the rigid disk drive market, 3.5-inch drives dominated last year and are expected to continue to do so throughout the forecast period.

New technologies being developed in the computer storage industry will enable the computer equipment manufacturers to incorporate four to five times the storage capacity in their 1995 models, compared with their 1990 models. Dataquest expects this increased storage capacity to be available at nearly the same cost as in 1990.

Dataquest's forecast for the computer storage market is for a 5.6 percent CAGR through 1995 (see Table 7). Rigid disk drive revenue grew to 80 percent of total computer storage revenue during 1990 and is expected to remain at that level. The flexible disk drive and tape drive portions of the market are expected to decline slowly in the years ahead as the optical disk drive portion increases.

Display Terminals

Worldwide display terminal unit shipments grew by 3.3 percent in 1990. However, a sharp decrease in shipments of the relatively expensive IBM 3270-compatible terminals, coupled with the declining prices in the ASCII/ANSI/PC segment, resulted in a 10.5 percent decrease in factory revenue for the display terminal market.

During 1990, growth in the microprocessor-based UNIX and DOS multiuser systems and

Table 6
CAD/CAM/CAE Market Forecast by Region (Factory Revenue in Millions of Dollars)

	1990	1991	1995	CAGR (%) 1990-1995
North America	5,003	5,378	8,276	10.6
Europe	4,893	5,616	9,199	13.5
Japan	3,573	4,240	6,681	13.9
Asia/Pacific-ROW	563	709	1,535	23.7
Total Worldwide	14,031	15,943	25,692	12.9

Source: Dataquest (July 1991)

Table 7
Computer Storage Market Forecast by Region (Factory Revenue in Billions of Dollars)

	1990	1991	1995	CAGR (%) 1990-1995
North America	11.0	11.4	12.4	2.6
Europe	4.8	5.4	6.7	6.9
Japan	3.5	4.1	5.8	10.3
Asia/Pacific-ROW	1.8	2.1	2.9	9.6
Total Worldwide	21.1	23.0	27.8	5.6

Source: Dataquest (July 1991)

data communications networks markets created an 8.0 percent increase in demand for ASCII/ANSI/PC display terminals. Expansion of the IBM AS/400 market resulted in a 17 percent increase in IBM 5250-compatible display terminal unit shipments.

Dataquest forecasts the worldwide display terminal market to grow at a CAGR of 0.3 percent, remaining at its steady $4.6 billion level (see Table 8). However, there will be significant changes within the display terminal market. It is expected that ASCII/ANSI/PC terminals will dominate the market by 1995, while IBM 5250-compatible display terminals are expected to maintain their current portion of the market at the expense of the IBM 3270-compatible and asynchronous/synchronous markets.

Electronic Printers

During 1990, North American factory revenue grew by less than 1 percent for the electronic printer market. Unit shipments were less than Dataquest had expected, especially in the higher-value (price per unit) page and line printer segments. Fewer than anticipated unit shipments and accelerated price decreases contributed to the slow revenue growth.

Unit shipments grew by 8.5 percent during 1990. Serial printer unit shipments were up only slightly from 1989, and line printer shipments actually decreased nearly 20 percent. Page printers continued to be dominant components of the printer market, with unit shipment growth of nearly 70 percent during 1990.

Dataquest's forecast for the North American electronic printer market is a 5.6 percent CAGR through 1995 (see Table 9). Page printers currently represent about 25 percent of the market in both unit shipments and revenue. By 1995, the page printer portion is expected to grow to nearly 40 and 60 percent, respectively, of the total unit and revenue market.

The use of color is gaining market acceptance. Printing speeds and quality continue to increase, and more and more businesses are using electronic printers and desktop publishing. Growth rates of total printing capabilities will be in double digits during the forecast period.

In the past, the standalone PC dominated the electronic printer growth path. Now, the electronic printer market profile is changing. In the years ahead, work group clusters, LANs, and file servers/networks will enable rapid growth in printing capabilities, utilizing high-end specialty printers. In addition, there will be increased demand for personal slower-speed (1- to 4-ppm) printers. In total, these networks will increase the overall ratio of PCs to electronic printers, thus contributing to slower market growth rates than what was experienced in the last half of the 1980s.

Table 8
Worldwide Display Terminal Market Forecast (Factory Revenue in Billions of Dollars)

	1990	1991	1995	CAGR (%) 1990-1995
Total Worldwide	4.6	4.5	4.6	0.3

Source: Dataquest (July 1991)

Table 9
North American Electronic Printer Market Forecast (Factory Revenue in Billions of Dollars)

	1990	1991	1995	CAGR (%) 1990-1995
North America	6.2	6.8	8.2	5.6

Source: Dataquest (July 1991)

Table 10
U.S. Plain Paper Copier Market Forecast
(End-User, Service, and Rental Revenue in Billions of Dollars)

	1990	1991	1995	CAGR (%) 1990-1995
United States	14.6	15.1	15.2	0.8

Source: Dataquest (July 1991)

Plain Paper Copiers

During 1990, revenue increased by 6.2 percent, while placements (new and rental units) grew by 3.3 percent. Rental revenue grew by more than 10 percent, which pushed total revenue slightly above our previous projections.

Competition in this market remains intense, as manufacturers try to maintain or improve their market share. Dataquest forecasts a number of dramatic changes to this mature market. At the very high end of the copier spectrum, light lens copiers are being supplanted by machines with digital front ends, which eventually will be networked as output devices for demand publishing operations. At the lower end of the copier market, we expect a continuing healthy personal copier market as distribution through nontraditional copier channels improves.

Dataquest forecasts the U.S. plain paper copier market to grow at a CAGR of 0.8 percent (see Table 10). Dataquest believes that the percentage of total pages printed is gradually being shifted away from the traditional copier market into that of the desktop laser printers. This trend is expected to continue and will contribute to many new changes in the copier marketplace as manufacturers try to differentiate their products' performance and reliability.

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Dataquest Perspective

Semiconductor Equipment, Manufacturing, and Materials

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Semiconductor Manufacturing

Market Analysis

Semiconductor Manufacturing

Japanese Semiconductor Companies' Capital Spending Highlights: 1990-1991

Dataquest has just completed its analysis of Japanese merchant semiconductor manufacturers' capital expenditures and plans for calendar years 1990 and 1991. This article highlights the major features of those plans and expenditures.

The Japanese merchant semiconductor manufacturers' plans and expenditures are shown in Japanese yen and U.S. dollars in Tables 1 and 2. Japanese expenditures show healthy growth measured both in yen and dollars. We believe that Japanese manufacturers will increase their spending levels to $6,699 million or ¥897 billion. This is an increase of 16 percent as measured in dollars or 7 percent as measured in yen. The larger dollar growth rate is due to the appreciation of the yen against the dollar from the end of 1990—from 144 to 134 yen to the dollar during the first three months of 1991.

Japanese Semiconductor Capital Spending: 1990-1991

Fuji Electric plans to increase its capital spending from $28 million in 1990 to $112 million in 1991 (¥4 billion versus ¥15 billion). The company is planning expansions at its Matsumoto and Yamanashi fabs.

Table 1
Worldwide Japanese Companies' Semiconductor Capital Spending (Billions of Yen)

Company	1990	1991	CAGR (%) 1990-1991
Fuji Electric	4	15	275
Fujitsu	95	107	13
Hitachi	95	100	5
Kawasaki Steel	9	5	-44
Matsushita	72	74	3
Mitsubishi	60	87	45
NEC	90	110	22
New Japan Radio Company	7	5	-29
NKK	6	7	17
NMB	30	15	-50
Oki	30	35	17
Rohm	12	15	25
Sanken Electric	8	8	0
Sanyo	37	33	-11
Sharp	45	35	-22
Shindengen	3	3	20
Seiko Epson	15	6	-60
Sony	50	70	40
Tohoku Semiconductor	20	12	-40
Toshiba	90	100	11
Other Japanese Companies	57	55	-4
Total Japanese Companies	834	897	
Percent Change	10	7	

Source: Dataquest (July 1991)

Table 2
Worldwide Japanese Companies' Semiconductor Capital Spending
(Millions of Dollars)

Company	1990	1991	CAGR (%) 1990-1991
Fuji Electric	28	112	303
Fujitsu	660	799	21
Hitachi	660	747	13
Kawasaki Steel	62	37	-40
Matsushita	500	553	11
Mitsubishi	417	650	56
NEC	625	822	31
New Japan Radio Company	49	37	-23
NKK	42	52	25
NMB	208	112	-46
Oki	208	261	25
Rohm	83	112	34
Sanken Electric	56	60	8
Sanyo	257	246	-4
Sharp	313	261	-16
Shindengen	17	22	29
Seiko Epson	104	45	-57
Sony	347	523	51
Tohoku Semiconductor	139	90	-35
Toshiba	625	747	19
Other Japanese Companies	396	411	4
Total Japanese Companies	5,795	6,699	
Percent Change	6	16	
Exchange Rate	144	134	

Source: Dataquest (July 1991)

Fujitsu is planning to increase its spending by 13 percent in yen (21 percent in dollars) in 1991 from $660 million in 1990 to $799 million in 1991 (¥95 billion to ¥107 billion). Its expenditure level is one of the largest in the world. In addition to expansions and upgrades to its fabs in both the United States and Japan, Fujitsu has also embarked on significant new fab activity for gate arrays and 16Mb and 64Mb DRAMs. The company is currently adding new fabs or new fab lines at three locations in Japan and Newton-Aycliffe in Scotland.

Although Hitachi is planning to increase its spending levels in yen by only 5 percent (13 percent in dollars), its level of spending is very high—$747 million or ¥100 billion. In addition to expansions of its facilities in the United States and Japan, the company is building four new fabs: three in Japan, including a 16Mb DRAM fab at Naka, and a new DRAM fab in Germany.

Kawasaki Steel's capital spending level will be down 44 percent in yen in 1991 (40 percent in dollars) from $62 million in 1990 to $37 million in 1991 (¥9 billion to ¥5 billion). This decrease is due to the company completing its wafer fab at Utsunomiya. This plant has a current capacity of 3,000 wafers per month and will start full-scale production in fall 1991.

Matsushita plans to increase its spending by 3 percent in yen in 1991 (11 percent in dollars) from $500 million to $553 million (¥72 billion to ¥74 billion). Matsushita's plans include upgrading equipment at its fab in Puyallup, Washington, which it recently purchased from National Semiconductor and also building a new 16Mb DRAM fab at Tonami in Japan.

Mitsubishi is planning significant new capacity and boosting its capital spending levels significantly—up 45 percent in yen and 56 percent in dollars. Its spending level in 1991 is planned to be $650 million (¥87 billion). New fabs for Mitsubishi include a 4Mb DRAM fab in Germany and new DRAM fabs at Saijo and Kita-Itami in Japan.

This will be the fifth straight year of capital spending increases for Japanese semiconductor manufacturers.

NEC's spending plans in 1991 exceed those of any other Japanese semiconductor company. It plans to increase its spending levels by 22 percent in yen to ¥110 billion (31 percent in dollars to $822 million). NEC's spending plans in 1991 are exceeded only by Intel. In addition to capacity expansions and upgrades in Japan, NEC is building two new overseas DRAM fabs; one in Roseville, California, and another in Scotland. NEC has more capacity overseas than any other Japanese semiconductor manufacturer. NEC is also building two new DRAM fabs in Japan.

New Japan Radio is planning to decrease its capital spending by 29 percent in yen to ¥5 billion (23 percent in dollars to $37 million). The company's plans for 1991 include an expansion of its facility at Kowagoe.

NKK plans to increase its spending level by 17 percent in yen to ¥7 billion (25 percent in dollars to $52 million). NKK's 1991 spending plans include a new fab at Ayase in Japan.

NMB's capital spending plans are down significantly (50 percent in yen; 46 percent in dollars) in 1991. The company recently completed a major new production facility at Tateyama. It plans to spend $112 million or ¥15 billion on new equipment and begin construction of a new 16Mb DRAM fab.

Oki Electric plans to increase its capital spending by 17 percent in yen (25 percent in dollars) to ¥35 billion, or $261 million in 1991. The company's plans include the construction of a 16Mb DRAM fab at Miyazaki, Japan.

Rohm plans to increase its spending level in 1991 by 25 percent in yen to ¥15 billion (34 percent in dollars to $112 million). In 1990, Rohm completed a new SRAM facility at Fukuoka, Japan.

Sanken Electric's spending level measured in yen will remain unchanged in 1991 at ¥8 billion. Measured in dollars, however, the company's spending level will increase 8 percent to $60 million. The bulk of Sanken's spending in 1991 will be for equipment added to its Yamagata facility.

Sanyo's spending plans in yen for 1991 show a decrease of 11 percent to ¥33 billion (down 4 percent in dollars to $246 million). The company's 1991 plans include a new fab at Niigata and an upgrade of its facility at Hanyu, Japan.

Sharp plans to decrease its spending level in 1991 by 22 percent in yen to ¥35 billion (a decrease of 16 percent in dollars to $261 million). The Company's plans include expansions of its 4Mb DRAM fab at Fukuyama and of its 4- and 5-inch lines at Tenri, Japan.

Shindengen plans to increase its spending level by 20 percent in yen to ¥3 billion (29 percent in dollars to $22 million). The company's plans include a new assembly line in Thailand.

Seiko Epson plans to decrease its spending by 60 percent in yen to ¥6 billion (57 percent to $45 million). Seiko's plans include a new assembly line at Nagano and expansion of existing fab lines, including its 0.5-micron line at Fujimi, Japan.

Sony plans to increase its spending level by 40 percent in yen to ¥70 billion (51 percent in dollars to $523 million). The company's plans include a new assembly line at Shiraishi and expansion of both bipolar and MOS lines at Kokubu, new equipment for its recently acquired facility in San Antonio, Texas, and a new 4Mb SRAM fab in Nagasaki, Japan.

Tohoku Semiconductor, the joint venture between Motorola and Toshiba, will decrease its capital spending by 40 percent in yen to ¥12 billion (35 percent in dollars to $90 million). Tohoku is currently qualifying its new 4Mb DRAM facility at Sendai and also building a new 1Mb SRAM fab at Sendai.

Toshiba plans to increase its capital spending in yen by 11 percent to ¥100 billion (19 percent in dollars to $747 million). Toshiba's plans for 1991 include a new assembly line in Thailand, installing equipment at Iwate, and building a new 16Mb DRAM fab at Yokkaichi, Japan.

Table 3
Top 10 in 1991 Semiconductor Capital Spending
(Millions of Dollars)

Company	Amount
Intel	900
NEC	822
Fujitsu	799
Texas Instruments*	790
Toshiba	747
Hitachi	747
IBM	733
Mitsubishi	650
Motorola	640
Matsushita	553
Total	7,380

*Includes $330 million in non-TI-funded joint ventures
Source: Dataquest (July 1991)

Dataquest Perspective

In 1991, worldwide capital spending for Japan's semiconductor companies should increase by 7 percent in yen and 16 percent in dollars to ¥897 billion, or $6,699 million. This will be the fifth straight year of capital spending increases for Japanese semiconductor manufacturers.

Japanese semiconductor manufacturers have a larger share of the semiconductor market than any other regionally based semiconductor manufacturers. Japanese manufacturers also represent the largest market for semiconductor capital goods (47 percent). Additionally, Dataquest estimates that Japan will account for 6 of the top 10 in semiconductor capital spending in 1991 (see Table 3).

Clearly, with their worldwide efforts to expand 4Mb DRAM capacity and build 16Mb DRAM facilities, Japanese manufacturers are acting strategically to maintain their leadership in the worldwide semiconductor market. Currently, Fujitsu, Hitachi, Matsushita, Mitsubishi, NEC, and Sony have fabs in either Europe or the United States.

Those equipment and materials vendors that have global capabilities and have developed successful relationships with Japanese semiconductor manufacturers should have a good year in 1991, whether they measure their results in yen or in dollars.

By George Burns (San Jose)
Kunio Achiwa (Tokyo)

A Billion-Dollar Investment—Boom or Bust?

Introduction

From 1990 to 1994, silicon wafer manufacturers will be investing more than $1 billion in new capacity worldwide (see Table 1). Many industry watchers are questioning whether the silicon companies are not making the same mistake as they did in 1984. The binge of new plant construction in 1984 led to severe pricing pressures and eventually an industry shakeout. Will history repeat itself?

It's Not 1984

Dataquest does not believe so. The comparisons between 1984 and today are weak. The silicon wafer shortage of 1984, which prompted wafer suppliers to rush to market with new capacity, was artificially created by device manufacturers. On the other hand, the tight market for silicon wafers today is a real imbalance between supply and demand.

In the 1984 time frame, IC manufacturers, especially Japan's DRAM suppliers, overbuilt IC inventories and in the process were double and triple ordering wafers to guarantee a steady supply. The bubble eventually burst in 1985 when IC makers had to cut production in order to work off excess inventories.

The inventory excesses of 1984 sent the worldwide semiconductor industry into a tailspin. For the silicon wafer suppliers, the ensuing recession could not have happened at a worse time. A large amount of new plant capacity was coming on-line in 1985, just as silicon wafer demand dropped 25 percent. Needless to say, the recession for silicon vendors was longer and deeper than it was for the rest of the semiconductor industry.

Today's environment is completely different. IC inventories are well balanced and tightly controlled. The tight market for silicon, especially 6-inch wafers in Japan, is a result of the phenomenal growth in the demand for the larger-diameter wafers.

Moreover, the outlook for silicon consumption during the next several years is bright. Dataquest expects worldwide consumption of silicon

Table 1
Silicon Wafer Plant Expansions and New Lines

Company	Location	Status	Size	K Wafers per Month	Start Date*	Capital (US$M)	Spending (¥M)
Shin-Etsu Handotai	Shirakawa	R&D			1990/3	14.3	2,000
	Isobe	Epi expand				14.3	2,000
	Nagano	New volume production line	6"		1991/2	25.0	3,500
	Naoetsu	New volume production line	6"		1991/3	32.1	4,500
	Mimasu	Polishing line			1991/4	39.3	5,500
	Shirakawa	8" volume production	8"	30	1992/4	107.1	15,000
	Camus, Oregon	8" volume production	8"	10	1991/2	7.1	1,000
	England	6" volume production	6"	200	1991/1Q	32.1	4,500
						271.4	38,000
Osaka Titanium	Imari	#3 volume production line	6", 8"	300	1991/1Q	8.6	1,200
	Mainville, Ohio	Expand			1992/1Q	7.1	1,000
						15.7	2,200
Mitsubishi Materials	Noda	Pilot line	8"	5	1990/9	28.6	4,000
	Yonezawa	Volume production	6"	250	1990	28.6	4,000
	Noda	R&D for 4Mb			1990/4	14.3	2,000
	Cntrl Rsrch	R&D for 16Mb	8"		1990	14.3	2,000
	Ikuno	8" volume production	8"	20	1991/1Q	53.6	7,500
	Chitose	Epi production line			1992/4Q	71.4	10,000
						210.7	29,500
Komatsu Electronic Metals	Nagasaki	Volume production line	6", 8"	200	1992/1Q	28.6	4,000
	Miyazaki	R&D				14.3	2,000
	Hiratsuka	Technical center			1991/3Q	14.3	2,000
	Portland, Oregon						
						64.3	9,000
Toshiba Ceramics	Yamagata	Expand at Okuni plant	6"			28.6	4,000
	Cntrl Rsrch	Pilot line	8"		1990/9	3.6	500
	Niigata	Volume production line	8"	100	1993/1	158.6	22,210
	Tokuyama	Epi expansion	5"	90	1994	35.7	5,000
						226.5	31,710
Kawatec	Santa Clara, California	First expansion	5", 6", 8"	70	1990/7	44.3	6,200
		Second expansion	5", 6", 8"	80	1992/7	20.0	2,800
						64.3	9,000

(Continued)

Table 1 (Continued)
Silicon Wafer Plant Expansions and New Lines

Company	Location	Status	Size	K Wafers per Month	Start Date*	Capital (US$M)	Spending (¥M)
Showa Denko	Chichibu	Expand	6", 8"	30	1990/4Q	14.3	2,000
Nittetsu	Hikari	Expand	8"		1991	21.4	3,000
MEMC	St. Peters, Missouri	Expand	8"	30	1991/11	31.0	4,340
Posco-Huels	Korea	Volume production line	6", 8"		1992/3	110.0	15,400
Oriental Electronic Metals	Korea	Volume production line	6", 8"		1992/1Q	35.0	4,900
Wacker-Chemitronic	Wasserburg, Germany	Expansion of epi	6"		1990/6	5.0	700
Total						1,062.5	148,750

*Start date indicated by month or quarter.
Source: Dataquest (July 1991)

wafers to increase at a compound annual growth rate of 10.4 percent through 1993. Therefore, new investments in silicon wafer capacity today will be ramping up at the same time demand is growing.

Finally, the economies of the major silicon-consuming regions of the world look strong. Japan, barring a catastrophe in the domestic equities market, is expected to skirt a recession altogether. Japan's capital investment, although down from historic highs in the latter half of the 1980s, is still impressive.

Dataquest believes that the U.S. economy has bottomed out and that the next several years will show moderate growth. Asia/Pacific countries are forecast to continue their strong growth patterns provided individual countries do not suffer political setbacks. Europe, although forecast to be weak next year, appears to have bright prospects, particularly toward the 1993 time frame when foreign investment in new IC plants will begin ramping. Market conditions should be favorable in terms of absorbing this new capacity.

200mm Investment

The lion's share of today's new silicon plant investments is being made in Japan in anticipation of the growth of the 200mm market. The demand for 200mm wafers in Japan is expected to grow to 4.17 million pieces by 1995, surpassing all other regions (see Table 2).

At first glance, the 200mm capacity going into Japan appears to be in excess of what will be required in 1995. However, there are two factors that suggest that this will not be the case.

Table 2
200mm Wafer Market
(Millions of Pieces)

	1987	1988	1989	1990	1991	1992	Forecast 1993	1994	1995
Worldwide	0.08	0.25	0.56	0.98	1.62	2.78	4.37	6.15	9.38
United States	0.06	0.19	0.41	0.70	1.01	1.36	1.81	2.35	3.54
Japan	0.01	0.03	0.06	0.10	0.34	1.04	2.03	3.05	4.17
Europe	0	0.03	0.10	0.15	0.20	0.28	0.38	0.50	0.94
Asia/Pacific-ROW	0	0	0	0.02	0.06	0.11	0.16	0.24	0.73

Source: Dataquest (July 1991)

First, the specifications for 200mm wafers used for 16Mb and 64Mb processes are so severe that wafer production yields are expected to be very low as these new facilities ramp. So the reported capacity (Table 1) reflects the facility's potential capacity rather than its start-date capacity. In fact, a good share of the investment being made in Japan is not in production facilities at all, but rather R&D or pilot lines, which are required to solve some of the problems associated with tight wafer specifications.

Second, it requires roughly a year for a new wafer plant to be qualified by a device manufacturer. Therefore, production volumes of wafers at a new plant will only be achieved well past the start date. These two trends should ensure a balance between supply and demand.

Dataquest Perspective

The billions of dollars invested in new worldwide silicon wafer plants is not expected to result in an oversupply. The investment, which is primarily occurring in Japan, is largely in anticipation of the strong growth in demand for 200mm wafers. To a lesser extent, the investment in Japan is also addressing the current shortage of 150mm wafers.

Two new production facilities are starting up in Korea within the next two years. These plants will reduce the Asia/Pacific region's dependence on imported wafers. Dataquest estimates that Asia/Pacific countries import roughly 60 percent of their current wafer requirements largely from the United States.

As a result, about 90 million square inches of U.S. production capacity will be freed up by the middle of the decade as these Korean plants reach their full potential. Dataquest believes that this capacity can easily be absorbed by the growth in the U.S. domestic market.

It is unlikely that the management at silicon wafer companies has forgotten its recent past. The current round of investment in new plants will be carefully driven by market demand rather than speculative excesses. ■

By Mark FitzGerald

Market Analysis

RTP Equipment—1990 Market in Review

Summary

Dataquest estimates the worldwide 1990 rapid thermal processing (RTP) equipment market to be $32.9 million in 1990, up 17 percent from its $28.1 million 1989 value. RTP appears to be finally making the transition from R&D to full-scale production. Applications such as titanium silicide formation and anneal, BPSG reflow, implant anneal, thin-gate dielectric and DRAM capacitor dielectric growth, and reactive barrier metal formation are driving the growth of the RTP market. Dataquest expects a significant RTP module market to develop over the next few years in addition to the standalone RTP systems market. Cluster tool equipment companies and semiconductor manufacturers will procure RTP modules for integration into their thin film processes. North American companies, with their extensive research efforts, dominate the 1990 RTP market with 76 percent of the total market.

Regional Markets

Figure 1 shows the worldwide 1990 RTP market segmented by region and ownership. North America, as a region, is the largest market segment, with 42 percent of the worldwide market. North America is in the forefront of RTP applications research for advanced submicron processes. Companies such as Intel, Motorola, and Texas Instruments have active programs aimed at moving RTP technology into production.

Japan accounted for 38 percent of the 1990 RTP market. Japan is a high-growth RTP equipment market. Japan-based DRAM companies are evaluating RTP technology for multiple applications in the 64Mb DRAM generation. Dataquest expects Japan's RTP market to quickly surpass the North American RTP market as RTP technology moves into production for 200mm 4Mb shrink/16Mb DRAM applications.

The European and Asia/Pacific-ROW markets represented 12 and 8 percent of the 1990 worldwide RTP market, respectively. Dataquest expects these two regions to also quickly embrace RTP production due to the globalized nature of semiconductor manufacturing technology.

Regional Ownership

Figure 1 also shows regional ownership of the worldwide 1990 RTP market. North American companies dominate the market (owning 76 percent). North American companies invented RTP technology and were the fist to commercialize the technology. Subsequently, they have pursued a strategy of incremental innovation in RTP lamp technology, heating uniformity, new process applications, and production equipment development. North American RTP start-up companies nurture the hope that the RTP market may someday replace the far bigger $322-million diffusion/oxidation equipment market. Dataquest believes that the RTP market will complement the diffusion equipment market over the next few years rather than replace it. However, in the long term, Dataquest believes that RTP and single-wafer RTP-based chemical vapor deposition (CVD) technology may replace large-batch and small-batch deposition systems such as tube furnaces and batch reactors for 200mm- and 300mm-wafer fabs.

Japanese and European companies owned 19 and 5 percent of the 1990 RTP market, respectively. Dataquest expects these companies to challenge North American equipment company dominance of the RTP market. Technology diffuses rapidly in today's global manufacturing environment. Dataquest believes that infrastructural development will ensure that strong regional RTP companies emerge in all the major manufacturing regions.

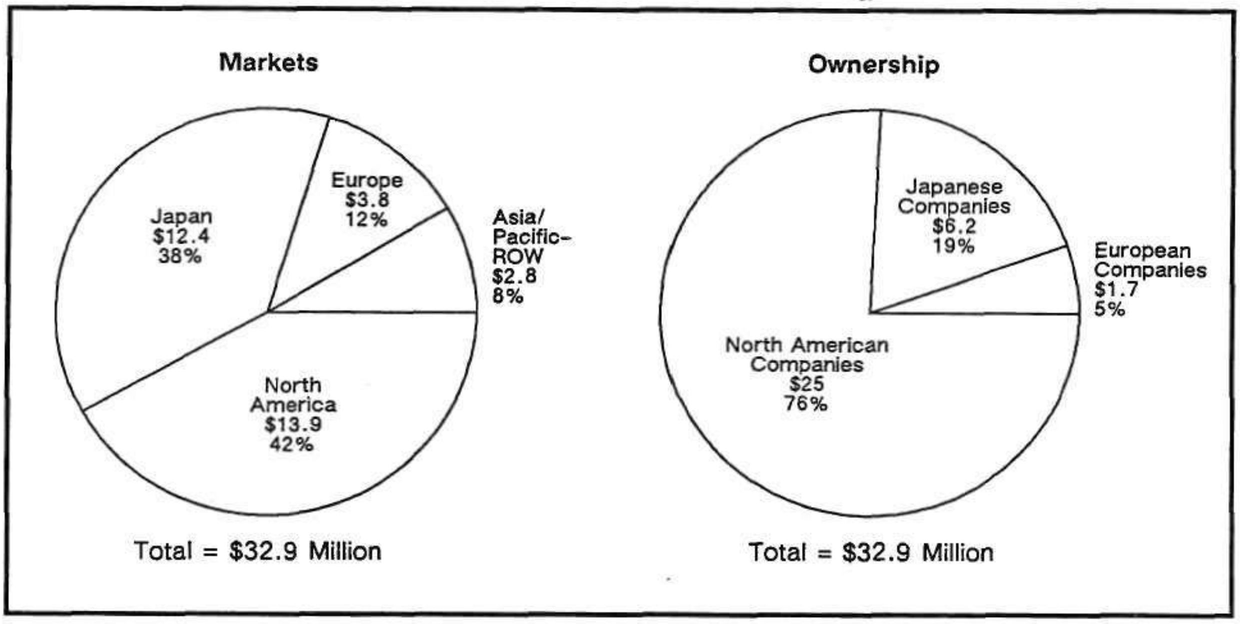
Company Rankings

Table 1 shows the 1990 worldwide RTP equipment company revenue rankings. The rankings comprise five North American companies, three Japanese companies, and two European companies.

AG Associates, with 44 percent of 1990 revenue, is the top-ranked RTP company. The company played a key role in the commercial exploitation of RTP technology in its infancy. AG Associates uses tungsten filament lamp-heating technology. The entire RTP industry, except for Peak Systems and High Temperature Engineering, has elected to use tungsten lamp-heating technology. AG Associates has exhibited rapid growth in 1990 with multiple production shipments to major regions. This company, through Canon Sales, is well poised to capture a significant share of Japan's RTP market.

Peak Systems, the second-ranked 1990 company, captured 26 percent of the RTP market. Peak

Figure 1
RTP Equipment—1990 Market in Review



Source: Dataquest (July 1991)

Table 1
1990 Worldwide RTP Equipment Company Rankings
(Millions of Dollars)

Company	Revenue	Market Share (%)
AG Associates	14.6	44.4
Peak Systems	8.4	25.5
Ushio	3.2	9.7
Dainippon Screen	2.3	7.0
Process Products	1.2	3.6
Sitesa	1.0	3.0
Koyo Lindberg	0.7	2.1
Jipelec	0.7	2.1
Nanosil	0.5	1.5
High Temperature Engineering	0.3	0.9
Total Worldwide Market	32.9	100.0

Note: The table shows calendar year 1990 system revenue; spares and service are not included.
Source: Dataquest (July 1991)

Systems differentiates itself in the RTP market through its unique, proprietary high-intensity arc lamp. Peak Systems claims that its lamp source is well suited for good heat absorption, ramp rates, and temperature control of the processed wafer. The company has recently spun off a subsidiary (Aktis Inc.), which will pursue RTP applications within the LCD flat panel manufacturing industry.

The companies ranked three through nine in Table 1 all have tungsten-filament-based lamp RTP systems. These companies have adopted different lamp filament configuration, temperature, sensing, and control systems, but their basic system architectures and heating mechanisms are similar to AG Associates' system.

High Temperature Engineering Corporation (HTEC) is a newcomer to the RTP market. The company is pursuing a radically different RTP concept based on a furnace-like, small-chamber design. The furnace is held under a constant linear temperature gradient from top to bottom. The wafer's ascent ramp rate and position within the tube determines its temperature. HTEC claims to deliver good temperature control and uniformity with this approach. In essence, HTEC is pursuing a minidiffusion furnace design for the single-wafer RTP environment.

Dataquest Perspective

Dataquest believes that the $32.9 million 1990 RTP market is poised on the threshold of rapid growth as RTP technology finally moves into production. North American companies dominate the RTP market because of their early technology-development lead in this area. Europe and Japan's RTP companies should challenge this dominance in the years ahead. New RTP start-up companies are already emerging with new reactor concepts that challenge the entrenched market leaders.

By George Burns

Dry Strip Equipment—1990 Market in Review

Summary

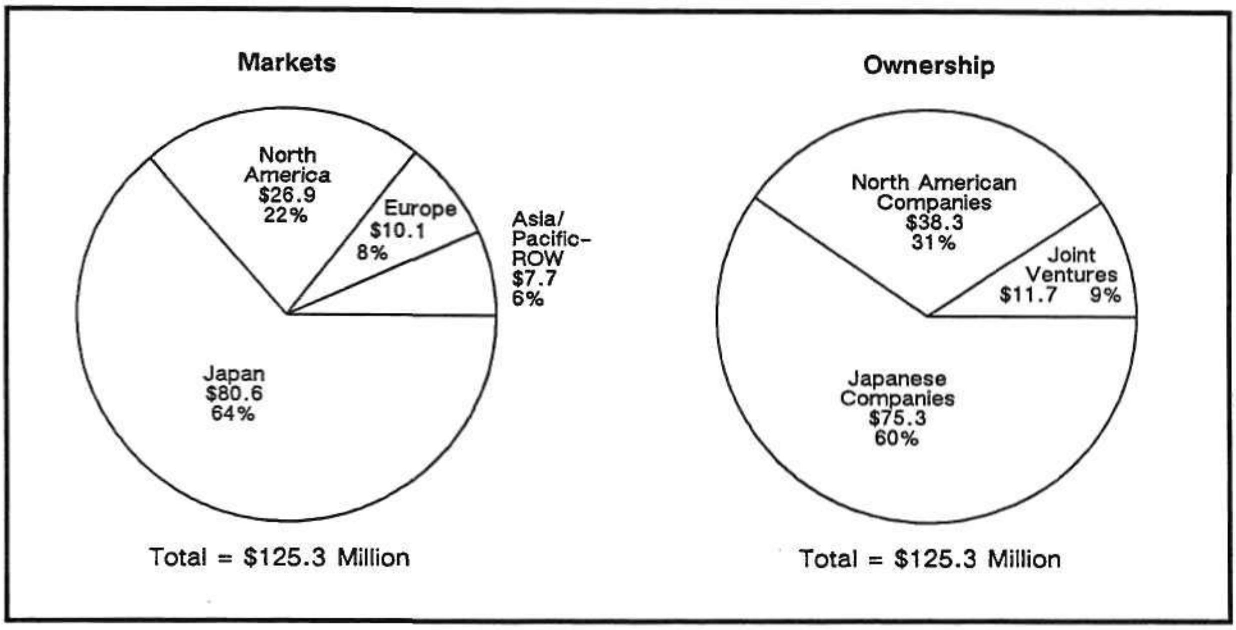
Dataquest estimates that the 1990 worldwide 1990 dry strip market will be $125 million, up about 4 percent from its 1989 value of $121 million. Increases in average selling prices (ASPs) due to increased process complexity and automation were a key factor in the slight growth of the 1990 market. Japan, the largest regional wafer fabrication equipment market, accounted for 64 percent of the total 1990 dry strip market. Japan's dry strip companies owned 60 percent of the 1990 market. Dataquest · expects the dry strip equipment market to make the transition from being a niche, low-technology market to being a high-growth, technology-driven market in the next few years.

Regional Markets

Figure 1 shows the worldwide 1990 dry strip equipment market by region and ownership. Japan's dry etch market, with $80.6 million (64 percent) of the 1990 market, is the largest regional market. Japan's emphasis on 200mm fabs for advanced 4Mb shrink production and 16Mb DRAM pilot line production is a key factor in its role as the largest dry strip market. Japanese DRAM fabs, with their extensive automation, have driven rapid increases in dry strip ASPs. The Japanese dry strip market uses a combination of single-wafer and automated batch technologies for various mask levels within the manufacturing process. Critical levels such as poly-gate mask, contact mask, and metal mask use downstream single-wafer RF and microwave dry strip technologies, while noncritical levels such as CMOS well mask, active area mask, pad mask, and others use automated large-batch barrel strippers.

The North American dry strip market accounted for 22 percent of the 1990 market. Dry strip

Figure 1
1990 Dry Strip Equipment Regional Markets and Ownership
(Millions of Dollars)



Source: Dataquest (July 1991)

unit volume trends within the North American market have not grown as rapidly as in the Japanese market. North American semiconductor companies' exit from high-volume memory markets has resulted in reduced dry strip market demand. North American fabs are less automated compared with their Japanese counterparts. Hence, dry strip ASPs within North America have not increased as rapidly as the Japanese market ASPs. However, Dataquest believes that the North American dry strip market will accelerate its growth during the next few years because of a new round of capital spending by large North American merchant and captive semiconductor companies. The growing presence of high-volume offshore Japanese fabs will also add to the growth of the North American dry strip market.

Europe and Asia/Pacific-ROW accounted for 8 and 6 percent, respectively, of the 1990 dry strip market. An increasing number of offshore North American and Japanese fabs within Europe contributed to a strong 1990 European dry strip market. The Asia/Pacific-ROW dry strip market contracted dramatically in 1990 because of significant cutbacks in capital spending related to new fabs within that region.

Regional Ownership

Figure 1 shows the regional ownership of the worldwide 1990 dry strip market. Japanese companies owned 60 percent of the market. Japanese companies have the advantage of home-field access to the large, technologically demanding domestic Japanese market. Japanese dry strip companies also have a strong presence in technologies such as downstream, microwave dry strip processes. Japanese companies typically offer a high degree of customized automation in order to meet the unique fab automation strategies of various Japanese semiconductor companies.

North American companies owned 31 percent of the 1990 market. North American dry strip companies are more focused on downstream single-wafer systems in comparison with large-batch automated barrel systems. North American companies are confronted with a slow-growing domestic market. At the same time, the R&D requirements and customer support costs continue to increase as the wafer fab equipment industry globalizes in the submicron era. North American companies such as Branson/IPC and Gasonics have merged in response to the need for critical mass within the fragmented dry strip business.

Table 1
1990 Worldwide Dry Strip Equipment Company Rankings (Millions of Dollars)

Company	Revenue	Market Share (%)
Plasma Systems	24.9	19.9
Tokyo Ohka Kogyo	23.9	19.1
Ramco	16.0	12.8
Branson/IPC	14.5	11.6
Alcan Technology	11.7	9.3
Matrix	9.0	7.2
Gasonics	8.2	6.5
Ulvac	4.2	3.4
Tegal	3.0	2.4
Hitachi	2.7	2.2
Others	7.2	5.7
Total Worldwide Market	125.3	100.0

Source: Dataquest (July 1991)

Company Rankings

Table 1 shows the worldwide 1990 dry strip equipment company rankings. Five Japanese companies, four North American companies, and one joint-venture company (Alcan Tech) made up the top 10 rankings. Plasma Systems and Tokyo Ohka Kogyo vied closely with each other for the top-ranking spot. Both companies offer a full range of automated large-batch barrel systems and single-wafer downstream stripper products. Gasonics' recent acquisition of Branson/IPC will catapult the merged company much higher within the 1991 dry strip rankings.

Dataquest Perspective

Competition is heating up in the $125 million worldwide dry strip market. Consolidation within the North American equipment industry, globalization of the Japanese dry strip companies, and new entrants such as Bjorne Enterprises, IPEC, and Mattson Technologies may significantly affect the balance of power in the highly fragmented market. Dataquest believes that the dry strip market is emerging from its niche, low-tech stature to become a critical, enabling, fast-growing market. The emergence of cluster tools that integrate dry etch, dry strip, and wet clean will have profound implications for the relationships among merchant dry strip system vendors, dry strip module vendors, cluster tool vendors, and semiconductor manufacturers. ■

By Jeff Seerley (San Jose)
Kunio Achiwa (Tokyo)

In Future Issues

The following topic will be featured in a future issue of the Semiconductor Equipment, Manufacturing, and Materials *Dataquest Perspective*:

- Texas Instruments' harmonization program

Errata

Please note that the European and Asia/Pacific-Rest of World (ROW) market share tables for optical CD and CD SEM equipment (Tables 4.56 and 4.57 in the SEMMS Wafer Fab Equipment Market Share Estimates 1990 booklet) erroneously reproduce the worldwide market share estimates (Table 4.58). If you require updated market share tables for the optical and CD SEM equipment categories, please contact Peggy Wood in the Dataquest San Jose office or Kunio Achiwa in the Dataquest Japan office. We apologize for any inconvenience that our error may have caused you.

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Dataquest Perspective

Semiconductor Equipment, Manufacturing, and Materials

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Semiconductor Manufacturing

The Fab Database Series: New Fabs in Europe

With a unified Europe around the corner, the near-term outlook for construction of wafer fabrication facilities on the continent looks subdued. This article highlights new facilities scheduled to begin production during the 1991-to-1994 time frame and punctuates the manufacturing shift to centers of regional demand.

According to Dataquest's European Semiconductor Application Markets service, electronic equipment production in Europe is forecast to have a compound annual growth rate (CAGR) of 10.6 percent between 1990 and 1994. The data processing segment is expected to have a 14.2 percent CAGR, and the transportation segment should have a 20 percent CAGR over the same period. Semiconductor manufacturers will be there to supply this production growth.

A Bit of History

The late 1980s were accompanied by a boom in the construction of European production and pilot lines. From a base of 102 in 1987, semiconductor fabrication lines flourished. By 1990, there were 124 fabs—up over 20 percent from 1987 levels. Figure 1 depicts growth in new production and pilot lines from 1987 to 1994.

Leveling Off

Dataquest expects four production and one quick-turn line to begin operation during 1991. Table 1 presents 14 new fab lines by company with planned start dates between 1991 and 1994.

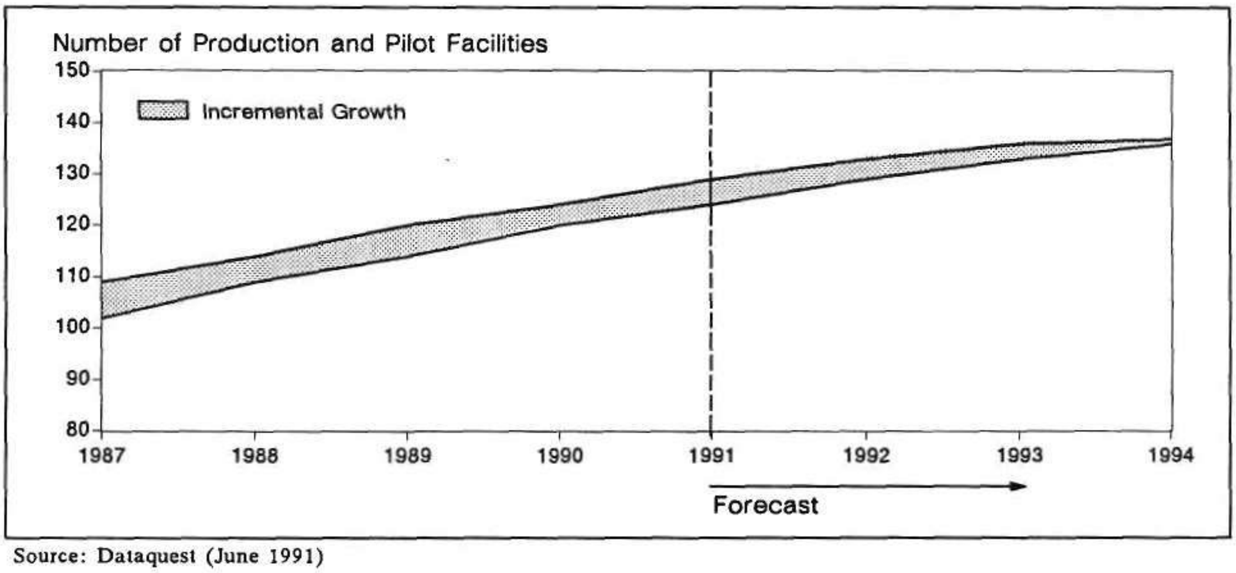
Foreign semiconductor manufacturers have been making considerable capital investments in Europe with a conspicuous pickup in levels of expenditure occurring in 1990. This increase has, in some circles, been perceived as an evasive move to thwart the European Community's (EC's) 14 percent tariff on ICs diffused outside of Europe. *Yet, more importantly, there has been a movement by semiconductor device manufacturers to respond to the needs of their European customer base.* Foreign producers have acknowledged this new directive by transplanting manufacturing facilities to the region of device consumption.

Late Arrivals

Of the top 10 semiconductor manufacturers in 1990, all, with the exception of Matsushita and Toshiba, have announced plans for European production lines.

One decidedly late arrival on the European scene was Intel Corporation, which only last year broke ground on a production wafer fab within the EC. Intel has been operating a plant

Figure 1
European Production/Pilot Lines



Source: Dataquest (June 1991)

Table 1
Planned European Fabs by Company

Company	City	Country	Fab Type	Target Production Date
Fujitsu	Newton Aycliffe	England	Production	1992
				1993
				1994
Hitachi	Landshut	Germany	Production	1992
IBM	Sindelfingen	Germany	Production	1991
ITT	Freiburg	Germany	Production	1991
Intel	Leixlip, Kildare	Ireland	Production	1993
Mitsubishi	Alsdorf	Germany	Production	1992
NEC	Livingston	Scotland	Production	1991
Qudos	South Yorkshire	England	Quick Turn	1991
SGS-Thomson	Agrate	Italy	R&D	1991
Sharp	Oxford	England	R&D	1991
Siemens	Regensburg	Germany	Production	1991
Texas Instruments	Avezzano	Italy	Production	1992

Source: Dataquest (June 1991)

in Israel, which has enjoyed preferential trading status with the EC since 1987. Dataquest believes that Intel's decision to build a facility in Ireland had little to do with whether the EC will maintain its current relationship with Israel. Its new Irish manufacturing facility will accompany systems manufacturing work. This 200,000-square-foot facility housing a Class 1 clean room represents the state of the art in fabrication facilities. When fully operational, the plant is expected to employ 500 to 1,000 people. Dataquest views Intel's move as strategic in order to address the needs of its European customer base as well as intracompany demands.

Toshiba, which has assembly and test facilities in Braunschweig, Germany, has yet to announce construction of a diffusion facility on European soil. Matsushita has yet to disclose its plans for production or assembly and test in the EC.

Dataquest Perspective

"To every action there is always opposed an equal reaction . . ."
- Sir Isaac Newton

No new major facilities have been announced other than those highlighted in this article. Dataquest, however, believes that a possibility exists for additional new announcements, and we also believe that there is a major opportunity for strategic alliance between domestic and foreign companies seeking to enter the European market without the added financial barrier of a production facility. ■

By Rebecca E. Burr

Market Analysis

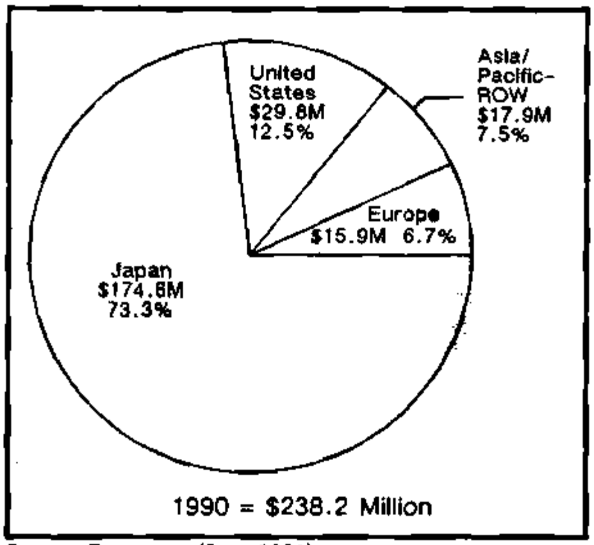
The Dynamic Japanese Integrated Wet Station Market

The worldwide integrated wet station market has grown rapidly in the last five years, from $78.5 million in 1986 to $238.2 million in 1990. The compound annual growth rate (CAGR) for this period is 32 percent. The integrated wet station equipment segment grew at a faster rate than the entire semiconductor front-end equipment market, which registered a 20.9 percent CAGR during this period.

The robust growth of the integrated wet station equipment is attributable to several trends. First, the number of cleaning processes has expanded with the increased level of semiconductor integration. Second, more wet stations are used because they are being dedicated to one process. And finally, the average selling price of integrated wet stations has increased dramatically because of the increased level of system automation and interface required for factory automation systems.

Geographically, Japan is the world's largest market for integrated wet station equipment (see Figure 1). Japanese companies, namely Dainippon Screen, Sugai, Sankyo Engineering, and Kaijo Denki, also lead the worldwide ranking (see Table 1) in sales of integrated wet station equipment. The size of the Japanese

Figure 1
Integrated Wet Station Market by Region



Source: Dataquest (June 1991)

market and the dominance of Japanese vendors can be explained partly by the sheer size of the device production capacity of Japanese fab lines and partly because the U.S. semiconductor equipment makers have focused their efforts on dry processing rather than wet processing.

History

In the early stages of the semiconductor industry in Japan, device manufacturers designed their own wet stations through trial and error. The systems were manufactured for the device maker by subcontractors in the plastics industry that had little knowledge of semiconductor process technology.

The device makers developed very close relationships with their subcontractors, often taking an equity stake in the vendor although very rarely transferring critical technical design know-how to the subcontractor. This was the beginning of a relationship between chipmakers and equipment makers—a unique partnership formed by customers and subcontractors.

As the semiconductor manufacturers' demand for wet stations grew, they were forced to find second sources for this equipment. A second tier of independent wet processing companies emerged to meet this demand. These companies had no direct ties with the device makers.

The second-tier companies sold equipment to the various device makers, and, in the process, they were exposed to different equipment designs. Borrowing the best ideas from each design, the second-tier companies were soon manufacturing systems that surpassed the device makers'

Table 1
1990 Worldwide Integrated Wet Station Revenue by Company
(Millions of Dollars)

Company	Revenue	Market Share (%)
Dainippon Screen	43.4	18.2
Sugai	34.3	14.4
Sankyo Engineering	33.8	14.2
Kaijo Denki	30.9	13.0
Shimada	16.4	6.9
SubMicron Systems Inc.	10.0	4.2
Kuwano Electric	9.6	4.0
Santa Clara Plastics	9.2	3.9
ETE Company Ltd.	5.9	2.5
Musashi	5.9	2.5
Maruwa	5.9	2.5
Enya	5.6	2.4
Universal Plastics	4.5	1.9
Toyoko Chemical	3.8	1.6
Semifab	3.5	1.5
Tohokasei	3.4	1.4
S&K Products International	3.0	1.3
Fuji Electric	2.0	0.8
Dalton Corporation	1.7	0.7
Pokorny	1.2	0.5
Verteq	1.1	0.5
Pure Aire Corporation	1.1	0.5
Dan Science Co. Ltd.	1.1	0.5
Dexon	0.5	0.2
SCI Manufacturing	0.4	0.2
	238.2	100.0

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (June 1991)

internally designed systems. Today, the rise of second-tier companies has evolved into a very structured market in which device makers are allied with three external vendors in addition to their captive operation (see Table 2).

Trends

Although the increasing complexity of the semiconductor process has been spurring steady expansion of the wet station market, a limited number of vendors can meet requirements for rapidly advancing process technology, thus increasing lead time for wet stations. In response, integrated wet station makers are expected to boost production capacities and hire additional employees.

The size of the equipment has increased year after year. Currently, the average fab uses about 15 wet stations, which occupy 30 to 40 percent of expensive floor space in the clean room. Obviously, the space will further increase in the 200mm wafer fab, so that some efforts are needed to reduce equipment footprints. The

Table 2
Japanese Wet Station Market Interrelationships

Semiconductor Company	Captive Subsidiary	Main Vendors 1st	2nd	3rd
NEC	Kaijo	Dainippon Screen	Kaijo	Toyoko
Toshiba	Sankyo	Sankyo	Enya	
Hitachi	Maruwa	Maruwa	Ete	Sugai
Fujitsu	Enya	Dainippon Screen	Enya	
Mitsubishi	Shimada	Shimada	Dainippon Screen	Dan
Oki	Kuwano	Kuwano	Kuwano	Kaijo
Sanyo		Dainippon Screen	Maruwa	Kaijo
Sharp	Sugai	Sugai	Dainippon Screen	
Matsushita	Kaijo	Kaijo	Sugai	
Sony	Kyoritsu	Dainippon Screen	Kyoritsu	Sugai

Source: Dataquest (June 1991)

single-wafer processing system is available, but its low throughput is not suitable for volume production.

Regarding high purity, energy saving, and environmental issues, HF and H_2SO_4 reprocessing equipment have been introduced by Athens Corporation and Alameda Instruments. However, the equipment is very costly, and only a few units are being used on an experimental basis. Full market penetration has to wait until tighter standards for industrial wastes are enforced.

Dataquest Perspective

Traditionally, wet stations have been a niche market populated by a large number of regionally focused companies. Now that the market has grown into a major semiconductor equipment market, entry by large equipment makers is foreseeable.

Although wet processing is a mature technology, Japanese equipment vendors are extending its useful life. Japanese vendors' know-how has evolved over time, and the level of integration and design detail built into their equipment is unrivaled.

By Kunio Achiwa (Tokyo)

Ion Implantation Equipment Market—1990 Market in Review

Summary

The worldwide ion implantation equipment market was $370.8 million in 1990, down 19 percent from its 1989 level of $456.6 million. All three segments of the implant equipment market—medium-current, high-current, and high-voltage systems—experienced a decline. The worldwide market for medium-current implant equipment was $116.3 million, down 11 percent from its 1989 level; the worldwide market for high-current implant equipment was $249.5 million, down 17 percent; and the worldwide market for high-voltage implant equipment was $5.0 million, down 80 percent from its 1989 level.

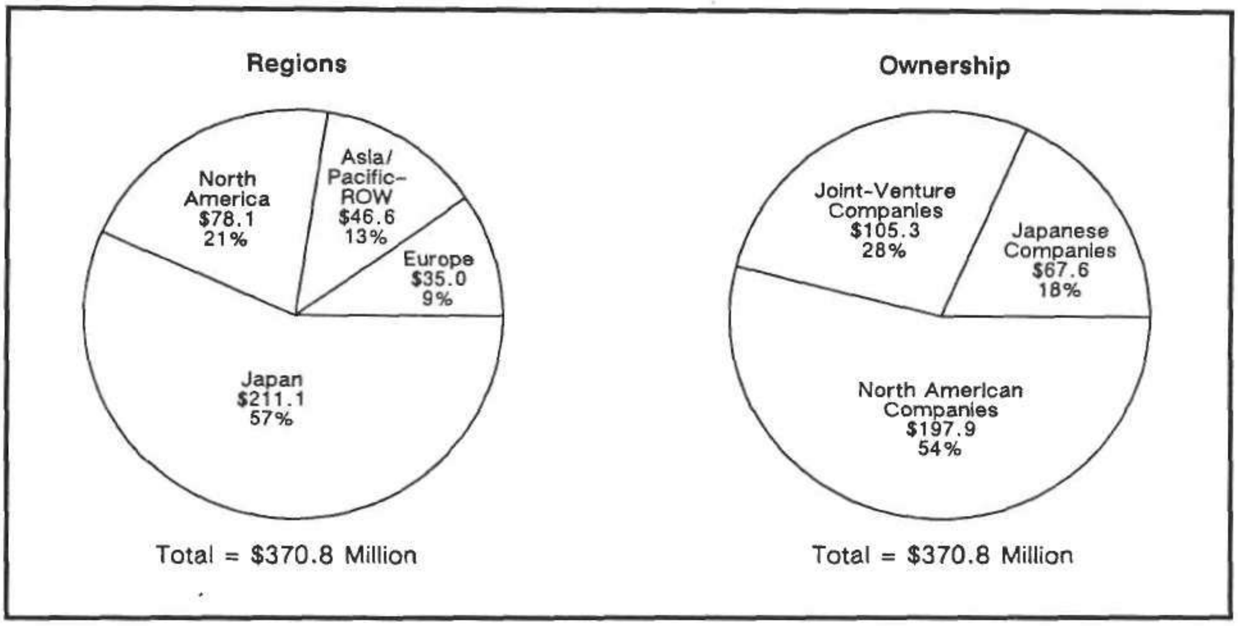
The reduced demand for medium- and high-current implant equipment in 1990 can be attributed to the fact that many semiconductor companies with a focus on high-volume device manufacturing such as 1Mb and 4Mb DRAMs had already installed a significant level of implant systems in 1988 and 1989. Unlike other wafer fab equipment segments such as lithography, CVD, or etch, much of the ion implantation equipment technology developed in the mid-1970s is still sufficient for manufacturing advanced devices such as 16Mb DRAMs in the mid-1990s. This means that the implant market is largely a capacity-driven market, and thus it experiences significant swings relative to the semiconductor business cycle. In contrast to the 19 percent decline in the implant market in 1990, the overall wafer fab equipment market was only down a modest 3 percentage points.

The decline in the high-voltage implant market in 1990 was because much of the equipment bought in 1989 and earlier years was for R&D evaluation. The volume market for high-voltage systems for use in the production environment has yet to be established.

Regional Markets

Figure 1 presents the regional segments of the ion implantation equipment market in 1990. Japan was the largest regional market for ion implantation equipment in 1990, accounting for $211.1 million, or 57 percent, of the worldwide

Figure 1
1990 Ion Implantation Equipment Regional Markets and Ownership
(Revenue in Millions of Dollars)



Source: Dataquest (June 1991)

market. This is not surprising because Japan is the leading production region for high-volume advanced devices and represents the largest regional market for other core segments of wafer fab equipment such as steppers, etchers, CVD, PVD, and diffusion. Overall, the Japanese implant equipment market experienced a decline of 18 percent from its 1989 level.

Semiconductor manufacturers in North America have largely retreated from memory, low-end gate arrays, and other high-volume, low-margin commodity devices. That retreat from high-volume device production, coupled with the new wave of fabless North American companies, translates to a substantially smaller equipment market than in Japan. The ion implantation equipment market in North America was $78.1 million in 1990, representing 21 percent of the worldwide demand for implant equipment. Like Japan, the North American market for implant equipment in 1990 was down from its 1989 level, in this case down 13 percent.

The European market for ion implantation equipment was $35.0 million in 1990, representing 9 percent of the worldwide market. Demand for ion implantation equipment in Europe was flat relative to 1989. The ion implantation equipment market in Asia/Pacific-Rest of World (ROW) was $46.6 million, down 37 percent from its 1989 level. This decline can be attributed to the weak capital spending environment in Asia/Pacific-ROW that was pervasive throughout all segments of the wafer fab equipment market.

Regional Ownership

Figure 1 illustrates the regional ownership of companies supplying ion implantation equipment in 1990. North American companies continue to maintain their dominant share position in the ion implantation equipment market and, in 1990, captured 54 percent share of the $370.8 million market. Two long-time suppliers to the industry, Eaton and Varian, and a more recent player, Applied Materials, account for all of the medium- and high-current implanter shipments by North American companies. Dataquest believes that U.S. companies have continued to maintain dominant share in the implant equipment market because all three vendors have a strong international presence, particularly in Japan, through joint-venture companies (Sumitomo/Eaton Nova and TEL/Varian) or overseas operations (Applied Materials Japan). This strong international presence ensures that these vendors are able to meet the needs of a diverse and global client base.

Three Japanese implant equipment companies accounted for $67.6 million, or 18 percent share, of the 1990 ion implantation equipment market. These three suppliers—Hitachi, Nissin Electric, and Ulvac—historically have focused exclusively on their home market of Japan. Only one Japanese implant company to date, Nissin Electric, has exported any implant equipment; its first year of exports was in 1988. In 1990, Nissin's sales of ion implanters outside of Japan represented $8.8 million, or about 13 percent, of total Japanese company implant revenue. Japanese implant companies face a particularly tough competitive environment. Their export business activities are small or nonexistent, and they face considerable competition from other companies in their home market where they supplied only a little more than one-fourth of the implant equipment purchased in Japan in 1990.

Two joint-venture companies—Sumitomo/Eaton Nova and TEL/Varian—accounted for $105.3 million, or 28 percent share, of the 1990 worldwide ion implantation equipment market. Although both companies are located in Japan and focus on that regional market, Dataquest chooses to report these companies in a separate category rather than bundle them with the other Japanese companies. That is because the products offered by these joint-venture companies represent technological contributions of North American as well as Japanese corporations. Historically, both Eaton and Varian have sent implant kits to their respective joint ventures in Japan for assembly. In addition, Sumitomo Eaton/Nova and TEL/Varian produce some subassembly products, prepare implanters for the Japanese market, and provide sales, service, and support for their respective product lines. In 1990, Sumitomo/Eaton Nova and Eaton started shipments of a new high-current implanter, the NV-GSD. Contrary to the historical practice of shipping kits from the United States to Japan, this tool was developed jointly in Japan by Sumitomo/Eaton Nova and Eaton. The technology for the NV-GSD has been transferred back to Eaton's facility in the United States, and the system now can be manufactured in either region of the world.

Company Ranking

Table 1 ranks the suppliers of ion implantation equipment by worldwide sales. One of the most significant changes in the implant market in 1990 was the loss in share for TEL/Varian. TEL/Varian held the number one position in the 1989 implant market, accounting for $100.0 million, or 22 percent, of the $456.6 million market. In 1990, TEL/Varian's implant revenue dropped by almost one-half to $53.7 million. This drop in revenue placed the company third in worldwide market share ranking behind Varian and Eaton. The reason for TEL/Varian's decline in sales revenue was due to a changeover in the product mix that TEL/Varian was offering to its customers. Dataquest expects TEL/Varian's position to improve in 1991 and 1992 now that TEL/Varian is supplying Varian's newer products—the E-220 medium-current and E-1000 high-current implant systems—to semiconductor manufacturers in Japan.

Varian ranked number one in the worldwide ion implantation equipment market with $79.3 million, or 21.4 percent worldwide share. The company is well positioned with three key 200mm wafer product offerings: two high-current, batch-processing systems, the E-1000 and 180XP, and a single-wafer, medium-current implanter, the E-220. These systems represent the major platforms that Varian will be using for its implanters in the 1990s. Good customer acceptance of these products helped propel Varian into the number one position in the 1990 market.

Although TEL/Varian lost some ground in the 1990 implant market, Eaton and Sumitomo/Eaton Nova both increased their market share position. Eaton ranked second in the 1990 worldwide market with revenue of $67.6 million, while Sumitomo/Eaton Nova ranked fourth with $51.6 million. Together, these two implant operations increased their combined worldwide

Table 1
1990 Worldwide Ion Implantation Equipment Company Ranking
(Revenue in Millions of Dollars)

			Market Segments		
Company	Revenue	Market Share (%)	Medium Current	High Current	High Voltage
Varian	79.3	21.4	31.2	48.1	0
Eaton	67.6	18.2	17.5	50.1	0
TEL/Varian	53.7	14.5	20.4	33.3	0
Sumitomo/Eaton Nova	51.6	13.9	0	51.6	0
Nissin Electric	46.7	12.6	37.5	9.2	0
Applied Materials	46.0	12.4	0	46.0	0
Hitachi	11.2	3.0	0	11.2	0
Ulvac	9.7	2.6	9.7	0	0
Genus	5.0	1.3	0	0	5.0
Worldwide Market Total	370.8	100.0	116.3	249.5	5.0

Note: The table shows calendar year 1990 systems revenue; spares and service are not included. Some columns do not add to totals shown because of rounding.
Source: Dataquest (June 1991)

market share of 28 percent in 1989 to 32 percent share in 1990. Dataquest believes that Eaton and Sumitomo/Eaton Nova have successfully positioned their products to provide lower cost of ownership to semiconductor manufacturers by focusing on providing very high throughput implanters with relatively small footprints. The major product offerings of Eaton and Sumitomo/Eaton Nova include the NV-20A and NV-GSD high-current implanters and the NV-10 and 6200 family of medium-current implanters.

Nissin Electric's ion implantation equipment revenue in 1990 was $46.7 million, down almost 15 percent from its 1989 level. The company, however, ranked number one in the 1990 worldwide medium-current implanter market, a position the company has maintained since 1988. Nissin's shipments of implanters outside of Japan represented $8.8 million in 1990, or 19 percent, of company revenue. Nissin, the only Japanese implant company to export its implanters, shipped systems to North America, Europe, and Asia/Pacific-ROW in 1990.

Applied Materials' high-current implanter revenue of $46.0 million in 1990 placed the company sixth in the worldwide market share ranking with 12.4 percent share. At SEMICON/West in May, Applied introduced an enhanced version of its high-current ion implant system, the Precision Implant 9200XJ. This tool provides improved system performance and process capability and a new ion source. The company claims that new beamline components and wafer-handling materials have also helped reduce particulate contamination.

Hitachi's 1990 ion implantation equipment revenue was $11.2 million, representing 3.0 percent share of the world market. Hitachi only participates in the high-current segment of the market and is focused on its home market of Japan. At SEMICON/Japan in December 1990, Hitachi introduced a new 200mm high-current machine, the IP-2500.

Ulvac ranked eighth in the 1990 worldwide ion implantation equipment market with revenue of $9.7 million. In both 1989 and 1990, Ulvac's implant equipment shipments were all medium-current systems. At SEMICON/Japan in December 1990, the company introduced a new 200mm medium-current implanter, the IPX-7800. Also at the end of 1990, Ulvac reentered the high-current ion implant equipment market with the IR-120, a tool aimed at 125mm and 150mm wafer processing. This tool, priced at approximately $1.5 million, is relatively inexpensive compared with the 1990 average selling price of $1.85 million for high-current implanters.

Genus was the only participant in the high-voltage ion implantation equipment market in 1990. The company's revenue of $5.0 million was down significantly from the $17.7 million the company generated in 1989. The high-voltage implant equipment purchased by semiconductor manufacturers over the past several years was for R&D evaluation. The volume market for high-voltage implanters, which is targeted at such applications as latch-up prevention and retrograde well formation, has yet to be established. Dataquest believes that high-voltage implanters will not see any level of significant use until at least the 64Mb DRAM generation. The poor financial performance of Genus' implant division in 1990 has been part of the impetus behind the company's search for a technology development partner to help shoulder the costs of further product and applications development work in this area.

Dataquest Perspective

The behavior of the ion implantation equipment market with respect to the semiconductor business cycle can best be characterized as manic-depressive. When the overall wafer fab equipment market experiences a downturn from the previous year's level, the implant market often suffers a much more abrupt decline. In contrast, when the overall wafer fab equipment market is enjoying vigorous growth, the implant equipment market is bursting through the roof. For example, in 1986 and 1990 (slow years in the industry), the wafer fab equipment market was down 19 and 3 percent, respectively, from the prior year's level. The corresponding market for ion implantation equipment declined a precipitous 60 percentage points in 1986 and was down 19 percent in 1990. In 1987 and 1988, years of healthy growth, the worldwide wafer fab equipment market grew at a rate of 16 and 59 percent, respectively. The implant equipment market, on an upswing surge, experienced tremendous growth of 56 and 103 percent in those same two years.

The reason behind the implant equipment market's manic-depressive behavior is that fundamentally, the market is driven by capacity demands rather than technological innovation. Much of the equipment manufactured in the mid-1970s has the technological capability to manufacture 16Mb DRAMs in the mid-1990s. Parallel beam scan and variable beam tilt angle, two innovations introduced over the last several years, are now virtually standard on every implanter. The key factors that drive the implant market are equipment reliability and uptime, particulate control, and automation. Implant companies will need to continue to distinguish themselves in the market on the basis of service, support, and timely response on spare parts replacement regardless of whether the customer is in Seoul or the Silicon Valley.

By Peggy Marie Wood (San Jose)
Kunio Achiwa (Tokyo)

Automatic Photoresist Processing Equipment Market—1990 Market in Review

Summary

The worldwide market for automatic photoresist processing equipment (track) was $338.2 million in 1990, basically a flat market when compared with the 1989 market of $333.6 million. The important design elements in today's state-of-the-art track systems are focused on reducing contamination, improving process control, increasing system flexibility with random access robotic wafer handling, and providing a stable process environment with carefully controlled temperature and humidity. Recent models of equipment are equipped with highly improved photoresist dispense nozzles, which can reduce photoresist consumption by up to 40 percent. Other aspects of the business, such as service and support on a global level along with the ability to interface a company's track to various stepper systems, are also key factors by which companies differentiate themselves in this market.

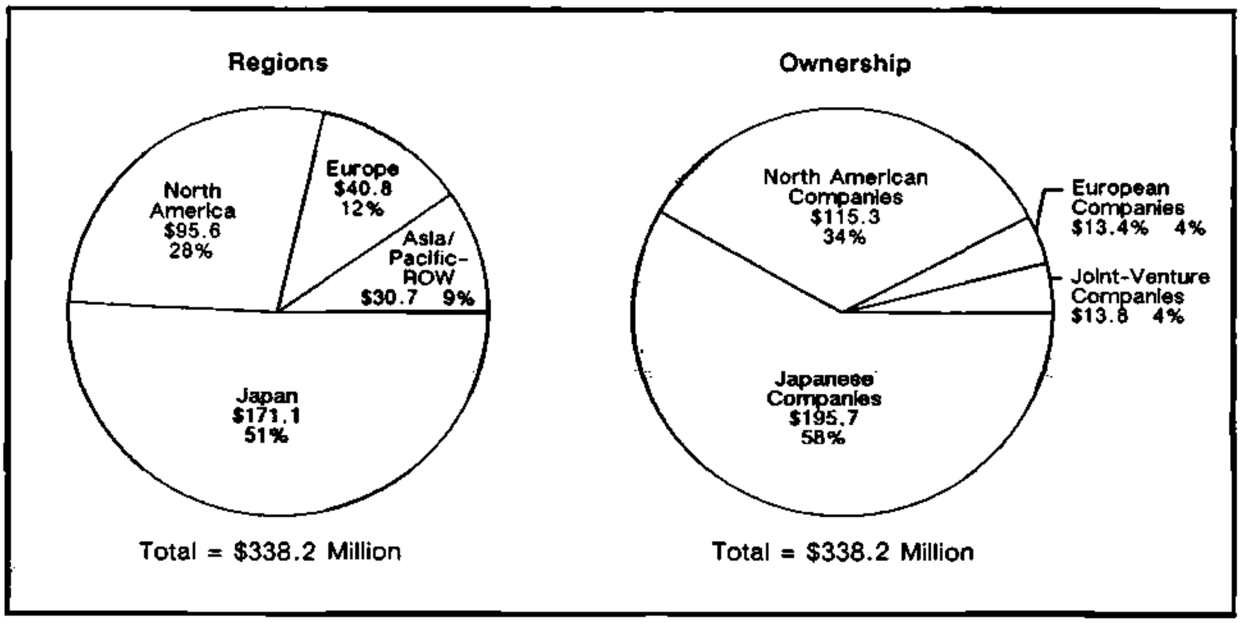
Regional Markets

The track equipment market is closely tied to the demand for lithography equipment. This is because track equipment is used to apply and process the photoresist film that transfers the IC pattern to the wafer during lithographic processing. It is not surprising, then, that the regional share of the track equipment market in 1990 was the same as the regional share of the stepper market. As shown in Figure 1, Japan was the largest regional market for track equipment, representing $171.1 million, or 51 percent, of the worldwide market. Japan, the world's largest semiconductor manufacturing region, similarly accounted for 51 percent of the worldwide stepper market of $1,066.8 million. The other regions of the world—North America, Europe, and Asia/Pacific-Rest of World (ROW)—accounted for 28, 12, and 9 percent, respectively, of the worldwide track market, the same regional percentage shares for the stepper market in 1990.

Regional Ownership

Figure 1 illustrates that Japanese companies dominate the track equipment market, representing $195.7 million, or 58 percent, of the 1990 worldwide track market. Historically, the Japanese track companies have "owned" their home market of Japan, accounting for more than 98 percent share of the market every year since 1985. The Japanese track companies have benefited from their close working relationships with the Japanese stepper companies, which in turn dominate the worldwide stepper equipment market. By developing the appropriate interfaces between their track equipment and Japanese stepper systems, the Japanese track companies have been able to grow their business alongside that of the Japanese stepper companies.

Figure 1
1990 Automatic Photoresist Processing Equipment Regional Market and Ownership (Revenue in Millions of Dollars)



Source: Dataquest (June 1991)

Similarly, Japanese track companies have been able to enjoy a number of new export market opportunities as semiconductor manufacturers in Japan began to build their own facilities overseas as well as influence the choice of equipment in joint manufacturing efforts with companies in North America and Europe.

Five North American companies participate in the track equipment market and together accounted for $115.3 million, or 34 percent, of the worldwide market in 1990. Exports represent 36 percent of North American company track revenue, which came almost entirely from Europe and Asia/Pacific-ROW. Only one European company, Convac, participates in the track equipment market, and it focuses its activities on the European and North American markets.

Finally, one joint-venture company, Varian/TEL, participates in the track market. This joint venture, established in 1989, is specifically focused on providing track, diffusion, and etch products from TEL in Japan to semiconductor manufacturers in the United States and Europe. The Varian/TEL joint venture is supported by the sales, marketing, and service organization of Varian.

Company Ranking

As shown in Table 1, Tokyo Electron Ltd. (TEL) and Dainippon Screen (DNS) of Japan ranked first and second in the 1990 worldwide track market with $105.9 million and $59.2 million, respectively. TEL and DNS have been significant competitors from both a technology and marketing perspective for many years. In 1985, DNS' best-selling track system, the D-Spin 636, dominated the market, particularly in Japan. TEL then introduced its new Mark II system. This new system propelled the company into the number one ranking in the worldwide track market in 1987, a position TEL has maintained since that time. In 1988, DNS introduced its D-Spin 629 system and by 1989 was able to successfully increase its worldwide market share to 20 percent. But in 1989, TEL introduced its new Mark V track system, which has helped solidify TEL's position as the leader in the worldwide track equipment market. DNS' newest track tools that compete against the Mark V are the D-Spin 60A/80A systems.

Table 1
1990 Worldwide Automatic Photoresist Processing Equipment Company Ranking (Revenue in Millions of Dollars)

Company	Revenue	Market Share (%)
Tokyo Electron Ltd.	105.9	31.3
Dainippon Screen	59.2	17.5
Silicon Valley Group	55.0	16.3
Semiconductor Systems Inc.	23.0	6.8
Machine Technology Inc.	21.0	6.2
Tazmo	16.4	4.8
Varian/TEL	13.8	4.1
Convac	13.4	4.0
Eaton	10.5	3.1
Canon	8.4	2.5
Solitec	5.8	1.7
Yuasa	5.8	1.7
Worldwide Market Total	338.2	100.0

Note: The table shows calendar year 1990 systems revenue; spares and service are not included. Some columns do not add to totals shown because of rounding.
Source: Dataquest (June 1991)

Much of the strength of TEL and DNS in the worldwide track market comes from their dominance of their home market of Japan. In 1990, Japan accounted for more than 80 percent of the track revenue for both companies. Both DNS and TEL are intent on building their export business activities. Dainippon Screen utilizes local sales offices and reps to sell its track systems. TEL established the Varian/TEL joint venture to sell and support its track products in North America and Europe. Under the Varian/TEL joint venture, TEL benefits from the name recognitions and support of the worldwide Varian organization as it builds its export market opportunities. Varian/TEL ranked seventh in the 1990 worldwide track market with $13.8 million in revenue. Together, TEL and Varian/TEL account for 35.4 percent, or more than one-third, of the worldwide track market in 1990.

Silicon Valley Group (SVG) is the third major player in the worldwide track market along with TEL and DNS. The company had track revenue of $55.0 million in 1990 to account for 16.3 percent share of the worldwide track equipment market. SVG ranked number one in the regional track markets of North America, Europe, and Asia/Pacific-ROW in 1990. The company, however, has been unsuccessful in its penetration of the Japanese market. Dataquest estimates SVG's track shipments in Japan corresponded to only $0.5 million in revenue. SVG introduced its newest track system, the 90 Series, in May 1990. The 90 Series system can transfer wafers through either serial or random access and can optimize throughput with its "MultiPath" technique, a combination of both wafer-handling modes. Like other advanced track systems, the 90 Series carefully controls both temperature and humidity in the wafer processing environment.

Semiconductor Systems Inc. (SSI) ranked fourth in the 1990 worldwide track market with $23.0 million in revenue. In December 1990, a management buyout of SSI from General Signal was finalized. (This management buyout was one in a series of wafer fab equipment company divestitures that General Signal has considered or approved during the last several years.) SSI derived some benefit from its relationship with General Signal, in particular with the General Signal lithography companies GCA and Ultratech. SSI absorbed GCA's track equipment business when GCA came under the General Signal umbrella in 1988. In addition, SSI worked closely with GCA and Ultratech to develop track interfaces to their steppers. Historically, greater than 85 percent of SSI's track revenue has come from customers in the United States with the remainder attributable to business activities in Europe.

Machine Technology Inc. (MTI) ranked fifth in the worldwide track market with $21.0 million in revenue. MTI experienced a significant increase in track revenue in 1990 from its 1989 level of $11.3 million. Dataquest understands that the tremendous growth in MTI's track business was due in large part to its business activities at IBM, where it supplied track equipment that interfaces to the Micrascan advanced lithography systems. Ironically, the Micrascan is manufactured by SVG Lithography (SVGL), the former Perkin-Elmer optical lithography group acquired by SVG in May 1990. Dataquest anticipates that SVG will also offer an interface between its 90 Series track system and future generations of the Micrascan system.

In addition to TEL and DNS, there are three other Japanese suppliers of track systems. Tazmo, with revenue of $16.4 million, ranked sixth in the 1990 worldwide track market. Tazmo's track product offerings are focused primarily on deposition and processing of spin-on-glass (SOG). Over 90 percent of Tazmo's track revenue in 1990 was in Japan, where SOG deposition is a well-established method for planarization. Canon and Yuasa, with products targeted at standard resist processing, had revenue of $8.4 million and $5.8 million, respectively, in 1990. Yuasa has focused its activities exclusively on the Japanese market, while Canon had 26 percent of its 1990 track revenue in export markets, specifically North America and Asia/Pacific-ROW.

Convac ranked eighth in the 1990 worldwide track equipment market in 1990 with revenue of $13.4 million. Historically, Convac's track activities have been focused on the European and North American marketplaces. FSI International had responsibility for Convac's North American market activity through a manufacturing and marketing agreement. In January 1990, the agreement between FSI and Convac was terminated because Convac had become increasingly interested in marketing and manufacturing directly in the United States since its 1989 acquisition of APT, a mask and wafer-cleaning equipment company. To leverage its considerable experience in the photoresist equipment business, FSI signed a long-term agreement to manufacture and sell a photoresist system developed by Texas Instruments. In early 1991, FSI installed its first Polaris Photoresist Processing Work Cell at a customer site on evaluation.

Dataquest estimates that Eaton had $10.5 million in track revenue in 1990. Historically, Europe has represented the company's largest regional market for its track equipment. In 1990, Europe represented 65 percent of total Eaton track revenue. The company has been particularly successful in establishing business in Eastern Europe. At SEMICON/West 1991, Eaton exhibited its new System 10 track equipment. Like other advanced resist processing systems, the System 10 employs flexible pick-and-place robotics.

Dataquest Perspective

For the past six years, Japanese track companies have commanded greater than 98 percent share of the track equipment market in Japan. By 1990, with Japan well established as the world's major semiconductor manufacturing region, the track market in Japan represented 51 percent of the worldwide track market. What this means is that non-Japanese track companies participate in a market only one-half the size of the total worldwide market. This situation is even more serious for non-Japanese track companies because the Japanese track suppliers and the Varian/TEL joint venture together accounted for 23 percent of the track market outside of Japan in 1990.

Dataquest recognizes that establishing business activities in Japan is costly and requires a long-term commitment. However, North American and European track companies must seriously evaluate the impact of their future market strategies when it is clear that the market available to them is steadily shrinking as a percentage of the total. Dataquest believes that North American and European track companies must work closely with the major stepper companies such as Canon, Hitachi, and Nikon and develop interfaces to their steppers, even if only for beta site installations. This involvement will allow the North American and European track companies and the Japanese stepper companies to gain a better understanding of the mechanical and electrical interfaces that are required. At the same time, service and support will continue to be the watchword in the highly competitive track market environment, where companies struggle to differentiate both their products and technology. ■

By Peggy Marie Wood (San Jose)
Kunio Achiwa (Tokyo)

News and Views

Advanced Technology Materials of New Milford, Connecticut, has sold a hydride gas generator to Hughes Malibu. The hydride gas generator will produce arsine gas at the point of use, replacing the need for bottled arsine gas.

Air Products and Chemicals of Allentown, Pennsylvania, has received a $2.8 million gas cabinet order from Intel Corporation of Santa Clara, California. The gas systems will be installed at Intel's D2 fab in Santa Clara. In the past, Intel had purchased gas cabinets exclusively from Semi-Gas Systems Inc. of San Jose, California, but the recent purchase of Semi-Gas by Japan-based Nippon Sanso has caused Intel to search out another U.S.-based supplier.

Athens Corporation of Oceanside, California, has received an order from Digital Equipment Corporation (DEC) of Hudson, Massachusetts, for an acid reprocessing system. The unit is the first reprocessor purchased by DEC and will provide the company with an opportunity to evaluate the technology. ■

By Mark FitzGerald

In Future Issues:

The following topic will be featured in a future issue of *Dataquest Perspective:*

- Dry Strip: 1990 in Review

The topics covered by SEMMS newsletters are selected for their general interest to SEMMS clients, which include wafer fab equipment suppliers, semiconductor materials companies, and semiconductor device manufacturers. The topics selected indicate the broad range of research that is conducted in the SEMMS group. Clients, however, often have specific information requirements that either go beyond the level of detail contained in the newsletters or beyond the scope of what is normally published in the newsletters. In order to provide complete decision support to our clients, Dataquest has a consulting service available to handle these additional information needs. Please call Stan Bruederle at (408) 437-8272 or Joe Grenier at (408) 437-8206 to discuss your custom requirements.

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Dataquest Perspective

Semiconductor Equipment Manufacturing, and Materials

Vol. 1, No. 3 **June 10, 1991**

Semiconductor Manufacturing

Fab Construction Time: How Long Is Too Long?

Costs for a new fab clean room without processing equipment and capable of running volume production can run as high as $100 million. Fully equipped, these costs can reach $350 million or more. Although there is some debate about how high fab costs will rise in the next 10 years, there is very little, if any, debate over the question of whether or not they will rise. They will.

Because fabs are so expensive, the time that it takes to actually construct a fab has become very consequential over the last few years. One of the principal reasons for this is fairly obvious: the time value of money as related to the cost of capital.

Consider, for example, a $350 million fab having initial production delayed for three months because of problems of obtaining permits from a government agency. The interest cost of a $350 million investment sitting idle for three months is almost $8 million at 9 percent interest.

The process of building a fab can be divided into several phases—planning, permits, and design; building the shell; and installing the clean room and equipment.

Two other reasons, however, are just as important as the time value of money. These are time to market and experience curve effects on manufacturing costs. Time to market refers to the time a company takes to get its product to the customer, where it counts. Very often in the marketplace, the company that can say "I was here first" will be the dominant company in terms of market share. This is especially true when product life cycles are only two years or less in length—six-month construction delay equals 25 percent of a two-year product life cycle. Fabs that do not come up on time also mean that orders are not delivered to customers when promised. When that happens, customers begin looking for other sources.

Experience curve effects on manufacturing costs are primarily a matter of learning how. If a company gets its fab up and running before its competitors do, it will be learning how to improve its yield and lower costs, while its competitors are still trying to install equipment.

How Long Does It Take to Build a Fab?

The process of building a fab can be divided into several phases—planning, permits, and design; building the shell; and installing the clean room and equipment (see Figure 1). After the equipment is installed, manufacturers typically begin running silicon through the fab in order to qualify the fab. This procedure is called first silicon.

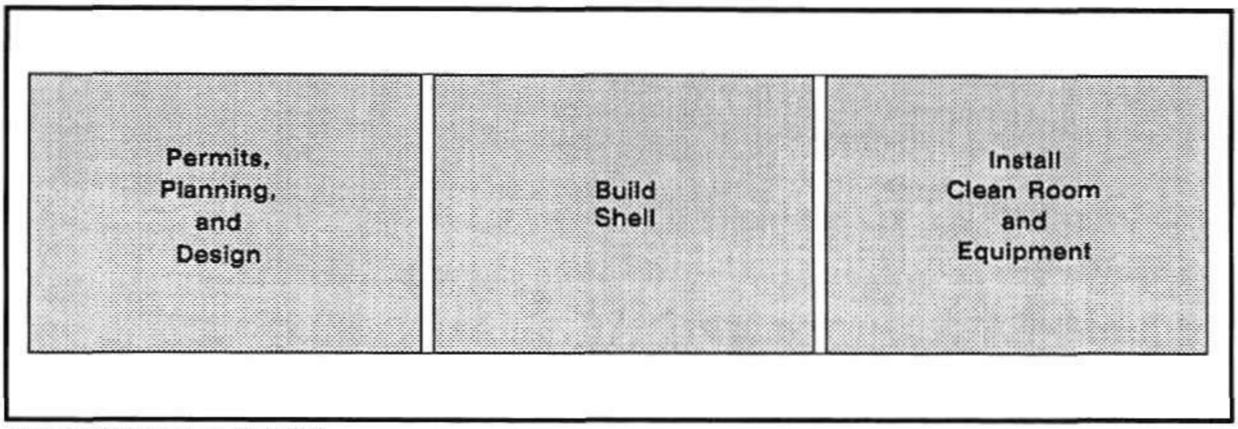
Japanese and U.S. manufacturers differed markedly. Japanese manufacturers tended to spend much more time up front in planning than did their U.S. counterparts.

Dataquest has analyzed the length of time it takes Japanese and U.S. semiconductor manufacturers to construct a fab from the beginning of the planning process to the completion of installing the clean room and processing equipment. In 1989, the times were remarkably similar—26 months for Japanese manufacturers and 27 months for U.S. manufacturers.

However, in the amount of time allocated to the different phases of the fab construction process, Japanese and U.S. manufacturers differed markedly. Japanese manufacturers tended to spend much more time up front in planning than did their U.S. counterparts. U.S. companies tended to spend more time building and less time planning.

Planning has been identified by several semiconductor companies as the most important variable affecting the fab construction process.

Figure 1
The Fab Construction Process



Source: Dataquest (June 1991)

Since 1989, however, the time to build has shortened in both regions. The time to build now ranges from 22 to 24 months. Texas Instruments recently was able to build and equip its fab in Avezzano, Italy, in just 20 months. It was able to do this by actually beginning construction before the entire design and permit process was fully completed.

Factors Affecting the Fab Construction Process

Planning

Planning has been identified by several semiconductor companies as the most important variable affecting the fab construction process. The design/build or turnkey approach is an effective new planning modality that has been used extensively in Japan and is now finding favor in the United States.

Bechtel Corporation, for example, used this modality in building the Advanced Lithography Facility for IBM at its Advanced Semiconductor Technology Center in East Fishkill, New York.

A key feature of the design/build approach is to have the design team manage the construction project and also have construction personnel participate in the design process. This approach allows for better communication and fewer mistakes and redesigns; therefore, the construction process is faster and less expensive.

Working 24 hours a day may cut construction time by as much as two-thirds.

This approach is similar to that used by semiconductor manufacturers in the design of their developmental lines: Manufacturing personnel are a part of the developmental team so that the device is designed for manufacturability (see the Semiconductor Equipment, Manufacturing, and Materials newsletter entitled "Motorola's New Advanced Technology Center," December 1990). Similarly, by having construction personnel as a part of the fab design team, fabs can be designed for constructability.

The Permit Process

The permit process can have a serious effect on fab construction time and may be required by governmental agencies for the following:

- Air emissions
- Water treatment
- Sewage treatment
- Toxic and hazardous materials
- Impact of local traffic

Semiconductor manufacturers generally regard the concerns of political entities and their constituents about these matters as valid.

However, many semiconductor manufacturers also believe that the regulatory process is too time-consuming.

As the semiconductor industry becomes both more capital intensive and more competitive, fab construction time will become ever more important in order to save money and get to market faster.

Sometimes the delay may be attributed to the fact that the agency responsible for a permit is understaffed. Sometimes, however, the delay is "designed in." A case in point is the tendency of agencies, in an attempt to control environmental emissions, to require permits for changes in equipment and processes within a fab. This requirement has the effect of forcing a semiconductor manufacturer to go through the permit process every time it wants to change a piece of equipment or process. A less onerous and time-consuming alternative would be to set an emission ceiling for the whole fab; as long as emissions remain below this ceiling, no action would be required.

Because of the effects of these time delays in the permit process, semiconductor manufacturers now regard a policy's permit process as a major factor to be considered in their site selection process.

Use of Pre-Existing Shells

Another technique that can be very effective in reducing fab construction time is the use of pre-existing shells. A good example is Intel's facility in Albuquerque, New Mexico. When Intel built the facility in 1986, it built a shell capable of housing four separate clean rooms. In 1988, Intel installed and equipped only one clean room, Fab 9.1, leaving the company with approximately 75 percent of its square footage unfacilitized and capable of being committed to additional clean rooms. In 1990, Intel began facilitizing some of the unfacilitized shell for a new processing line, Fab 9.2. Intel estimates that the time needed to facilitize and equip 9.2 will be about one year, approximately one-half the time necessary if it had to build 9.2 from "green field."

The 24-Hour Build

A final strategy that can be used by semiconductor manufacturers in constructing a fab is to employ the 24-hour build: construction occurs 24 hours a day. This method was used to build the Sematech facility in Austin, Texas, in just 32 weeks.

Working 24 hours a day may cut construction time by as much as two-thirds. However, it is more expensive than using the regular 8-hour day and possibly more prone to errors and mistakes because of the time intensity of the build.

Dataquest Perspective

As the semiconductor industry becomes both more capital intensive and more competitive, fab construction time will become ever more important in order to save money and get to market faster.

To be successful in attracting and maintaining a semiconductor manufacturing base, a region will have to have a user-friendly permit process that does not scrimp in meeting its health, safety, and environmental goals.

Planning will become more important in building a fab. It is likely that, just as design for manufacturability is becoming standard for making the devices in the fab, design for constructability will become standard for building the fab. This step will likely involve some form of design/build concept, as well as construction of the shell well before subsequent clean rooms are needed.

The effects of rising fab costs will be particularly large for political entities that want to attract or maintain semiconductor manufacturers as a source of both local employment and taxes. These political entities will have to give serious consideration to their permit granting process. To be successful in attracting and maintaining a semiconductor manufacturing base, a region will have to have a user-friendly permit process that does not scrimp in meeting its health, safety, and environmental goals.

By George Burns

The Fab Database Series: New Fabs—North America

Summary

This article highlights wafer fab activity planned or initiated to begin operation during the 1991 to 1997 time frame in North America. As of 1991, North America accounts for 29 percent of the total theoretical worldwide production fab capacity as measured in millions of square inches. Dataquest defines a production fab as wafer fab capable of front-end processing greater than 1,250 wafers per week. As this article illustrates, there will be plenty of opportunities in North America, especially in Texas.

Planned Fabs by State

As depicted in Figure 1, there are currently 37 new fabs planned to come on-line in North America between now and 1997. Production, pilot, and R&D fabs are included in the 37 new planned fabs. However, 81 percent of the new planned fabs for this region are production fabs. (These numbers reflect announced fabs to date.)

Dataquest expects the number of planned fabs to increase as semiconductor manufacturers continue to announce new planned fabs. For example, fabs that are expected to go into production in 1996 may not be announced until 1994, allowing for a conservative two-year lead time for construction and equipment installation. It is interesting to note that 35 percent of the new announced fabs will be in Texas.

Planned Fabs by Company

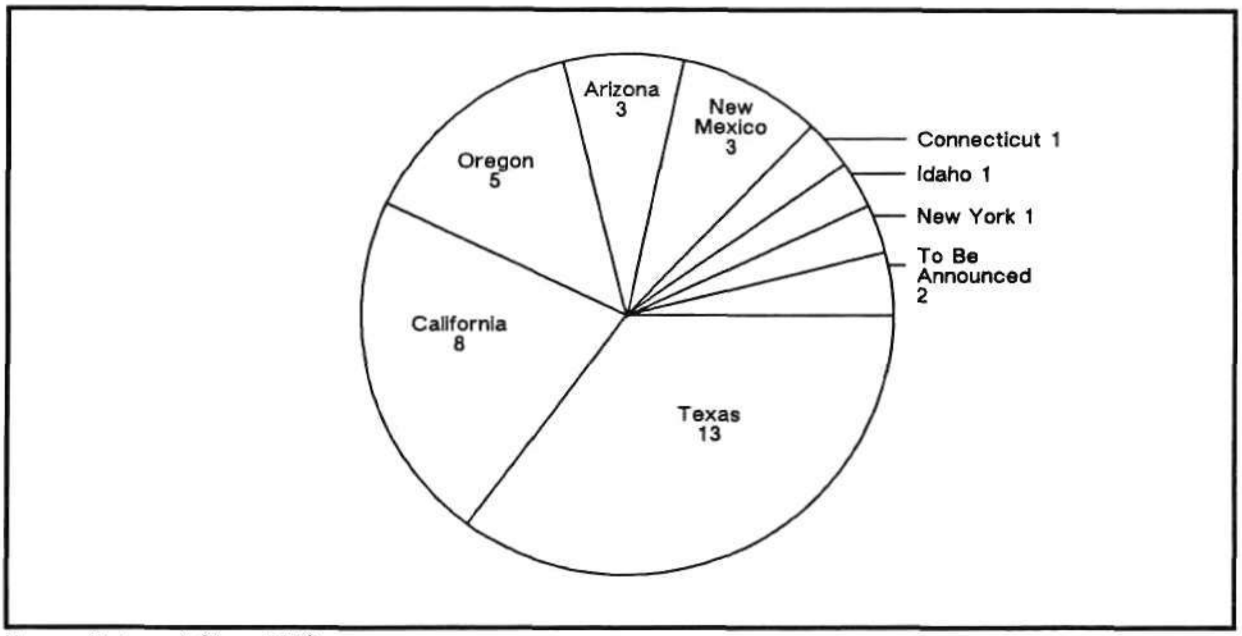
Table 1 lists North American fabs by company. Intel and Motorola appear to be the most aggressive companies; each has plans for four additional production fabs and one R&D facility between now and 1997.

Dataquest Perspective

Microprocessors, SRAMs, EPROMs, and ASICs will account for the majority of products produced in these fabs. The average drawn linewidth of the new fabs is 0.80 micron, and the average clean room size is 27,000 square feet. Dataquest believes that with 37 new fabs planned to begin operation from 1991 through 1997, the North American region presents many opportunities for semiconductor equipment and materials suppliers.

By Jeff Seerley

Figure 1
North American Planned Fabs by State (1991-1997)



Source: Dataquest (June 1991)

Table 1
North American Planned Fabs by Company (1991-1997)

Company	State	Fab Type	Target Date of Operation
Actel	TBA	Production	1992
AMD	TX	Production	1994
Crystal Semiconductor	TX	Production	1995
Cypress Semiconductor	TX	Production	1994
Dallas Semiconductor	TX	Production	1991
Exar	CA	Production	1992
Genesis Microchip	CN	Production	1991
Hitachi	TX	Production	1993
Hewlett-Packard	OR	Production	1993
IBM	NY	R&D	1991
Intel	NM	Production	1991
Intel	OR	R&D	1992
Intel	NM	Production	1993
Intel	OR	Production	1993
Intel	NM	Production	1995
LSI Logic	CA	R&D	1992
LSI Logic	CA	Production	1994
Matsushita	TX	Production	1994
Matsushita	TX	Production	1997
Maxim	CA	Pilot	1995
Micron Technology	ID	Production	1993
Motorola	AZ	Production	1991
Motorola	TX	Production	1991
Motorola	AZ	R&D	1991
Motorola	AZ	Production	1992
Motorola	TX	Production	1994
National Semiconductor	TX	Production	1992
NEC	CA	Production	1991
Oki	OR	Production	1994
Sierra Semiconductor	CA	Production	1992
Silicon Systems (TDK)	CA	Production	1992
Sony	TX	Production	1992
Sony	TX	Production	1996
Texas Instruments	TX	Pilot	1993
Toshiba	OR	Production	1993
United Si Structures	TBA	Pilot	1991
Western Digital	CA	Production	1991

TBA = To be announced
Source: Dataquest (June 1991)

Market Anaylsis

1990 Regional Wafer Fab Equipment Markets in Review

Summary

In 1990, the worldwide market for wafer fab equipment was $5,813 million, down 3 percent from its 1989 level of $5,996 million. Figure 1 presents the regional wafer fab equipment markets by percent share in 1990. Japan increased its share of worldwide demand for wafer fab equipment from 47 percent in 1989 to 51 percent in 1990 to account, for the first time, for more than one-half of the worldwide wafer fab equipment market. Europe captured a 13 percent share, representing an increase of 1 percent over its 1989 share level of 12 percent, while North America essentially maintained its 1989 regional percent share of 27 percent in 1990. The Asia/Pacific-Rest of World (ROW) region posted a decline of 5 percentage points to ultimately account for 9 percent of the worldwide wafer fab equipment market in 1990. This article reviews the 1990 regional wafer fab equipment markets.

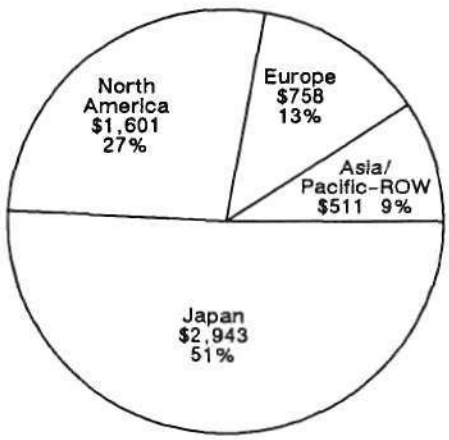
Japan

Japan is the largest regional wafer fabrication equipment market in the world. In 1990, the market for wafer fab equipment in Japan was $2,943 million, up 5 percent from its 1989 level of $2,798 million. Japan is the leading production region for high-volume advanced devices such as 4Mb DRAMs, 1Mb SRAMs, gate arrays, embedded microcontrollers for consumer electronics, high-integration VLSI chip sets, and systems logic for Japan's burgeoning computer industry. Hence, the Japanese wafer fab equipment market drives the requirements of high-throughput and leading-edge process technology. It is no surprise then that Japan constitutes the largest regional market for all core segments of the wafer fabrication equipment market such as steppers, etchers, CVD, PVD, diffusion, and ion implant.

North America

The 1990 wafer fab equipment market in North America was $1,601 million, down 4 percent from its 1989 level of $1,664 million. North America, as a region, did not add many large production fabs in 1990. Fab capacity expansion, upgrades, and offshore Japanese fabs in North America accounted for the bulk of the

Figure 1
1990 Wafer Fab Equipment Market by Region
(Millions of Dollars)



Source: Dataquest (June 1991)

1990 market. Captive semiconductor manufacturers such as Digital Equipment Corporation (DEC), Hewlett-Packard, and IBM were more consistent in new fab addition and capacity expansion purchases than were their merchant counterparts.

Although the semiconductor industry is becoming more and more global, it certainly is not homogeneous. Each of the major semiconductor manufacturing regions of the world has its own unique set of market dynamics.

North American semiconductor companies have largely retreated from memory, low-end gate arrays, and other high-volume, low-margin commodity devices. High device average selling prices (ASPs) and lower unit volumes for leading-edge devices such as 32-bit microprocessors and VLSI systems logic have enabled North American semiconductor manufacturers to achieve targeted revenue and profitability levels with lower capital spending expenditures. The new wave of fabless North American semiconductor companies appears to stretch this business model to the limit by completely eliminating wafer-fab-related capital spending and relying instead on foundry capacity in Japan and the Asia/Pacific-ROW region. The growing presence of offshore Japanese fabs focused on high-volume commodity manufacturing should again help stimulate growth in the North American wafer fab equipment market.

Europe

The 1990 wafer fab equipment market in Europe was $758 million, up 5 percent from the 1989 market of $720 million. In 1990, most of the European wafer fab equipment market activities revolved around offshore Japanese and North American fabs located in Europe. Companies such as DEC, Fujitsu, Hitachi, IBM, Mitsubishi, and Texas Instruments continued to expand their European operations in order to comply with possible future requirements for domestically fabricated European semiconductors. These offshore European fabs typically were clones of parent North American and Japanese fabs.

Dataquest firmly believes that today's wafer fab equipment companies benefit from having a global presence in the semiconductor industry. The downside of establishing an international sales/service/support organization is that it certainly stretches the resources of the company.

This strategy of duplicating an existing fab allows a semiconductor manufacturer to ramp a new facility and process more quickly. The choice of a global equipment vendor ensures a consistent process implementation for global semiconductor manufacturers with many regional fabs.

Asia/Pacific-ROW

The Asia/Pacific-ROW wafer fab equipment market was $511 million in 1990, down a substantial 37 percent from its 1989 level of $814 million. Factors such as depressed DRAM prices and excessive PC chip set competition together with political and economic uncertainties were responsible for the decline in the 1990 market. Reduced spending levels were pervasive throughout all segments of the wafer fab equipment market in Asia/Pacific-ROW in 1990. Dataquest believes that the 1991 wafer fab equipment market in Asia/Pacific-ROW will stage a moderate recovery as new 16Mb pilot lines and submicron ASIC/foundry fabs are built.

Dataquest Perspective

Although the semiconductor industry is becoming more and more global, it certainly is not homogeneous. Each of the major semiconductor manufacturing regions of the world has its own unique set of market dynamics. Japan is focused on high-volume manufacturing of advanced devices, while many semiconductor manufacturers in North American have targeted high ASP, low-unit-volume device production that requires comparatively lower capital spending expenditures. The European market for wafer fab equipment is strongly influenced by the presence of a number of North American and Japanese fabs that are duplicates of sister fabs in other regions. The Asia/Pacific-ROW wafer fab equipment market in 1990 suffered a serious decline and, as such, was completely out of sync with the capital spending activities in other regions of the world.

Dataquest firmly believes that today's wafer fab equipment companies benefit from having a global presence in the semiconductor industry. The downside of establishing an international sales/service/support organization is that it certainly stretches the resources of the company. At the same time, a global presence increases the total available market for an equipment company's products and protects it from relying too heavily on a single region's market dynamics to spur its future growth.

By Peggy Marie Wood

Optical CD and CD SEM Equipment Market—1990 Market in Review

Summary

The worldwide combined market for optical CD and CD SEM equipment was $150.5 million in 1990, overall a flat market when compared with the 1989 market of $150.2 million. The two segments of the CD measurement equipment market, however, exhibited different market dynamics in 1990. Optical CD equipment revenue totaled $60.0 million, down 14 percent from the 1989 level of $69.6 million. The market for CD SEM measurement equipment, however, was $90.5 million, up 12 percent from its 1989 level of $80.6 million.

Japanese semiconductor manufacturers have chosen to leapfrog the advanced optical CD measurement technologies and move directly to SEMs because they are not convinced that advanced optical technologies can be pushed to or beyond the 0.5um processing regime.

The CD SEM equipment market has been growing steadily since the market was first established in the mid-1980s to provide submicron metrology tools for the production environment. Between 1986 and 1990, the market grew almost sixfold from $15.4 million to $90.5 million. Optical CD tools also experienced significant growth during the latter half of the 1980s as advanced optical measurement technologies and automated measurement performance were incorporated into new equipment designs. Between 1986 and 1988, the market for optical CD equipment more than doubled from $28.7 million to $79.4 million. However, in both 1989 and 1990, the market for optical CD tools suffered a decline, while CD SEM tools continued to grow at a healthy pace. Dataquest believes that the continued market growth for CD SEM systems reflects that these tools are becoming the established tool choice for CD measurement technology in submicron applications, particularly in the sub-0.8um regime.

Regional Markets

Japan

As shown in Figure 1, the market for CD measurement tools in Japan is much more heavily weighted toward CD SEM systems than optical CD tools. Japan accounted for $54.5 million, or 60 percent, of the worldwide CD SEM equipment market. In contrast, equipment spending on optical CD tools in Japan totaled only $16.2 million, or 27 percent, of the worldwide optical CD equipment market. This bias toward CD SEM equipment is due in large part to the prevalence of DRAM manufacturing in Japan, which is the technology driver for processing submicron geometries. Japanese semiconductor manufacturers have chosen to leapfrog the advanced optical CD measurement technologies and move directly to SEMs because they are not convinced that advanced optical technologies can be pushed to or beyond the 0.5um processing regime.

Dataquest estimates that close to 20 percent of the $60.0 million worldwide optical CD equipment market in 1990 was for dedicated overlay tools and that the majority of this equipment was sold to semiconductor manufacturers in Japan. Optical CD tools traditionally have performed both linewidth and overlay measurements. However, one of the important trends in the metrology equipment market is the emergence of dedicated overlay tools designed specifically to complement the measurement technology of CD SEM equipment. CD SEM equipment is not particularly well suited for overlay measurement because the physics of its measurement procedure restricts it to the measurement of surface features. An optical tool, however, can "see" through a transparent film to the alignment marks on an underlying layer.

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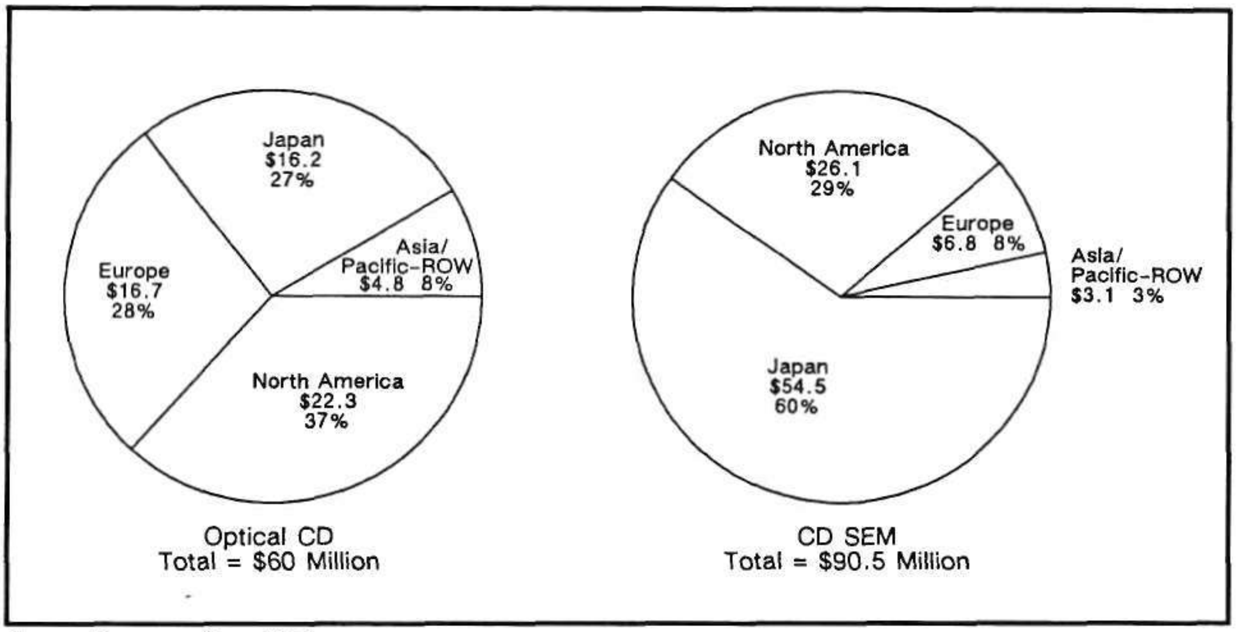
Figure 1
1990 Optical CD and CD SEM Equipment Regional Markets
(Revenue in Millions of Dollars)



Source: Dataquest (June 1991)

North America

In 1990, the market for CD measurement tools in North America was relatively balanced between optical CD and CD SEM tools. The CD SEM equipment market in North America was the slightly larger of the two at $26.1 million, while the optical CD market was $22.3 million. This market balance between the two different types of CD measurement tools reflects the strong position of optical CD tool suppliers IVS, Biorad, and KLA Instruments in their home market of North America. On the other hand, semiconductor manufacturers have a growing need for sub-0.8um metrology tools like the CD SEM systems supplied by companies such as Hitachi.

Europe

The European market for optical CD equipment was substantially larger than the CD SEM market in 1990. Optical CD equipment revenue was $16.7 million in contrast to CD SEM equipment sales of $6.8 million. The three largest suppliers of optical CD tools in Europe are all headquartered in Europe: optics giant Leica in Germany, newcomer Micro-Controle in France, and Biorad, an American-owned company with manufacturing facilities located in York, England. These three vendors accounted for $13.0 million, or 78 percent, of the European optical CD market. Dataquest believes that their local presence in the relatively small European marketplace has served to maintain high visibility for their products with customers in this region.

Asia/Pacific-Rest of World

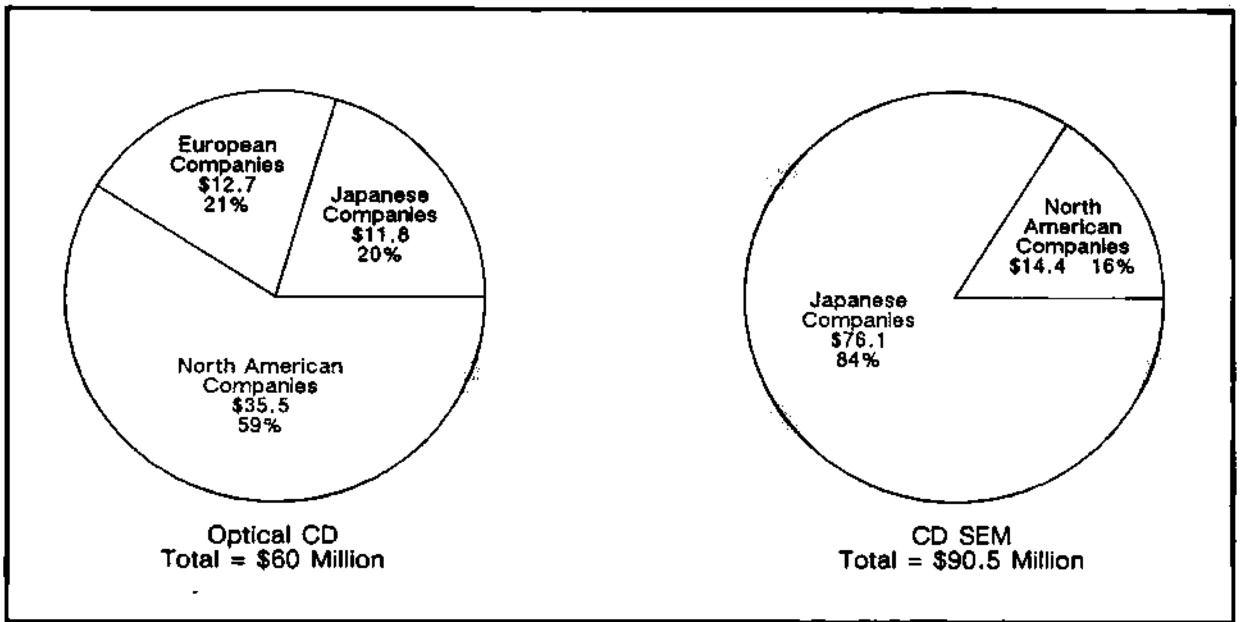
In Asia/Pacific-Rest of World (ROW), the 1990 optical CD equipment market took a tumble from its 1989 level of $10.8 million. Spending on optical CD tools in 1990 was only $4.8 million. This decline can be attributed to the weak capital spending environment in Asia/Pacific-ROW that was pervasive throughout all segments of the wafer fab equipment market. The market for CD SEM tools in 1990 also experienced a modest decline from its 1989 level of $3.5 million to 1990 revenue of $3.1 million.

Regional Ownership

Optical CD Equipment Market

As shown in Figure 2, North American companies continue to maintain a dominant position in the optical CD equipment market. The top three suppliers of optical CD tools in 1990—IVS, Biorad, and KLA Instruments—are all North American companies and together represented 49 percent of the worldwide optical

Figure 2
1990 Optical CD and CD SEM Equipment Regional Ownership
(Revenue in Millions of Dollars)



Source: Dataquest (June 1991)

CD market. The remaining 10 percent share held by North American companies is served by a handful of smaller suppliers that focus primarily on niche applications or specific regional markets.

European and Japanese companies held essentially equal share of the 1990 optical CD equipment market with 21 and 20 percent share, respectively. Both European and Japanese suppliers captured these market share positions by having a very strong focus on their respective home markets. In 1990, close to 95 percent of Japanese company sales of optical CD equipment were in Japan, while 86 percent of all European company sales were in Europe. In contrast, just a little more than one-half of all North American company sales of optical CD equipment were in North America.

CD SEM Equipment Market

Japanese equipment companies dominated the CD SEM equipment market with 84 percent share in 1990 and held three of the top four market positions in worldwide share. This dominance is due in large part to the commanding presence of Hitachi, which accounted for 69 percent of the worldwide CD SEM equipment market. Japanese companies have been the driving force behind the development and use of CD SEM systems for production manufacturing since this category of wafer fab equipment emerged in the mid-1980s. Five North American companies account for the remaining 16 percent share of the 1990 CD SEM worldwide market, with a single company, Biorad, accounting for one-half of that amount.

Company Ranking

Optical CD Equipment Companies

Table 1 identifies the major optical CD equipment suppliers in 1990. The three market leaders—IVS, Biorad, and KLA Instruments—are all North American companies. The year 1990 was the first that IVS attained the number one ranking position in the worldwide market. The company has done well in building its metrology systems business from a level of $0.5 million in systems revenue in 1986 to $10.8 million in 1990. Historically, more than 70 percent of the company's sales have been concentrated in North America.

Biorad Micromeasurements, with sales of $10.1 million, ranked second in the optical CD equipment market. The company's sales for its Quaestor and Q2 optical CD measurement

Table 1
1990 Worldwide Optical CD Equipment Company Rankings
(Revenue in Millions of Dollars)

Company	Revenue	Market Share (%)
IVS Inc.	10.8	18.0
Biorad	10.1	16.8
KLA Instruments	8.6	14.3
Leica	7.5	12.5
Hitachi	5.4	9.0
Micro-Controle	4.4	7.3
Nikon	3.8	6.3
Optical Specialties	1.9	3.2
SiScan Systems	1.3	2.2
Others	6.2	10.3
Worldwide Market Total	60.0	100.0

Note: The table shows calendar year 1990 systems revenue; spares and service are not included. Some columns do not add to totals shown because of rounding.
Source: Dataquest (June 1991)

tools are concentrated in North America and Europe. This former Vickers Instruments' operation came under the Biorad umbrella in January 1989 when it was acquired by the California-based manufacturer of life sciences research products, clinical diagnostics, and analytical instruments. Biorad Micromeasurements, like Hitachi, is well positioned in the CD measurement market with both optical and CD SEM product offerings.

KLA Instruments ranked third in the 1990 optical CD equipment market with revenue of $8.6 million. The KLA 5000 is a joint linewidth and overlay measurement tool that utilizes the company's patented coherence probe imaging technology for submicron metrology. In 1990, KLA also offered a dedicated overlay version of the KLA 5000 known as the 5000-R. Dataquest believes that more than one-half of KLA's optical CD equipment revenue in 1990 was for dedicated overlay systems.

European supplier Leica had optical CD equipment revenue of $7.5 million in 1990 to rank fourth in the worldwide market. This estimate includes approximately $1.0 million in systems revenue from Leica Lasertechnik, the former Heidelberg Instruments operation acquired by Wild Leitz. After several years of effort with only limited acceptance, Leica Lasertechnik will no longer be supplying its confocal tools to the semiconductor industry; instead, it will focus its efforts on the area of medical applications. Leica, its parent company, continues to be one of the major suppliers of white-light microscopy tools for CD metrology in the fab.

Hitachi had optical CD revenue of $5.4 million in 1990. The company offers a dedicated overlay measurement tool, the LAMU-600. All of Hitachi's optical CD equipment sales are in Japan. Like Biorad, Hitachi supplies both optical and CD SEM measurement tools to the semiconductor industry, although its market position in the area of CD SEM is considerably stronger than in the optical CD measurement arena.

Micro-Controle's optical CD revenue of $4.4 million placed the company sixth in the worldwide ranking for this market segment. The company's high-throughput ALARM optical CD system is designed around a very fast wafer stage. Dataquest believes that most of the company's activity has been focused on one major customer in Europe.

Nikon, in particular, has felt the market impact of CD SEM metrology tools on its optical CD equipment business. Nikon's optical CD equipment sales dropped from $8.0 million in 1989 to $3.8 million in 1990. At SEMICON/West in May 1991, Nikon exhibited a new dedicated overlay tool, the NRM-1. Surprisingly, this product comes not from the division within Nikon that manufactures the LAMPAS laser-based CD measurement equipment but from Nikon's Instrument Group, which focuses its activities on microscope-based products such as its Optistation family of wafer inspection systems.

Confocal Revisited—Again

One area of advanced CD measurement equipment that held much promise but has yet to experience any significant growth is confocal microscopy. Two companies—Leica Lasertechnik and SiScan Systems—pioneered this area with systems designed around laser-based confocal technology. Problems arose in characterization of these tools because of spurious signals generated by reflected and scattered laser light. Both companies made a change in laser sources, which required additional investment in time and money to recharacterize system measurement performance. Today, Leica Lasertechnik is no longer offering confocal tools for semiconductor applications. SiScan, while still providing a system for wafer metrology, has recently focused its efforts on a lucrative niche application in the area of mask metrology.

New confocal tools for the semiconductor production environment were exhibited by Prometrix and Carl Zeiss at SEMICON/West in May. Prometrix is offering a white light confocal tool, the ConQuest 2000. The company believes that its high-throughput product offering provides the benefits of confocal technology—0.5um resolution and z-axis profilometry—while eliminating the problems associated with laser sources. Carl Zeiss introduced new deep-UV optics for its Axioscan submicron measurement system. The Axioscan's UV compatibility enables users to avoid interference issues by working with ultraviolet light which, rather than being reflected or scattered, is absorbed by films such as photoresists.

CD SEM Equipment Companies

Table 2 identifies the major suppliers of CD SEM equipment in 1990. This market includes well-established equipment companies as well as start-ups. Hitachi, however, held and maintained the dominant market position throughout much of the 1980s. As shown in Table 2, Dataquest estimates that Hitachi captured 68.5 percent of world market share in 1990 with systems revenue of $62.0 million. Hitachi's success is due in part to the company's extensive experience in e-beam technology for

Table 2
1990 Worldwide CD SEM Equipment Company Rankings
(Revenue in Millions of Dollars)

Company	Revenue	Market Share (%)
Hitachi	62.0	68.5
Holon	8.9	9.8
Biorad	6.9	7.6
ABT	5.2	5.7
Nanometrics	3.1	3.4
Opal	2.4	2.7
Others	2.0	2.2
Worldwide Market Total	90.5	100.0

Note: The table shows calendar year 1990 systems revenue; spares and service are not included. Some columns do not add to totals shown because of rounding.
Source: Dataquest (June 1991)

electronics as well as other applications, in addition to its early product focus on developing a user-friendly CD-SEM tool for semiconductor production applications. The company has established such a dominant position in this market segment that its competitors face significant challenges overcoming the "play-it-safe" attitude of semiconductor manufacturers that choose to buy from the market leader.

Holon ranks second in the 1990 CD SEM market with sales of $8.9 million. Holon, formed by several ex-JEOL engineers, shipped its first CD-SEM tool in 1987. To date, all company sales have been in Japan because the company has no support base in other regions of the world.

Competition in the CD SEM market is heating up with the presence of several new players.

Biorad had CD SEM revenue of $6.9 million in 1990 to rank third in the worldwide market. The majority of Biorad's CD SEM equipment sales to date have been in North America. The company, however, may have a window of opportunity into the Japanese market through its parent corporation. Biorad's analytical instrumentation group has a large organization already established in Japan where it is one of major suppliers of FTIR analytical equipment in that region. Biorad's semiconductor equipment group should be able to take advantage of both name recognition and an already established Japanese operation as part of its strategy to target the Japanese wafer fab equipment market.

Akashi Beam Technology (ABT) ranked fourth in the 1990 CD SEM market with revenue of $5.2 million. In September 1990, the CD SEM group of ABT was acquired by Toshiba. Topcon, Toshiba's equipment subsidiary, will have responsibility for the CD SEM product line. Dataquest believes that the majority of ABT's 1990 CD SEM sales were to Toshiba, its new parent corporation.

New Players

Competition in the CD SEM market is heating up with the presence of several new players. New vendors include North American start-ups Angstrom Measurements and Metrologix. Both

Silicon Valley-based companies are focusing their product efforts on very high wafer throughput measurement systems. Angstrom Measurements designed its first Scanline product in the early 1980s but was unsuccessful in the marketplace with this product offering. With a new tool design, improved software, and system enhancements, the Scanline II was brought to market in 1989. Angstrom has been awarded a SEMATECH equipment improvement contract to further develop its ScanLine II CD SEM tool. Metrologix, incorporated in January 1990, evolved out of the former Advanced Engineering Group of Philips Electronics Instruments of the Netherlands. Metrologix has received venture funding from Nazem and Company.

With its 0.5um measurement capability and tool performance designed for the production environment, CD SEM equipment has become the preferred measurement technology for many semiconductor device manufacturers focused on advanced device fabrication.

JEOL is actually not a new player in the CD SEM market; it was one of the first companies to offer a CD SEM tool back in 1983. After several years of modest sales, the company's CD SEM business faltered because its product was not meeting the requirements of customers for profile measurements. JEOL introduced a new CD SEM system at SEMICON/Japan in December 1990 that it hopes will propel the company back into a competitive position within this market segment.

Dataquest Perspective

The CD SEM equipment market has been growing steadily since the market was first established in the mid-1980s. With its 0.5um measurement capability and tool performance designed for the production environment, CD SEM equipment has become the preferred measurement technology for many semiconductor device manufacturers focused on advanced device fabrication.

Although Dataquest anticipates that CD SEM tools will continue to capture a larger and larger segment of the overall CD measurement market, optical CD measurement tools are not expected to disappear entirely. Several of the advanced optical tools have been designed specifically for submicron measurement performance and thus will compete directly with CD SEM. In addition, conventional optical CD tools still provide a cost-effective, high-throughput option for the measurement of 1.0um geometries and larger. Finally, optical CD equipment—either as dedicated overlay tools or with joint linewidth and overlay measurement capability—will still be required to perform overlay measurements because CD SEM equipment is not well suited to address this important measurement task.

By Peggy Marie Wood (San Jose)
Kunio Achiwa (Tokyo)

Conferences and Exhibitions

SEMICON/West: Last Call for San Mateo

The major global semiconductor equipment and materials companies participated in the last SEMICON/West show to be held in San Mateo, California. Next year, the event will be moved to San Francisco.

Very few introductions of new products were made outside of some key lithography announcements.

New equipment announcements at this year's show were more evolutionary than revolutionary in nature. For the most part, equipment companies introduced enhancements to their equipment or new processes that will run on existing equipment. Very few introductions of new products were made outside of some key lithography announcements.

New material announcements centered around environmental issues and advancements in microcontamination areas. The environmental issues surrounding semiconductor manufacturing are increasing and materials vendors are moving quickly to supply a range of products to help device makers meet regulatory hurdles.

Microcontamination issues also dominated materials vendors' new product releases. Many vendors introduced tighter product specifications and improved packaging with a focus on point-of-use purity.

Dataquest Perspective

Perhaps the most controversial subject is the planned move to San Francisco next year. Many participants voiced concern about the added expense of the move. Hotel bills are expected to be higher, and, for those companies located in Silicon Valley, the trip to San Francisco will be less convenient than to the current San Mateo location. On the positive side, some companies consider San Francisco to be a better drawing card for overseas attendees. The final evaluation on the move will have to wait a year.

By Mark FitzGerald

In Future Issues:

The following topic will be featured in a future issue of *Dataquest Perspective:*

- Standard Mechanical Interface (SMIF)

The topics covered by SEMMS newsletters are selected for their general interest to SEMMS clients, which include wafer fab equipment suppliers, semiconductor materials companies, and semiconductor device manufacturers. The topics selected indicate the broad range of research that is conducted in the SEMMS group. Clients, however, often have specific information requirements that either go beyond the level of detail contained in the newsletters or beyond the scope of what is normally published in the newsletters. In order to provide complete decision support to our clients, Dataquest has a consulting service available to handle these additional information needs. Please call Stan Bruederle at (408) 437-8272 or Joe Grenier at (408) 437-8206 to discuss your custom requirements.

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Dataquest Perspective

Semiconductor Equipment, Manufacturing, and Materials

Vol. 1, No. 2 May 28, 1991

Semiconductor Manufacturing

North American Regional Capital Spending

Dataquest has just completed its analysis of 1991 capital spending plans for all companies in the North American geographical region. This analysis includes capital spending by Japanese and European semiconductor companies that takes place in North America, and it excludes capital spending by U.S. companies that takes place outside of North America. Our analysis indicates that there will be continued, albeit very small, growth (1 percent) in 1991 in North America.

In addition to continued growth, our analysis also reveals the growing importance of offshore companies for capital equipment in the North American market. The analysis also shows the emergence of the Pacific Northwest as a major center for semiconductor manufacturing and therefore as a major market for semiconductor capital equipment and materials. This article highlights these trends.

Offshore Capital Investment in North America

Although 1 percent growth in North American capital spending in 1991 is small, it does represent the fifth straight year of growth in North American capital spending since 1986 (see Figure 1). Offshore capital spending in North America (investment by Japanese or European semiconductor companies) reached $470 million in 1990. We expect offshore capital spending in North America to reach $495 million in 1991 (See Table 1).

This investment by offshore manufacturers in North America is led by Japanese semiconductor manufacturers building or acquiring fabs in North America—Fujitsu in Oregon, Hitachi in Texas, Matsushita in Washington, Mitsubishi in North Carolina, NEC in California, and Sony in Texas.

Dataquest believes that both Hitachi and Mitsubishi are likely to announce significant new capacity additions in North America within the next two years. We also believe that Toshiba and Oki are likely candidates to either build or acquire wafer fab capability in North America within the next two years.

Two European companies have silicon wafer fabs in the United States—Philips-Signetics in California, New Mexico, and Utah, and SGS-Thomson in Texas.

The Emergence of the Pacific Northwest

When reviewing capital spending in the last few years, it is striking how important the Pacific Northwest has become as a center for semiconductor manufacturing in North America. Fujitsu is currently manufacturing DRAMs at its new fab in Gresham, Oregon. Intel is currently building an 8-inch wafer fab in Aloha, Oregon. When this fab is completed, Intel plans to significantly upgrade its existing fab in Aloha. Matsushita is currently equipping its fab in Puyallup, Washington, which it bought from National Semiconductor. Both Oki and Toshiba have land in Oregon capable of supporting a wafer fab.

The amount of significant new wafer fab activity in Oregon and Washington in the last two years is of the same order of magnitude as in California. The reasons for the emergence of the Pacific Northwest as a center for device manufacturing are the abundance of relatively low-cost power, friendly and helpful governments, a well-disciplined labor force, nearby educational and service facilities, and, in the case of the Japanese semiconductor companies, proximity to Japan.

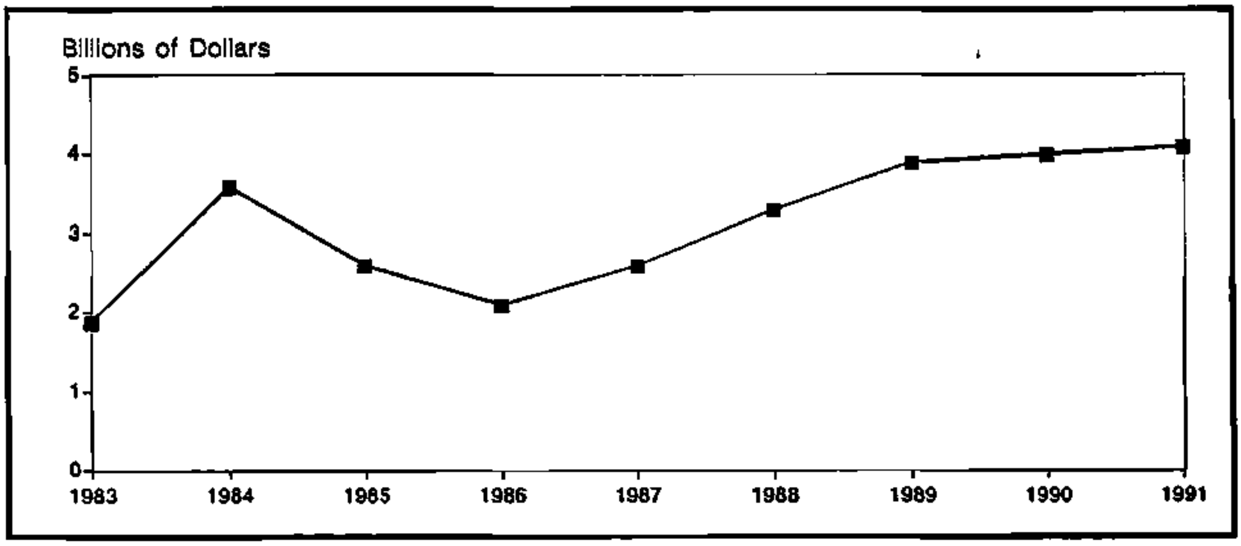
Dataquest Perspective

The U.S. market for capital spending will continue to grow. Growth in 1991 will be fueled by the continued expansion of offshore spending in North America, particularly by Japanese manufacturers and captives, especially IBM.

The reasons for the growth of offshore semiconductor manufacturing in North America are familiar—the growth of globalism, the desire to avoid trade friction and trade barriers, and the need for manufacturers to be close to the markets that they serve. Dataquest believes that these factors will continue to fuel the growth of offshore manufacturing in North America throughout the 1990s.

NEC reports that the yields from its Roseville, California, facility are comparable to the yields of its fabs in Japan. This is not surprising—a properly trained work force that has good

Figure 1
North American Semiconductor Capital Spending
(Revenue in Billions of Dollars)



Source: Dataquest (May 1991)

Table 1
Capital Spending in North America (Millions of Dollars)

			Percentage of Total	
	1990	1991	1990	1991
U.S. Merchant Companies	2,673	2,613	66	64
Japanese Companies	365	400	9	10
European Companies	105	95	3	2
Captive Companies	877	969	22	24
Total North America	4,020	4,077	100	100

Source: Dataquest (May 1991)

management to guide it will achieve good yields. Dataquest believes that other Japanese semiconductor manufacturers with proper planning and training will also achieve good manufacturing results with American workers.

We also believe that the emergence of the Pacific Northwest as a center of semiconductor manufacturing reflects a new sophistication on the part of semiconductor manufacturers. They are going to be just as careful in the selection and planning of fab sites as they are in the selection of products and processes. They have become intelligent shoppers and want areas that are close to markets, will minimize operating costs, have a support structure such as universities and service facilities nearby, and have governments with which they can have a close working relationship.

By George Burns

The Fab Database Series: New Fabs—ROW

Summary

This article will highlight wafer fab activity planned or initiated to begin operation during the 1991 to 1997 time frame in the Rest of World (ROW) region. As of 1991, ROW accounts for 11 percent of the total theoretical worldwide production fab capacity as measured in millions of square inches. Therefore, semiconductor equipment and materials suppliers should continue to focus on this region for sales opportunities. As this article illustrates, there will continue to be plenty of opportunities in this region, especially in Taiwan and South Korea.

Table 1
ROW Planned Fabs by Company (1991-1997)

Company	Country	Fab Type	Target Production Date
Erso	Taiwan	R&D	1991
	Taiwan	R&D	1995
Formosa Plastics	Taiwan	Production	1991
Goldstar	S. Korea	Production	1993
	S. Korea	Production	1996
Hanill	S. Korea	Pilot	1991
Holtek	Taiwan	Production	1991
Hualon	Taiwan	Production	1991
	Malaysia	Production	1992
Hyundai	S. Korea	Production	1991
Macronix	Taiwan	Production	1991
MOSel	Taiwan	Production	1991
	Taiwan	Production	1995
Samsung	S. Korea	Production	1991
	S. Korea	Production	1991
	S. Korea	Production	1993
	S. Korea	Production	1995
	S. Korea	Production	1997
Sanyo	Thailand	Production	1992
Semiconductor Complex	India	Production	1994
Shindengen	Thailand	Production	1991
Technology Semiconductor Singapore Ltd.	Singapore	Production	1994
TI/Acer	Taiwan	Production	1991
	Taiwan	Production	1992
TSMC	Taiwan	Production	1992
	Taiwan	Production	1994
United Microelectronics	Taiwan	Production	1991
	Taiwan	Production	1993
Utic	Taiwan	Production	1991
Vitelic	Taiwan	Production	1991
	Taiwan	Production	1994
Winbond	Taiwan	Production	1991
	Taiwan	Production	1993
Xicor	Israel	Production	1992

Source: Dataquest (May 1991)

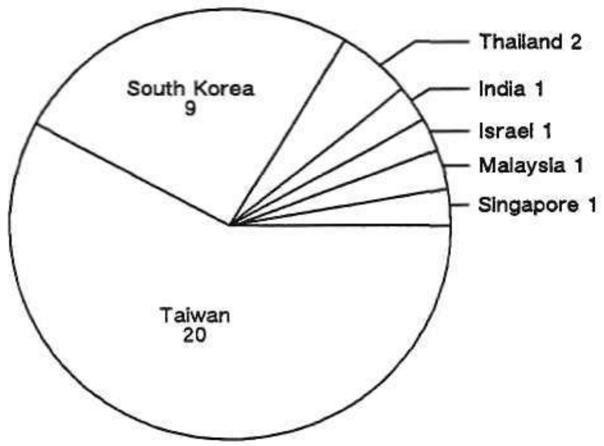
Planned Fabs by Country

As depicted in Figure 1, there are currently 34 new fabs planned for ROW between now and 1997. Production, pilot, and R&D fabs are included in the 34 new planned fabs. However, 91 percent of the new planned fabs for this region are production fabs. (These numbers reflect announced fabs to date.) Dataquest expects this number to increase as semiconductor manufacturers continue to announce new planned fabs. For example, fabs that are expected to go into production in 1996 may not be announced until 1994. This allows for a conservative two-year lead time for construction and equipment installation. It is interesting to note that about 50 percent of the new fab activity is in Taiwan. The only other country with major new fab activity currently planned is South Korea, with about 22 percent of the new announced fabs going into this region.

Planned Fabs by Company

Table 1 lists planned ROW fabs by company. Samsung appears to be the most aggressive

Figure 1
ROW Planned Fabs by Country (1991-1997)



Source: Dataquest (May 1991)

company with plans for five additional production fabs between now and 1997. Four of the five Samsung fabs are expected to be used for DRAM production. In fact, the majority of planned fabs in this region will be used for memory production.

Macronix's Hsinchu Fab

Macronix is constructing a new fab located in Taiwan's Hsinchu Science-Based Industrial Park. When this fab becomes operational later this year, it will be one of the largest fabs in Taiwan. The fab will be capable of 20,000 to 30,000 6-inch wafers per month using 0.6-micron CMOS technology. It will bring up its process using EPROMs. The fab is being constructed in three phases.

The first phase is expected to be completed this September, the second phase is expected to be completed by the end of 1992, and the third phase will be completed in 1993. Upon completion of the third phase, Macronix is expected to have incurred $250 million in costs.

Dataquest Perspective

Dataquest believes that, with 34 new fabs planned to begin operation from 1991 through 1997, the ROW region presents many opportunities for semiconductor equipment and materials suppliers, especially those that support memory production. ■

By Jeff Seerley

Market Analysis

Wafer Inspection Equipment Market—1990 Market in Review

The worldwide wafer inspection equipment market was $99 million in 1990, down 16 percent from its 1989 level of $117.2 million. The two segments of the wafer inspection equipment market experienced different market dynamics in 1990. Microscope-based station revenue totaled $40.2 million, down a modest 6 percent from the 1989 level of $42.7 million. The market for advanced defect detection tools, however, plunged 21 percent from its 1989 level of $74.5 million to $58.8 million in 1990. The drop-off in demand for advanced defect detection systems came about in the latter half of 1990 when market leader KLA Instruments announced a brand new family of defect inspection tools. This new product introduction, coupled with a cautious capital spending environment, had the effect of freezing much of the order activity during the months that semiconductor manufacturers evaluated the performance characteristics of the KLA product and the newest tool from KLA's chief competitor, Insystems. Dataquest expects the wafer inspection equipment market to pick up in 1991 as decisions are finalized and new orders turn into shipments. We forecast the 1991 wafer inspection equipment market to be $109 million, up 10 percent from 1990.

Regional Markets

As shown in Figure 1, North America accounted for $30.1 million of the $99 million wafer inspection market in 1990. Demand for wafer inspection equipment in North America was down 25 percent from its 1989 level of $40.1 million. In 1990, 74 percent of the North American wafer inspection market, or $22.3 million, was for advanced defect detection tools. North America, the home market for Insystems and KLA Instruments, has for the last four years spent more than one-half of its wafer inspection dollars on advanced defect detection tools. When the market freeze in advanced defect detection tools occurred in 1990, the North American market suffered a large decline because of its emphasis on this segment of the wafer inspection product mix.

In Japan, the market for microscope-based stations and advanced defect detection tools is more evenly balanced than in North America. In 1990, microscope-based stations accounted for $20.6 million, or 47 percent of the $43.7 million wafer inspection equipment market. Unlike North America, the market for advanced defect detection tools in Japan ($23.1 million) stayed fairly constant in 1990 relative to a 1989 spending level of $24.2 million. The total wafer inspection market in Japan was up 2 percent from a 1989 level of $42.9 million, a growth rate comparable to total wafer fab equipment growth in Japan of 5 percent.

In 1990, the market for wafer inspection equipment in Europe was $19.3 million, down 18 percent from its 1989 level of $23.4 million. The 18 percent decline may seem contrary in light of overall wafer fab equipment growth in Europe of 5 percent in 1990. Like North America, the decline in the wafer inspection market in Europe was due in part to the delay in purchasing decisions while semiconductor manufacturers evaluated new tools. The decline can also be viewed as a market correction after two years of explosive growth in the European wafer inspection market. The 1987 wafer inspection market in Europe grew 52 percent, followed by growth of 81 percent in 1988.

The Asia/Pacific-Rest of World (ROW) market for wafer inspection equipment was $5.9 million in 1990, down 45 percent from its $10.8 million level in 1989. Dataquest believes that the decline in the wafer inspection market in this region was strongly influenced by reduced spending levels pervasive throughout all segments of wafer fab equipment rather than by any factors specific to the wafer inspection equipment market. It is interesting that, as in Japan, the market demand for microscope-based stations and advanced detection tools is fairly balanced in both Europe and Asia/Pacific-ROW. In 1990, advanced defect detection systems accounted for 56 percent, or $10.9 million, of the European market, while these tools represented 42 percent, or $2.5 million, of wafer inspection equipment spending in Asia/Pacific-ROW.

Regional Ownership

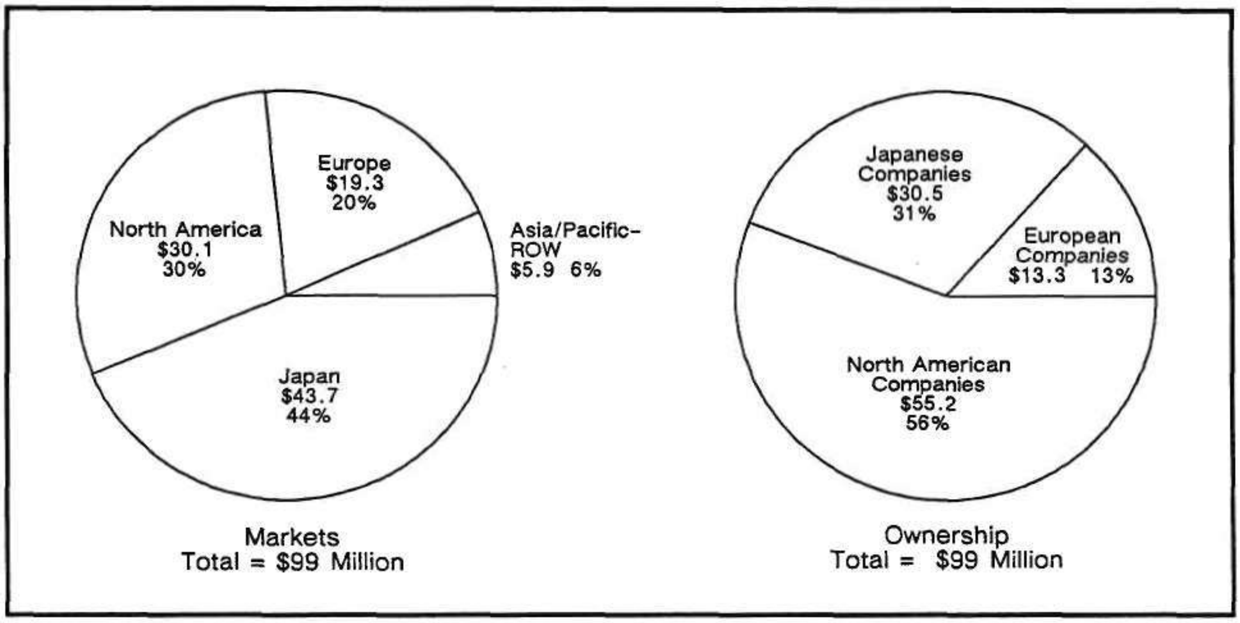
North American companies continue to maintain a dominant position in the wafer inspection equipment market. As shown in Figure 1, North American company sales total $55.2 million, or 56 percent, of the worldwide market in 1990. The advanced defect detection tools of two North American companies—Insystems and KLA Instruments—account for an overwhelming $53.8 million, or almost all of the revenue associated with North American vendors. Japanese wafer inspection companies, which supply only microscope-based stations, had sales of $30.5 million in 1990. European companies, accounting for $13.3 million in 1990, offer a mix of products. One vendor, Micro-Controle, provides advanced defect detection tools, which accounted for revenue of $5 million, or 38 percent, of European company revenue. The remaining $8.3 million of European company revenue was for microscope-based inspection stations.

Company Ranking

As shown in Table 1, KLA Instruments continued to rank as the number one supplier of wafer inspection equipment in 1990 with revenue of $37 million, down 35 percent from its 1989 level of $57.1 million. The company's decline in revenue and market share was attributable to a de-emphasis of its existing 20xx product family while marketing efforts were focused on launching its new 2110 automated defect detection system. In mid-1990, KLA began to talk with customers and demonstrate this first product in its new family of inspection tools, the 2100 series. The KLA-2110 has 0.25-micron defect sensitivity and greatly increased throughput compared to its predecessors.

At the same time that KLA began demonstrating its new product, Insystems, KLA's major competitor in this market, introduced its new

Figure 1
1990 Wafer Inspection Equipment Regional Markets and Ownership
(Revenue in Millions of Dollars)



Source: Dataquest (May 1991)

Table 1
1990 Worldwide Wafer Inspection Equipment Company Rankings

Company	Revenue ($M)	Market Share (%)	Market Segments Advanced Defect Detection	Microscope-Based Stations
KLA Instruments	37.0	37.4	X	
Nikon	19.3	19.5		X
Insystems	16.8	17.0	X	
Leica	6.8	6.9		X
Nidek	6.7	6.8		X
Micro-Controle	5.0	5.1	X	
Canon	3.8	3.8		X
Others	3.6	3.6		X
Worldwide Market				
Total	99.0	100.0		

Note: Some columns do not add to totals shown because of rounding.
The table shows calendar year 1990 system revenue; spares and service are not included.
Source: Dataquest (May 1991)

inspection tool, the Model 8800. This tool, like its predecessor, the Model 8600, uses spatial frequency filtering holography technology to automatically detect defects across an entire wafer surface. Like the KLA-2110, the Insystems 8800 system improvements are focused on increased throughput and improved defect sensitivity. Throughout the latter half of 1990, most equipment buy decisions for advanced defect detection tools were put on hold while semiconductor manufacturers evaluated these two new product offerings. Even with the freeze on advanced defect detection systems in the latter half of the year, Insystems still gained

5 percentage points in world market share in 1990. The company ranked third in the 1990 market with revenue of $16.8 million, or 17 percent share, of the $99 million market.

The third supplier of advanced defect detection systems is Micro-Controle of France. Micro-Controle ranked sixth in the wafer inspection equipment market with sales of $5.0 million. This was the second year of shipments for the company's IDIS advanced defect detection tool. All system shipments were in Europe and, Dataquest believes, to one customer.

A number of companies supply microscope-based inspection stations. Several of these companies—Canon, Leica, Nikon, Zeiss—are major manufacturers of optics systems and components. Nikon of Japan ranked second in the world wafer inspection equipment market in 1990 with revenue of $19.3 million. Its Optistation wafer inspection station family has been widely accepted in all regions of the world. In 1990, about 55 percent of Nikon's wafer inspection sales were in Japan, 23 percent in North America, 12 percent in Europe, and 10 percent in Asia/Pacific-ROW. These regional revenue percentages for Nikon's wafer inspection equipment are close to the regional share for the total 1990 wafer fab equipment market.

Leica, formed by the merger of Wild Leitz and Cambridge Instruments in 1989, ranked fourth in the 1990 wafer inspection equipment market with revenue of $6.8 million. Nidek's revenue in 1990 of $6.7 million placed the company fifth in the wafer inspection market share ranking, while Canon ranked seventh in the market with revenue of $3.8 million. Leica actively participates in the North American, European, and Asia/Pacific-ROW markets. Canon and Nidek, however, focus primarily on the wafer inspection equipment market in Japan.

Dataquest Perspective

The 1990 wafer inspection equipment market of $99 million was down 16 percent from its 1989 level of $117.2 million. KLA Instruments, the market leader, was the only company in this segment to experience a significant decline in revenue and market share. We believe that KLA took a gutsy tactical position to de-emphasize its market activity in its mainstream 20xx product family of advanced defect detection equipment while it introduced and demonstrated a new product. Although this move had a strong negative impact on the company's inspection equipment revenue in 1990, it also had the effect of temporarily freezing the market for its main competitor, Insystems. As a large international publicly held company with several product divisions, KLA was in a much better position to weather the storm than Insystems, a small privately held company manufacturing a single product family.

Dataquest expects the market for wafer inspection tools to rebound in 1991 with revenue up approximately 10 percent. We expect 1991 to be followed by two years of 20-percent-plus growth in the wafer fab equipment market as manufacturers buy equipment for 16Mb production and 64Mb pilot lines. KLA gambled in 1990 by accepting sharply reduced revenue and lower market share to better position its new product offerings. We believe that KLA is well positioned to win big in the wafer inspection market in years to come.

By Peggy Marie Wood (San Jose) and Kunio Achiwa (Tokyo)

1990 U.S. Specialty Gas Market

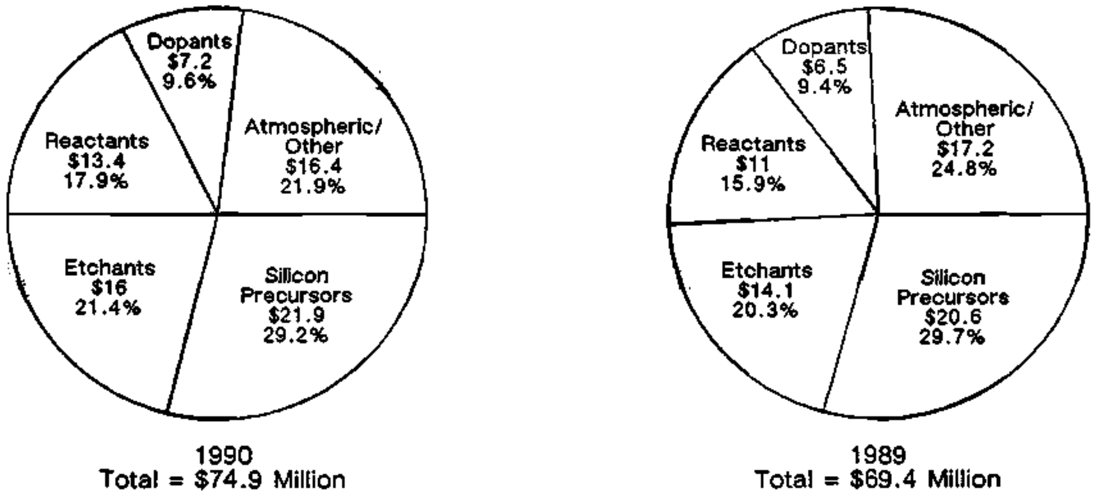
The North American semiconductor specialty gas market grew 7.9 percent in 1990. Gas vendors' sales to the semiconductor industry (see Table 1) totaled $74.9 million in 1990 versus $69.4 million in 1989 (see Figure 1). Revenue growth is largely attributable to the increased level of semiconductor device production. Using silicon wafer consumption as a yardstick, North American production grew 10.7 percent in 1990 on a square-inches basis. Historically, the ratio of specialty gas revenue per unit of silicon has increased (see

Table 1
1990 North American Specialty Gas Market Semiconductor Applications

	Revenue ($M)	Share (%)
Airco	26.2	35.0
Air Products	16.0	21.4
Linde/UCC	14.0	18.7
Matheson	10.2	13.6
Scott Specialty Gases	2.9	3.9
Solkatronics Chemicals	1.7	2.3
Liquid Air	1.6	2.1
Others	2.3	3.1
Total	74.9	100.0

Source: Dataquest (May 1991)

Figure 1
North American Specialty Gas Market—Semiconductor Applications



Source: Dataquest (May 1991)

Table 2
Specialty Gas Revenue per Square-Inch Silicon Consumption
Semiconductor Applications (Millions of Dollars)

	1986	1987	1988	1989	1990
Dollars per Square Inch	0.103	0.112	0.132	0.124	0.121

Source: Dataquest (May 1991)

Table 2). However, in the last two years this ratio has decreased. This trend is due partly to more efficient use of gases in the manufacturing process and partly to competitive pricing.

Gas vendors are reporting increased sales of higher-grade gases, which carry a higher average selling price. However, the demand for these high-purity gases is not large enough to offset efficiencies in the manufacturing processes and price erosion.

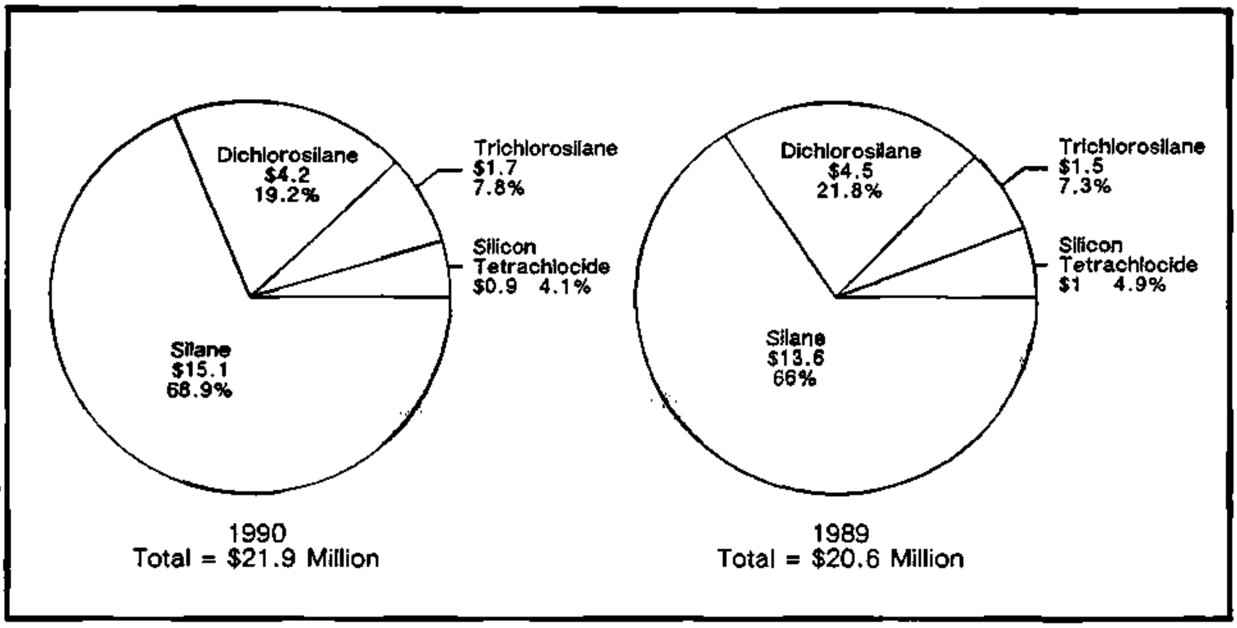
Product Trends

Every category of specialty gas except atmospheric/other grew in 1990. Dataquest believes that atmospheric gases suffered the most from competitive pricing. The atmospheric/other category also includes tungsten, which Dataquest estimates grew roughly 20 percent. The growth rate is based on 29 percent growth in the number of CVD reactors using tungsten gas that were installed in 1990.

The blanket tungsten CVD film segment will be the largest tungsten CVD market during the next five years. Blanket tungsten will be widely used in contact/via plug fills, metal interconnects, and gate conductor applications. The blanket process is a large volume user of WF_6 gas, and demand is expected to grow 20 to 30 percent during this period.

The demand for silicon precursor gases benefited from the strong demand for epi wafers in 1990. Epi wafer demand is estimated to have jumped 20 to 25 percent on a square-inch basis. The consumption of silicon precursor gases totaled $21.9 million (see Figure 2), an increase of 6.3 percent over 1989 levels. Silane, the largest segment of the precursor category, grew 11.0 percent on a year-to-year basis.

Figure 2
Silicon Precursor Market—by Product



Source: Dataquest (May 1991)

Trichlorosilane demand also pushed ahead. However, consumption of diclorosilane and silicon tetrachloride declined.

Sales of reactant gases, which include ammonia, hydrogen chloride (HCl), and nitrous oxide, jumped 21.8 percent in 1990. The reactant category benefited from strong demand for HCl, which is used in the manufacture of epi wafers.

The etchant gases include all Freon gases, nitrogen trifluoride (NF_3), and boron trichloride. This group of gases grew 13.5 percent in 1990. Demand for NF_3, largely used in cleaning applications, pushed ahead because of the short supply of Freon-116. DuPont, the primary manufacturer of Freon-116 in North America, expects to have the bottleneck in its plant eliminated by January 1992.

As Freon-116 availability improves, most cleaning applications are expected to switch from NF_3 to Freon-116. NF_3 is too aggressive an etch for cleaning applications. Most reactor OEMs have already developed cleaning processes around Freon-116.

DuPont is also planning to exit the Freon-14 market by this fall. North American plant utilization is currently running about 60 percent for Freon-14 and prices have been severely depressed. Even so, prices for Freon-14 are expected to move lower during the next several years because the patent for Freon-14/oxygen mixtures expires this year.

The dopant market showed good growth last year. Revenue was up 10.8 percent. Solkatronics, one of the few primary suppliers in the world, benefited from a very tight market for dopants. Linde, Union Carbide's industrial gas division, started production of dopants at its Kingman, Arizona, facility in 1990; however, production began in the latter half of 1990 and did little to relieve the tight market conditions.

Dataquest Perspective

As device manufacturers move to the submicron level, the demand for high-purity specialty gases is expected to expand. Volumes for specialty gases will grow faster than the silicon wafer market, which is forecast to have a 6.6 percent compound annual growth rate from 1991 to 1995 on a square-inch basis. Revenue may lag, as Dataquest expects pricing for the high-purity specialty gases to be increasingly competitive.

As Freon-116 availability improves, most cleaning applications are expected to switch from NF_3 to Freon-116. NS_3 is too aggressive an etch for cleaning applications. Most reactor OEMs have already developed cleaning processes around Freon-116.

By Mark FitzGerald

Second Quarter 1991 Semiconductor Industry Outlook: Recovery In A Maturing Industry

Introduction

Following a year in which the worldwide semiconductor industry grew less than 2 percent, an industry recovery is under way that Dataquest believes will result in dollar-based consumption growth of 13.7 percent in 1991. This is equivalent to 9.6 percent growth if constant 1990 exchange rates are used against the dollar. With first quarter results available already for the North American and European markets (which grew at approximately 3 and 11 percent, respectively, from fourth quarter 1990), it is clear that a turnaround has occurred. We expect every quarter this year to have positive growth worldwide; however, this will not be true for every region.

We have lowered our long-term growth rate expectations for the worldwide industry to 12.6 percent from 1990 to 1995. (Our previous expectation was 14 percent.)

Key events and assumptions driving our short- and long-term forecasts are as follows:

- Memories, microcomponents, and MOS logic are leading the industry recovery in 1991.
- Fluctuations of European and Japanese currencies against the U.S. dollar are skewing 1991 dollar growth upward.
- The European and Asian semiconductor markets are the hotbeds of activity for both the near and long term.
- As electronic equipment becomes an ever-larger component of the worldwide economy, semiconductor growth rates are slowing.
- The historical cyclicality of the industry, while still visible, has moderated.

Dataquest Forecast Scorecard

How good have our forecasts been in the past? As shown in the scorecard in Table 1, our forecast accuracy has improved over the last several years. In fact, we called 1989 and 1990 almost right on. But even in our forecasts of 1987 and 1988, we called the direction and general magnitude correctly.

In February, we forecast that first quarter 1991 growth in the North American market would be 1 percent and that the European market would grow by 6 percent. The actuals, per the WSTS flash report, were 3 percent and 11 percent, respectively.

Short-Term Outlook

Currency fluctuations are skewing our dollar-based growth outlook for 1991. As shown in Table 2, growth rates in local currencies are actually rather modest this year. The Japanese market will grow less than 9 percent in yen, but an astounding 17 percent in dollars. The European market will grow less than 10 percent in ECUs, but 15 percent in dollars. The North American and Asia/Pacific-Rest of World (ROW) markets, which we forecast only in dollars, will grow at 7.9 and 15.2 percent, respectively. All of this will yield dollar-based worldwide growth of 13.7 percent this year; using constant exchange rates, the growth will be only 9.6 percent.

Figure 1 shows our quarterly growth expectations worldwide. It is important to note, however, that we expect virtually all North American growth to occur in the first two quarters of the

Table 1
Dataquest Forecast Scorecard: Forecast of Worldwide Industry Growth (Percent Growth—Forecast versus Actual*)

Year Being Forecast	Forecast Growth (%)	Actual Growth (%)
1987	18	24
1988	24	33
1989	10	12
1990	2	2
1991	15	??? Current forecast = 13.7

*Actual is determined at completion of our final market share project in the second quarter of the year following the forecast year. The forecasts were made in October of the year preceding the forecast year.
Source: Dataquest (May 1991)

Table 2
Worldwide Semiconductor Consumption by Region (Factory Revenue in Local Currencies)

Company:	All	Distribution Channel:	Not meaningful
Product:	Total Semiconductor	Application:	All
Region of Consumption:	Each	Specification:	All

	1990	1991	Change (%) 1990-1991	1995	CAGR (%) 1990-1995
North America ($M)	17,386	18,761	7.9	28,001	10.0
Japan ($M)	22,508	26,354	17.1	40,762	12.6
Japan (¥B)	3,241	3,529	8.9	5,458	11.0
Europe ($M)	10,661	12,274	15.1	20,764	14.3
Europe (EcuM)	8,384	9,206	9.8	15,573	13.2
Asia/Pacific-ROW ($M)	7,670	8,834	15.2	16,004	15.8
Worldwide ($M)	58,225	66,223	13.7	105,531	12.6
Worldwide ($M at Constant Exchange Rate)	58,225	63,818	9.6	101,574	11.8

Source: Dataquest (May 1991)

year. We are forecasting no growth in the last two quarters of 1991 in North America. The April WSTS flash report confirms our outlook for the second quarter. In Japan, we believe that the first quarter declined from fourth quarter 1990, and we forecast growth to pick up through the rest of the year. Europe, as mentioned earlier, had 11 percent growth in the first quarter. Even with slow growth in the second quarter and negative growth in the third quarter, Europe will have a good showing on an annualized basis. We forecast negative growth in the first quarter for Asia/Pacific-ROW, with strong growth in the second and third quarters.

A pickup in DRAM pricing and a strong PC market are current market drivers. Our contacts tell us that the PC market weakness being experienced in the North American market is not occurring in Europe and Asia. In fact, many companies are experiencing their strongest business from the PC area. For the remainder of this year, we expect the telecom market to carry European semiconductor consumption.

Long-Term Outlook

General Trends

From its beginnings in the mid-1950s, through 1990, the worldwide semiconductor industry grew at a compound annual growth rate (CAGR) of 18.8 percent. However, the fastest growth occurred between 1970 and 1980. Since 1980, growth has slowed; the 1980-through-1990 CAGR was only 15.2 percent.

Through most of its history, the industry has been cyclical, reaching peaks of growth every four to five years. The magnitude of the peaks and valleys has been very large, reaching peaks of as much as 40 percent growth and valleys of as much as a 15 percent decline.

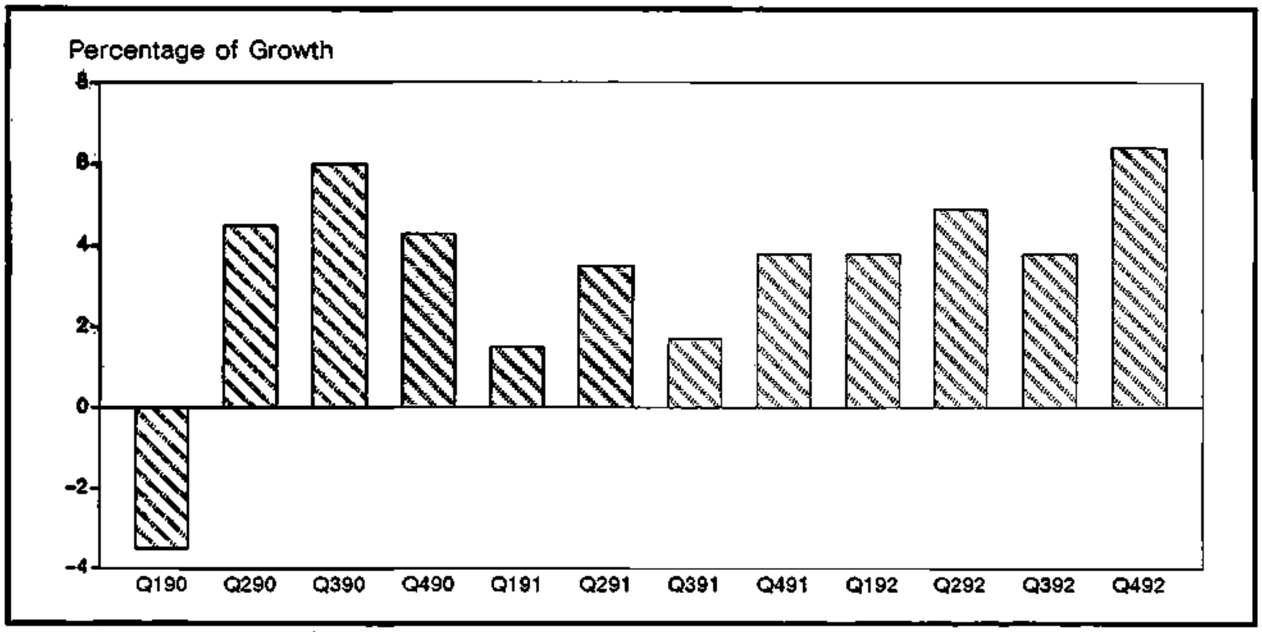
We believe that the long-term trend toward slower growth will continue. We are forecasting a CAGR of 12.6 percent from 1990 through 1995. In addition, we believe that the cyclicality of the industry, although still in evidence, will abate considerably in magnitude. We do not foresee annual growth approaching even the 25 to 30 percent range in any one year. Figure 2 shows the worldwide industry size in dollars from 1970 through 1995. Figure 3 shows the annual percentage of change for each year.

Reasons for Changes in Trends

Some reasons for generally slower growth and moderation of the silicon cycle are as follows:

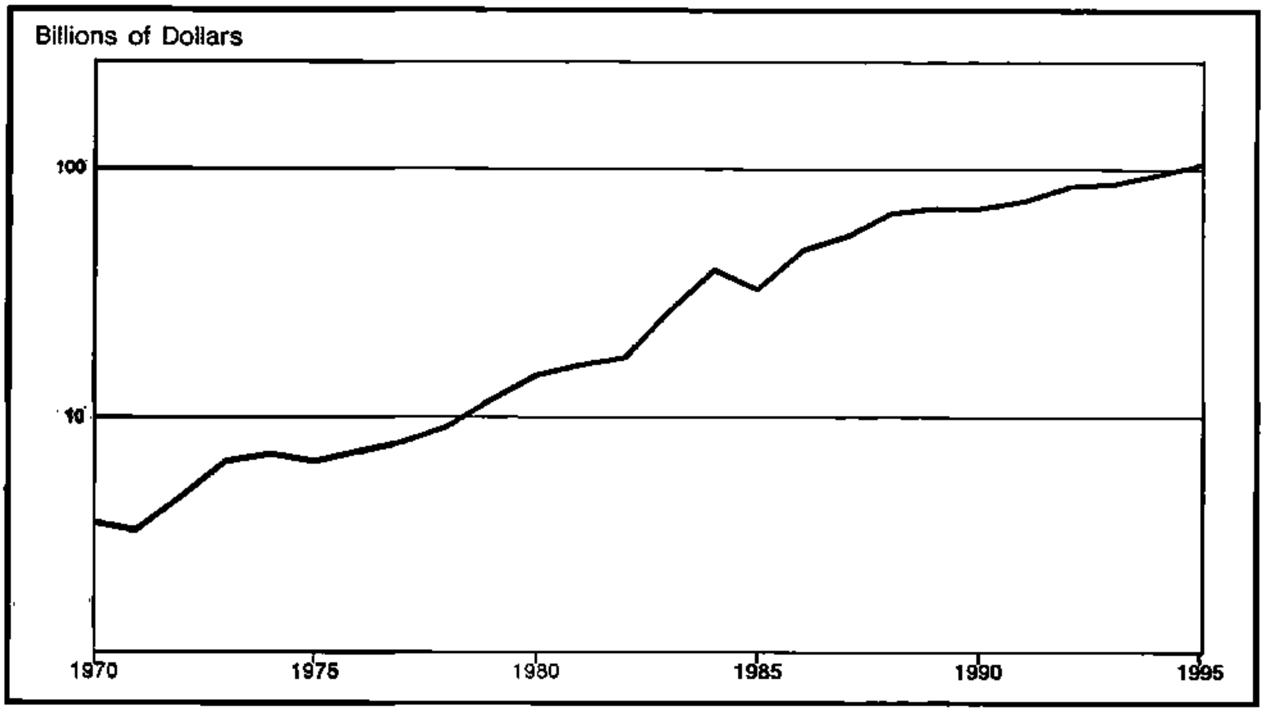
- In the United States, electronic equipment production is approaching 4 percent of GNP. As other industries have reached this rate, they have begun to grow in line with GNP growth rather than at a higher rate. In addition, many U.S. semiconductor and electronic equipment companies are building new manufacturing plants in Europe to capitalize on 1992 and the high growth that is currently being experienced and is expected to continue in that market. We forecast electronic equipment production in North America to grow at a 5.3 percent CAGR from 1990 through 1995.

Figure 1
Worldwide Semiconductor Consumption Quarterly Growth
(Percent Change in Dollars)



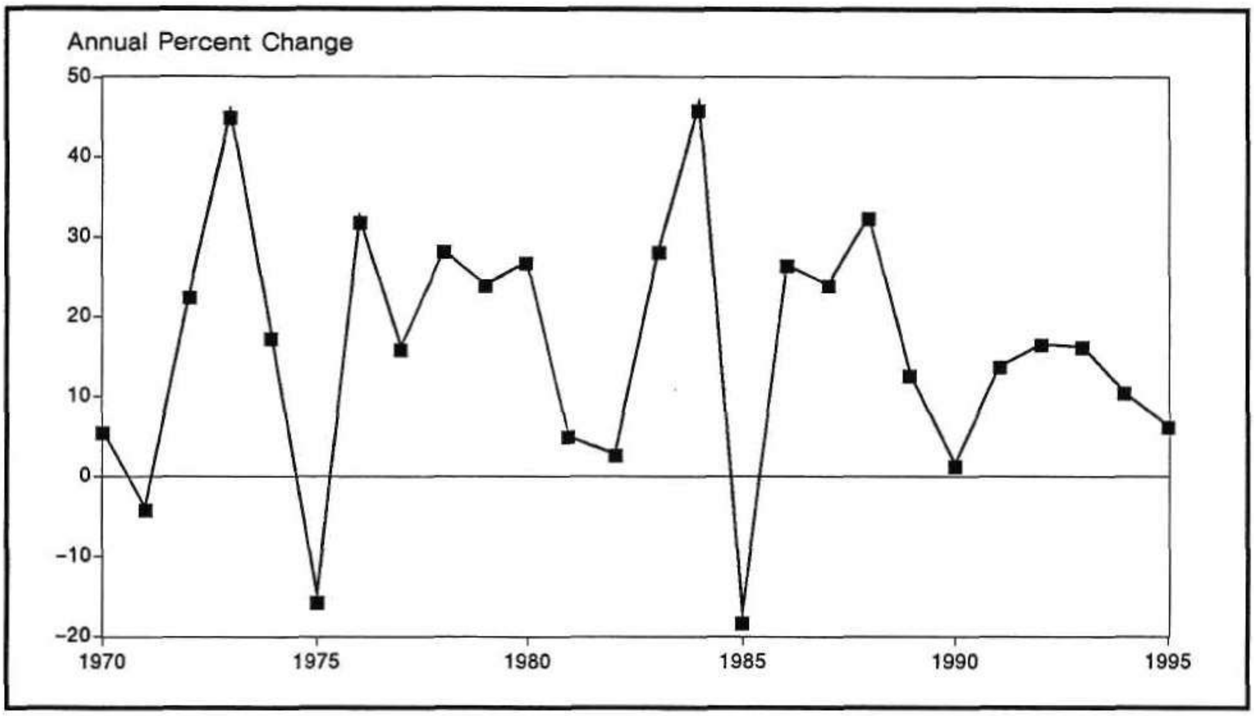
Source: Dataquest (May 1991)

Figure 2
Worldwide Semiconductor Consumption Long-Term Trend
(Factory Revenue in Billions of U.S. Dollars)



Source: Dataquest (May 1991)

Figure 3
Worldwide Semiconductor Consumption Long-Term Trend (Annual Percentage Change)



Source: Dataquest (May 1991)

- In general, most industrialized economies are now growing at a slower rate than in the 1980s. This is particularly true for the United States and Japan, both of which are moving manufacturing operations overseas to Europe and Asia. We forecast Japanese electronic equipment production to grow at a CAGR of 7.3 percent from 1990 through 1995. The biggest areas of activity during this period will be Europe and Asia/Pacific-ROW, with electronic equipment production CAGRs of 9.0 and 12.7 percent, respectively.
- There is no single product visible to us that can fuel the industry in the way that the hand-held calculator and the personal computer did in their early years.
- Improved relationships between semiconductor vendors and users have led to better inventory control by users and better capacity planning by vendors. In the past, poor management of these two variables has led to double and triple ordering and severe overcapacity situations.

The Forecast

Table 3 shows our forecast by region from 1990 through 1995. We expect the next market peak to occur in the 1992-to-1993 time frame, in keeping with historical cyclicality and the traditional market drivers of U.S. presidential elections and the Olympic games. We believe that the market will soften slightly in 1994 and 1995. Throughout the forecast period, we expect Europe and Asia/Pacific-ROW to consistently outperform North America and Japan.

Table 4 shows our worldwide semiconductor forecast by product category. We expect MOS memory and MOS microcomponents to continue to be the fastest-growing product categories. Analog and MOS logic will also do well. (We include mixed-signal analog/digital integrated circuits, a very fast-growing technology, in the Analog category.) We expect bipolar digital memory and logic to continue to decline as this technology is replaced by high-speed CMOS and BiCMOS.

Dataquest Perspective

The semiconductor industry of the 1990s will be different than that of the 1980s. Growth will be more moderate and less cyclical, as the electronics industry in general becomes a large enough component of the world economy to be driven by it, rather than to drive it.

Table 3
Worldwide Semiconductor Consumption by Region (Factory Revenue in Millions of Dollars)

Company:	All	Distribution Channel:	Not meaningful
Product:	Total Semiconductor	Application:	All
Region of Consumption:	Each	Specification:	All

	1990	1991	1992	1993	1994	1995	CAGR (%) 1990-1995
North America	17,386	18,761	21,386	24,810	26,895	28,001	10.0
Percent Change	-3.1	7.9	14.0	16.0	8.4	4.1	
Japan	22,508	26,354	30,762	34,655	38,200	40,762	12.6
Percent Change	-2.1	17.1	16.7	12.7	10.2	6.7	
Europe	10,661	12,274	14,416	17,313	19,326	20,764	14.3
Percent Change	9.3	15.1	17.5	20.1	11.6	7.4	
Asia/Pacific-ROW	7,670	8,834	10,625	13,025	14,804	16,004	15.8
Percent Change	17.6	15.2	20.3	22.6	13.7	8.1	
Total Worldwide	58,225	66,223	77,189	89,803	99,225	105,531	12.6
Percent Change	1.8	13.7	16.6	16.3	10.5	6.4	

Source: Dataquest (May 1991)

Table 4
Worldwide Semiconductor Consumption by Product Category
(Factory Revenue in Millions of U.S. Dollars)

Company:	All	Distribution Channel:	Not meaningful
Product:	Each	Application:	All
Region of Consumption:	Worldwide	Specification:	All

	1990	1991	1992	1993	1994	1995	CAGR (%) 1990-1995
Total Semiconductor	58,225	66,223	77,189	89,803	99,225	105,531	12.6
Percent Change	1.8	13.7	16.6	16.3	10.5	6.4	
Total IC	47,303	54,103	64,232	75,522	83,934	89,840	13.7
Percent Change	0.8	14.4	18.7	17.6	11.1	7.0	
Bipolar Digital	4,440	4,624	4,679	4,683	4,480	4,256	-0.8
Percent Change	-1.6	4.1	1.2	0.1	-4.3	-5.0	
Bipolar Memory	459	440	434	433	402	375	-4.0
Percent Change	-15.0	-4.1	-1.4	-0.2	-7.2	-6.7	
Bipolar Logic	3,981	4,184	4,245	4,250	4,078	3,881	-0.5
Percent Change	0.3	5.1	1.5	0.1	-4.0	-4.8	
MOS Digital	32,292	37,709	46,294	55,628	62,243	66,906	15.7
Percent Change	-2.2	16.8	22.8	20.2	11.9	7.5	
MOS Memory	13,091	14,974	18,798	23,001	26,078	28,283	16.7
Percent Change	-20.0	14.4	25.5	22.4	13.4	8.5	
MOS Microcomponent	10,068	12,118	14,907	17,917	20,076	21,604	16.5
Percent Change	22.8	20.4	23.0	20.2	12.1	7.6	
MOS Logic	9,133	10,617	12,589	14,710	16,089	17,019	13.3
Percent Change	7.9	16.2	18.6	16.8	9.4	5.8	
Analog	10,571	11,770	13,259	15,211	17,211	18,678	12.1
Percent Change	12.6	11.3	12.7	14.7	13.1	8.5	
Total Discrete	8,235	9,112	9,703	10,721	11,342	11,513	6.9
Percent Change	7.5	10.6	6.5	10.4	5.8	1.5	
Total Optoelectronic	2,687	3,008	3,254	3,560	3,949	4,178	9.2
Percent Change	2.3	11.9	8.2	9.4	10.9	5.8	

Source: Dataquest (May 1991)

Although growth rates will not be as high and as dynamic as in the past, opportunities still exist. The geographic regions of greatest opportunity will be Europe and Asia, driven by growing economies, communications standardization, and both new and reindustrialization. The applications with greatest opportunity will be personal communications, personal data processing equipment (such as laptop and palm-top PCs, personal faxes), workstations, and—particularly in Europe—transportation. ■

By Patricia S. Cox

In Future Issues

The following topic will be featured in a future issue of *Dataquest Perspective*:

- Fab Construction: How Long is Too Long?

The topics covered by SEMMS newsletters are selected for their general interest to SEMMS clients, which include wafer fab equipment suppliers, semiconductor materials companies, and semiconductor device manufacturers. The topics selected indicate the broad range of research that is conducted in the SEMMS group. Clients, however, often have specific information requirements that either go beyond the level of detail contained in the newsletters or beyond the scope of what is normally published in the newsletters. In order to provide complete decision support to our clients, Dataquest has a consulting service available to handle these additional information needs. Please call Stan Bruederle at (408) 437-8272 or Joe Grenier at (408) 437-8206 to discuss your custom requirements.

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Dataquest Perspective

Semiconductor Equipment, Manufacturing, and Materials

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Market Analysis

How Global Are Today's Wafer Fab Equipment Companies?

Advanced processing equipment technology and the ability to serve global customers are two cornerstones on which many wafer fab equipment companies build their business strategy. This newsletter characterizes the global activities of today's wafer fab equipment companies by examining the trends in export revenue for the top 10 equipment suppliers in 1990. These 10 equipment vendors accounted for 47 percent of the $5,813 million 1990 wafer fab equipment market and thus represent a good benchmark with which to compare the activities of the other 140+ wafer fab equipment companies participating in the industry today.

Top 10 Wafer Fab Equipment Company Ranking

Table 1 presents the top 10 company ranking for the 1990 wafer fab equipment market. Only moderate changes in company ranking occurred between 1989 and 1990. Silicon Valley Group and Kokusai entered the 1990 top 10 ranking from their 1989 positions of 11 and 13, respectively. At the same time, ASM Lithography (position 9 in 1989) and Dainippon Screen (position 10 in 1989) moved out of the 1990 top 10 ranking to positions 13 and 11, respectively.

Table 1 also presents the overseas or export revenue as a percentage of total company revenue for each of the companies in the top 10. Export revenue is defined as equipment

Table 1
1990 Worldwide Top 10 Wafer Fab Equipment Company Ranking (Millions of Dollars, Percentage of Dollars)

				Listed in Regional Top 10 Company Ranking			
1990 Rank	Company	Worldwide Revenue	Percent Exports	North America	Japan	Europe	Asia/Pacific-ROW
1	Nikon	542	34	X	X	X	X
2	Applied Materials	462	57	X	X	X	X
3	TEL	343	6		X		X
4	Hitachi	290	14		X		
5	Canon	272	55	X	X	X	X
6	Silicon Valley Group	205	39	X		X	X
7	General Signal	177	23	X			
8	Varian	167	64	X	X		X
9	Anelva	132	21		X		
10	Kokusai Electric	117	25		X		X
	Total Revenue for Top 10	2,706					
	Worldwide Wafer Fab Equipment Market	5,813					
	Percentage Revenue of Top 10	47					
	Total Export Revenues for Top 10 as a Percent of Total Revenue*	35					

*Total export revenue for the top 10 wafer fab equipment companies divided by total worldwide company revenue.
Source: Dataquest (May 1991)

revenue outside of a company's home market. For example, Applied Materials, the largest U.S. equipment company, had total equipment revenue of $462 million in 1990 of which 57 percent, or $262 million, was generated in the regions of Japan, Europe, and Asia/Pacific-Rest of World (ROW). For the top 10 companies as a group, export revenue accounted for 35 percent of total company revenue. It is interesting to note that the export level for the combined revenue of all U.S., Japanese, and European companies in 1990 is 35 percent, the same export percentage as the top 10 equipment vendors. Dataquest believes that the 35 percent export level is a good value by which companies can judge their global presence, because clearly it is characteristic of the top wafer fab equipment companies as well as the industry as a whole.

How Global Are the Top 10 Companies?

The top 10 equipment companies in 1990 can be categorized into two groups: those that achieved a top 10 ranking through a global presence in the equipment industry and hence have a high percentage of export revenue and those that received a top 10 ranking by having a particularly strong position in their home market. Five of the top 10 equipment companies have a global presence in the industry, with export revenue ranging from 35 to 64 percent. Three of these five companies—Applied Materials, Canon, and Nikon—ranked in the top 10 in each of the four major manufacturing regions of the world, while the two other companies—Varian and Silicon Valley Group—were positioned in the top 10 in three of the four major regions of the world.

The remaining five vendors in the 1990 top 10 company ranking only had export revenue ranging from 6 to 25 percent of total equipment sales. Three of these companies—Kokusai, Anelva, and Tokyo Electron (TEL)—ranked in the top 10 in only two regions of the world, while General Signal and Hitachi achieved top 10 ranking in only their home markets of the United States and Japan, respectively.

TEL had the lowest export percentage of any of the top 10 equipment companies in 1990, with only 6 percent of total revenue outside of Japan. It should be noted, however, that our analysis did not include any revenue associated with TEL's joint ventures with Varian. In particular, the Varian/TEL joint venture, established initially through a marketing and distribution agreement in 1988, was formed specifically to market TEL's track, etch, and diffusion products through the Varian organization in the United States and Europe. In 1990, Varian/TEL had equipment revenue of $36 million, which when added to TEL's revenue raises the export percentage of the combined TEL plus Varian/TEL organizations to 15 percent.

Regional Company Export Trends

Figure 1 presents the historical export revenue trends for U.S., Japanese, and European wafer fab equipment companies.

How Global Are European Companies?

The average export level of European companies has been relatively high throughout the 1980s, ranging between 50 and 60 percent of total European company revenue from 1982 to 1990. The majority of European company exports are to the United States. This is because historically the United States has represented a significant market opportunity for European companies whose home market of Europe is considerably smaller in size. The strong cultural and political ties between the United States and Europe have also made doing business in the United States relatively easy for a European company.

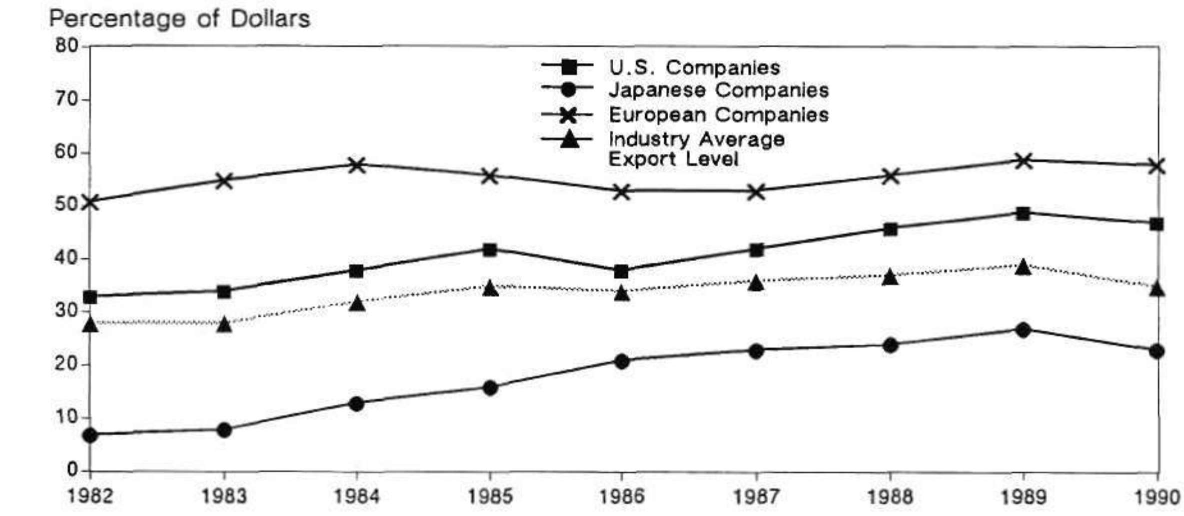
How Global Are U.S. Companies?

Exports by U.S. companies have been steadily increasing throughout the 1980s. In 1982, export revenue accounted for only 33 percent of U.S. wafer fab equipment company revenue. In 1990, this figure had climbed to 47 percent. In the early 1980s, Japan represented the major export market for U.S. companies. For example, U.S. wafer fab equipment sales to Japan in 1982 were 62 percent of total U.S. equipment exports. This level declined throughout the 1980s as the emerging Japanese equipment industry increased its market share in its home market of Japan. By 1990, U.S. wafer fab equipment company sales in Japan accounted for only 43 percent of total U.S. wafer fab equipment exports, but this is higher than the 30 percent level of the 1986 and 1987 time frame. Dataquest believes that the subsequent rise from 30 percent in 1986 and 1987 to 43 percent in 1990 is due in large part to the success of Applied Materials in Japan.

How Global Are Japanese Companies?

One of the major trends that emerged in the 1980s was the steady increase in market share

Figure 1
Export Revenue Trends of Regional Wafer Fab Equipment Companies, 1982-1990 (Percentage of Dollars)



Note: The industry average percent export level is the sum of individual company export revenues of all U.S., Japanese, and European wafer fab equipment companies divided by the sum of total company revenues.

Source: Dataquest (May 1991)

of the Japanese equipment companies. As Figure 1 illustrates, however, Japanese wafer fab equipment companies have an average export level lower than that of their U.S. and European counterparts. What this means is that Japanese equipment company share of the world market has grown primarily because of the tremendous growth of the wafer fab equipment market in Japan. As Figure 1 shows, Japanese equipment company sales outside of Japan accounted for only 7 percent of total revenue in 1982, but by 1990, the average export level had increased to 23 percent of total Japanese wafer fab company equipment sales. Dataquest believes that this increase can be attributed to several factors. In several key areas of process technology, such as steppers, Japanese companies command dominant share of the world market. In addition, Japanese companies have gained a broader visibility in the semiconductor industry as semiconductor manufacturers have globalized their operations.

Dataquest Perspective

How important is it for a wafer fab equipment company to have a global presence in the industry? One might argue that several companies have attained positions in the top 10 wafer fab equipment ranking by only being dominant in their home markets, which may be a successful short-term strategy for some companies. Dataquest believes, however, that long-term success in the wafer fab equipment industry is tied to establishing a balanced presence throughout the world. Many semiconductor manufacturers are globalizing their manufacturing operations while reducing their number of qualified vendors. This means that an equipment company may not get the order unless it can support its customers in every region that the company has a fab. In addition, an equipment company that ties its success to only one or two regions of the world considerably reduces its total available market.

Several pathways to expanding international presence exist in the wafer fab equipment industry. For larger companies such as Applied Materials, the strategy has been to establish large technology development and service/support organizations in key places throughout the world. Other companies such as Eaton, Varian, BTU International, Tokyo Electron, and Ulvac have established joint venture companies with partners in other regions of the world. Many equipment companies have set up their own offices in foreign markets, while others rely on representatives and distributors to increase their presence overseas. Regardless of which approach is employed, "go global" should be a rallying cry for wafer fab equipment companies in the 1990s. ■

By Peggy Marie Wood

Semiconductor Materials: Bulk Gas Revenue Stalls

The consumption of bulk gases (nitrogen, hydrogen, oxygen, and argon) used in North American semiconductor plants totaled $209.3 million in 1990 (see Figure 1). Revenue grew a mere 2.7 percent and volumes only 4.2 percent compared with 1989 levels. Both measures lagged well behind 1990 silicon wafer consumption, which grew 10.7 percent on a square-inch basis.

Product Trends

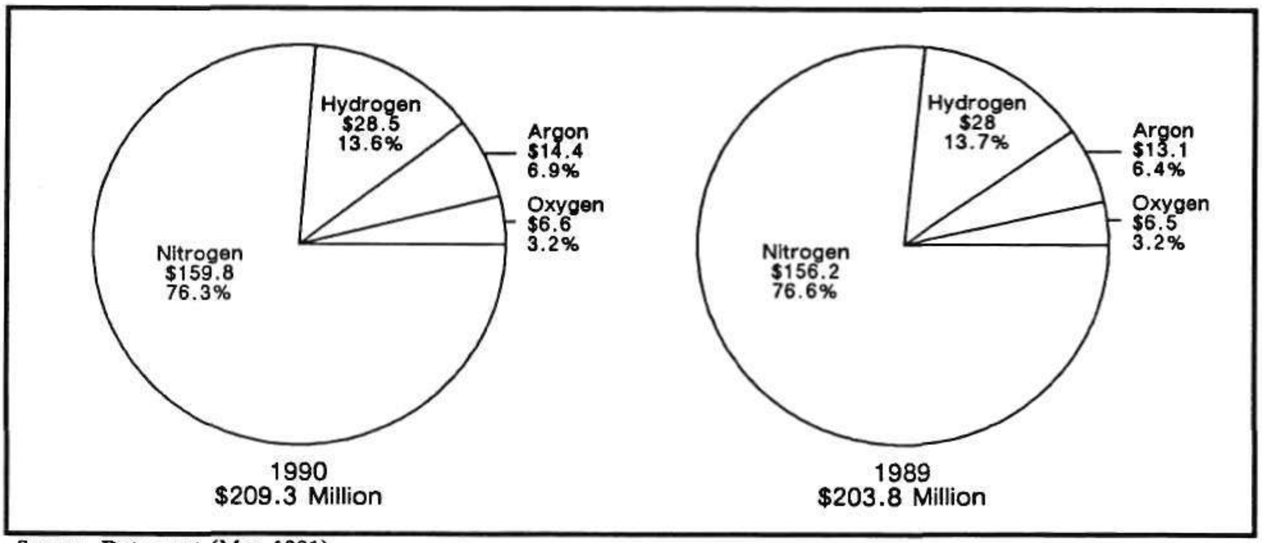
Nitrogen sales were by far the largest segment of industrial gas sales to the semiconductor industry. Nitrogen revenue totaled $159.8 million or 67.9 billion cubic feet (bcf) in 1990 (see Figure 2). Liquid nitrogen sales accounted for 60.6 percent of total (liquid, on-site, and pipeline) nitrogen revenue. Liquid nitrogen also suffered the largest price erosion. The average selling prices of liquid nitrogen fell 2 cents per hundred cubic feet (hcf), a decrease of 5.6 percent, squeezing what is already a very tight margin on this product. Volumes increased 7.3 percent in 1990.

On-site nitrogen sales pushed ahead in 1990, increasing 6.7 percent on a volume basis and 8.5 percent on a revenue basis. On-site is the lowest cost source of nitrogen, but it can only be justified for large-volume users because of the large capital cost associated with placing a nitrogen generator at a fab. On-site nitrogen is a bright spot as it is expected to benefit from the trend toward building larger fabs.

The health of the bulk gas industry in terms of semiconductor applications swings on one product—nitrogen.

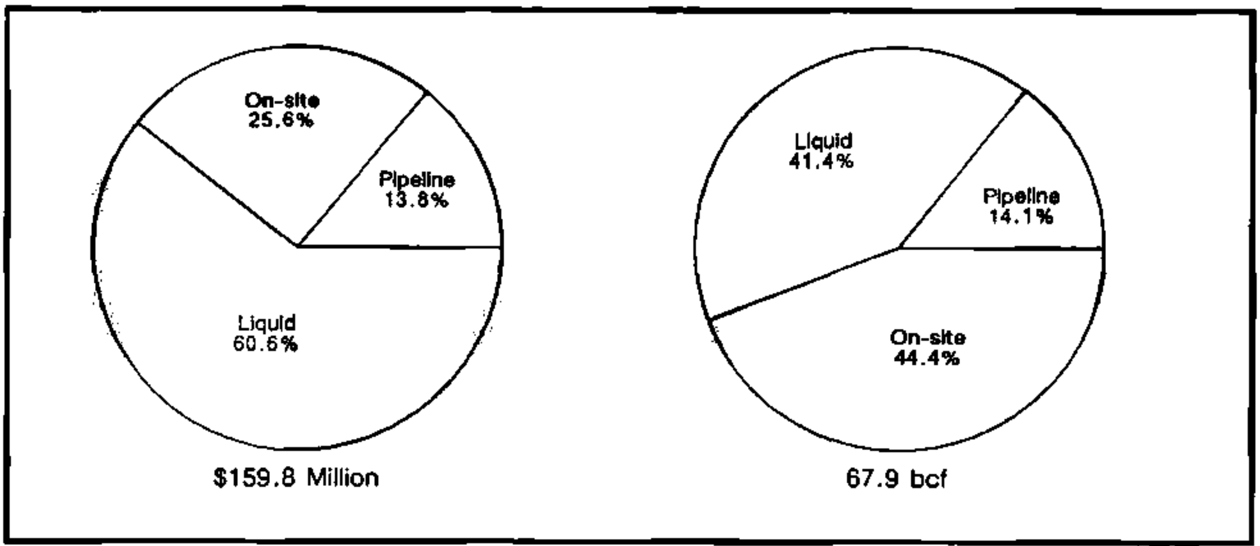
Pipeline nitrogen revenue totaling $22.1 million in 1990 was down 8.9 percent from 1989. Volumes fell (see Table 1) because of weak demand in the Northern California market, which has the largest pipeline network. Several large Silicon Valley fabs curtailed operations in 1990. Prices for pipeline nitrogen remained firm because there is little direct competition.

Figure 1
U.S. Bulk Gas Market—Semiconductor Applications (Millions of Dollars)



Source: Dataquest (May 1991)

Figure 2
1990 North American Nitrogen Market—Semiconductor Applications
(Percentage of Market)



Source: Dataquest (May 1991)

Table 1
North American Bulk Gas Market Volume and Average Selling Prices

	Volume Trend (bcf)		Average Selling Price ($1 per bcf)	
Bulk Gas Category	**1990**	**1989**	**1990**	**1989**
Nitrogen				
On-site	30.2	28.3	0.14	0.13
Pipeline	9.6	10.5	0.23	0.23
Liquid	28.1	26.2	0.34	0.36
Hydrogen	1.93	1.98	1.48	1.42
Oxygen	0.71	0.71	0.92	0.92
Argon	0.53	0.49	2.74	2.67

Source: Dataquest (May 1991)

Hydrogen revenue, which at $28.5 million accounts for the second-largest segment of the semiconductor bulk gas market, was flat in 1990. Consumption on a volume basis actually decreased 2.6 percent from the previous year; however, prices increased 4.2 percent, stemming any revenue erosion.

Argon sales totaled $14.4 million in 1990, and oxygen sales totaled $6.6 million. Argon volumes increased 8.2 percent, and prices edged up 2.6 percent over 1989 levels. Oxygen volumes and prices were flat.

Market Share

Bulk gas contracts are typically long term. An agreement will run anywhere from 5 to 15 years depending on if it is a liquid, pipeline, or on-site contract. For this reason, there are only incremental shifts in annual market shares. Indeed, 1990 market share data support this claim (see Table 2). No company's share changed more than a few percentage points.

Air Products' North American market share fell 2.4 percent. The slight erosion was attributable

Table 2
Bulk Gas Market—Semiconductor Applications (Millions of Dollars)

Company	Bulk Revenue	1990 Share (%)	1989 Share (%)
Airco	29.2	13.9	12.7
Air Products	94.7	45.2	47.6
Liquid Air	23.7	11.3	11.3
UCC, Linde	55.9	26.7	25.6
Others	5.8	2.8	2.8
Total	209.3	100.0	100.0

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (May 1991)

to a weak Northern California market, which it dominates due to the company's extensive pipeline network in Silicon Valley. On the other hand, Air Products' large pipeline operations also explain its unrivaled North American market share, 45.2 percent in 1990.

However, Dataquest expects this market share to be vulnerable over the long term because most of the new fabs being built in North America will be located outside of areas served by its pipelines. The alternative, on-site or liquid delivery, is not expected to provide any clear advantage for Air Products over the other three major competitors.

Both Linde's and Airco's North American market share edged up in 1990. Linde, the industrial gas division of Union Carbide, increased its market share 1.1 percent to a total of 26.7 percent. Market share for Airco totaled 13.9 percent, an increase of 1.2 percent. Liquid Air's business grew at the same rate as the overall market, resulting in no change of its market share, 11.3 percent in 1990.

Industry Trends

The health of the bulk gas industry in terms of semiconductor applications swings on one product—nitrogen. Currently, there is an excess capacity of nitrogen in North America, which has resulted in very competitive pricing, especially for liquid nitrogen. The price of liquid nitrogen has fallen well below the replacement cost of air separation plants. This trend has put a brake on any new plant capacity.

Although there are no new air separation plants being built, the near-term horizon for working off the excess liquid nitrogen capacity looks bleak for two reasons. First, the growth rate of the industrial sector of the North American economy is slowing. The Dun & Bradstreet Corporation estimates that the industrial sector will grow 2.5 percent through the 1990s.

Second, on-site nitrogen generation is cannibalizing liquid nitrogen sales. The conversion from liquid to on-site nitrogen is occurring among large-volume users. In addition, new technology threatens to make it more cost-effective for low-volume users to convert to on-site generation as well. If this technology is widely adopted, plant loading will suffer and margins on liquid nitrogen, already razor thin, are expected to fall further.

As the semiconductor industry moves to the submicron level, the investment in leading-edge gas technology is only getting steeper.

The profitability of semiconductor accounts is also affected by the fact that the four major industrial gas vendors operating in the North American market view the semiconductor industry as strategic. Their focus intensifies the competition for new business.

Although the competition for semiconductor business is stiff, the semiconductor industry is a relatively small segment of the overall industrial gas market. In 1990, bulk gas sales to the semiconductor industry represented less than 10 percent of the total North American bulk gas market. Dataquest estimates that even for Air Products, the market share leader, the semiconductor industry contributed less than 15 percent of its total North American gas revenue.

Dataquest Perspective

As the semiconductor industry moves to the submicron level, the investment in leading-edge gas technology is only getting steeper. The small size of the semiconductor gas market coupled with its thin returns raises the question as to whether or not all four vendors can maintain a leadership position.

Although the investment hurdle is rising, Dataquest believes that all four of the North American vendors will stay the course. These companies are all billion-dollar-plus multinational corporations, and their participation in the global semiconductor market is a better measure of their ability to serve the semiconductor industry than any regional statistic. Viewed on a global basis, no one company stands out above the other major vendors.

Dataquest sees little relief for gas vendors from thin operating margins and competitive pricing pressures.

It is also difficult for industrial gas companies to distinguish themselves based on technology. Innovation in semiconductor gas technology typically originates from small companies that sell the technology to all the major industrial gas companies. As a result, technology spreads very quickly among the major companies, providing very little opportunity for companies to differentiate themselves.

Looking back over the last five years, the industrial gas vendors have made tremendous strides in providing higher-purity products to the semiconductor industry. Leading-edge purity specifications have moved from the range of 10 parts per million to 10 parts per billion. These specifications were achieved by purifier, piping, valve, and regulator manufacturers. Very little of this technology originated in the labs of industrial gas companies.

Dataquest sees little relief for gas vendors from thin operating margins and competitive pricing pressures. Successful companies will identify regional opportunities early, increase the service content of their business, work closely with small technology companies, and keep their operating costs low. In short, management at industrial gas companies will have to be very good, because there is little room to stumble. ■

By Mark FitzGerald

Company Analysis

Motorola's Semiconductor Manufacturing Strategy

Summary

Motorola recently held a briefing in Austin, Texas, to communicate its vision for the future. The briefing was attended by more than 100 market analysts and technologists from around the world. This article highlights some of the key messages Motorola delivered throughout the event that are of significance to our Semiconductor Equipment, Manufacturing, and Materials service clients.

MOS 11

Motorola dedicated its MOS 11 fab in Austin, Texas, on April 22, 1991. MOS 11 is the first noncaptive 8-inch fab built in the United States. Motorola invested $650 million in this fab, stating that 87 percent of tool dollars went to U.S. equipment companies, and 97 percent of building dollars went to U.S. companies. The fab has 70,000 square feet of Class 1 clean room space and was designed to eventually handle 0.35-micron CMOS and BiCMOS processing of microprocessors and FSRAMs. Volume production of the first FSRAMs is expected near the end of 1992.

GaAs Investment

Motorola stated plans to invest $100 million in a GaAs fab located in Tempe, Arizona. The fab has 42,000 square feet of Class 10 clean room space and will employ 250 people when fully operational. Construction started in January 1991 and is expected to be completed by June. The construction project consists of upgrading an existing building located on Motorola's corporate research laboratories campus. This GaAs investment is the largest made by a U.S. semiconductor manufacturer, which exemplifies Motorola's commitment to the GaAs market.

The team to operate this fab includes people with silicon manufacturing expertise obtained at various existing Motorola fabs, GaAs processing expertise obtained at Motorola's corporate lab, and GaAs design and test expertise obtained at Motorola's equipment divisions.

First product sampling is expected in January 1992. Targeted products for this fab include monolithic microwave ICs, RFICs (0.5 to 3 GHz), RF power modules, and dense digital ICs. Motorola believes that GaAs technology is well suited for products that require high-frequency, low-power dissipation and a high level of integration. These devices will support Motorola's personal communications product line.

The Past Two Years

James Norling, president and general manager of Motorola's Semiconductor Products Sector, discussed some of the accomplishments that the products sector has made over the past two years. These accomplishments are significant and include a 43 percent reduction in process scrap coupled with a 28 percent improvement in cycle time. These two accomplishments alone accounted for a $70 million cost savings in 1990. Other accomplishments included Motorola being established as a leader in high-performance CMOS, a tenfold improvement in quality, and participation in an X-ray lithography program with IBM. Motorola has also had several strategic design wins in Japan, including Toyota's next-generation engine controller.

Toward the Perfect Factory

Dr. Hector Ruiz, senior vice president and director of Sector Technology, gave a presentation entitled "Toward the Perfect Factory." Dr. Ruiz discussed several "perfect factory specifications" that include the following:

- Standardized construction, facilities, processing, CIM/CAM
- Automated, computer-controlled
- Chip-design capability
- Combinational technologies
- Flexibility
- Single-wafer processing
- Real-time processing

Dr. Ruiz believes that the perfect factory will be built on a foundation that incorporates a rich technology base and a global infrastructure. The design methodology for this factory will focus on ensuring that there are zero known non-value-added steps. Motorola plans to accomplish this through six-sigma planning and modeling. The most important aspect of the perfect factory is a 10-day cycle time for fabrication, assembly, and test. Today, fabrication cycle times alone range from 30 to 45 days.

Dataquest Perspective

Motorola is number four in Dataquest's 1990 worldwide semiconductor market share rankings, reflecting Motorola's commitment to excellence. Motorola's commitment is exemplified by its ability to earn the first annual Malcolm Baldridge National Quality Award. Also, for the third consecutive year, Motorola earned the Dataquest Major Supplier-of-the-Year Award. Criteria for this award consist of performance in on-time delivery, quality, price, technical support, and customer service. Dataquest believes that programs such as Motorola's six-sigma plan have played a key role in obtaining these awards. We also believe that Motorola has a comprehensive semiconductor strategy to carry it forward through the 1990s. ■

By Jeff Seerley

A Quick Look at Micron Technology

This article provides a quick look at Micron Technology's semiconductor capital spending, R&D spending, capacity by line geometry, planned facilities, and recent company highlights as related to semiconductor manufacturing. It is part of the "Quick Look" series of articles from Dataquest's Semiconductor Equipment, Manufacturing, and Materials service.

Semiconductor Capital Spending and R&D Spending

Figure 1 illustrates Micron Technology's semiconductor capital spending and R&D spending as a percentage of semiconductor revenue by year from 1982 through 1990.

Manufacturing Facilities

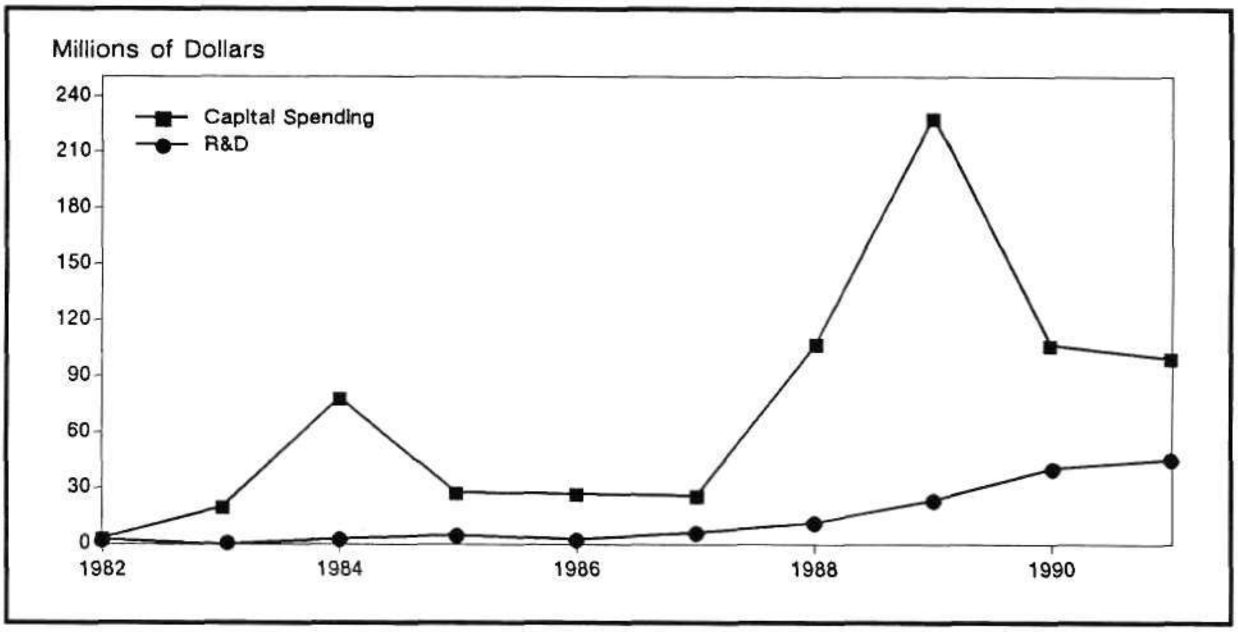
Table 1 shows additions to Micron's facilities in 1991. Figure 2 illustrates the percentage distribution of the company's existing worldwide semiconductor capacity by line geometries.

Company Highlights

The following discussion highlights significant events for Micron Technology.

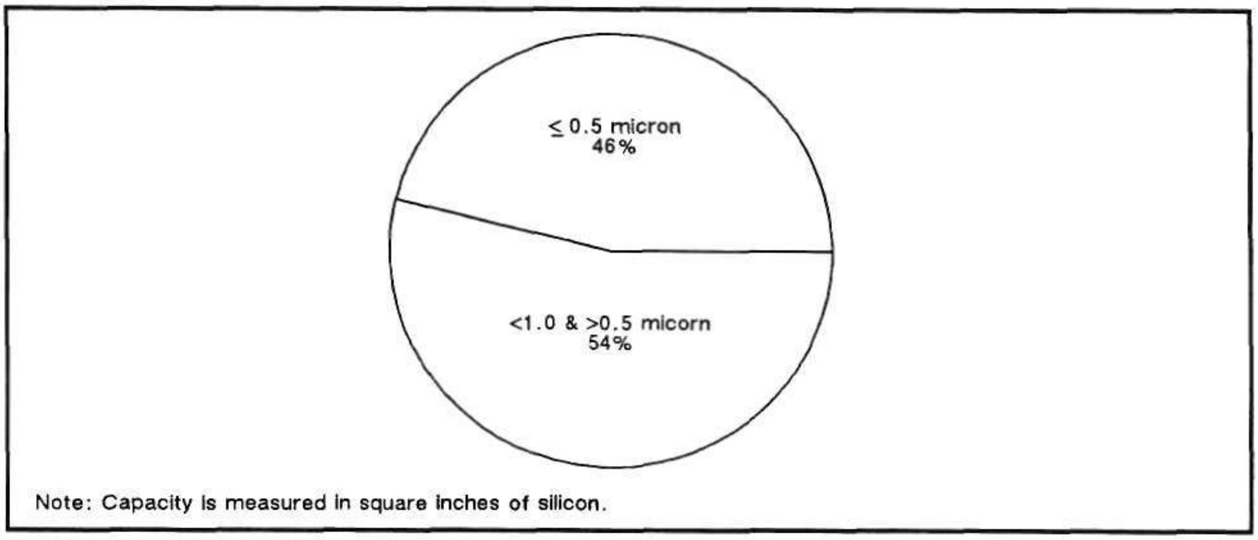
- Micron's newest fabrication facility, Fab III, is a sub-Class 1, highly automated 177,406-square-foot fab containing an assembly facility (Assembly II) and a process R&D line (PD1). Construction took only one year. Micron ramped up production in 1990 and plans to continue the ramp-up in 1991.

Figure 1
Micron Technology—Semiconductor Capital Spending and R&D Spending by Year



Source: Dataquest (May 1991)

Figure 2
Micron Technology—Existing Capacity by Line Geometry



Source: Dataquest (May 1991)

Table 1
Micron Technology—Recent and Planned Facilities, 1990-1991

Location	Product	Wafer Size	Year
Boise, ID	118,200 sq. ft. assembly facility	-	1990
Boise, ID	146,000 sq. ft. test facility	-	1991
Boise, ID (Fab I/II)	Upgrade: 5- to 6-inch wafers	6-inch	1991

Source: Micron Technology

- Micron Technology did its own project/construction management on Fab III and formed a wholly owned subsidiary, Micron Construction Inc., in October 1990. Micron Construction will do construction management and design/project management for companies outside Micron.
- Micron has already completed the second shrink of its 1Mb DRAM and will begin production on a third shrink in 1991. The die shrinks have increased die per wafer by 100 percent for 1Mb DRAMs and by 56 percent for 4Mb DRAMs. The Shrinks on VRAMs and SRAMs have achieved similar successes.
- Micron has announced no new fab plans at the present. The Company states that it plans to increase capacity through manufacturing efficiencies that include greater wafer throughput, shorter cycle times, increased line yields, and aggressive die shrinks on virtually all products.
- In 1990, Micron opened a state-of-the-art surface-mount assembly operation in Boise, Idaho.
- Also in 1990, Micron began shipping 300-mil SOJ 4Mb DRAMs and 25ns fast 1Mb SRAMs.
- In 1991, the company plans to introduce PQFP packaging for the Cache Data SRAM. ■

By George Burns

Semiconductor Manufacturing

Investing in Tomorrow: Steady Growth for U.S. Semiconductor R&D

Introduction

Dataquest has just completed its analysis of U.S. merchant semiconductor company-funded R&D spending. This article highlights the results of that analysis for U.S. merchant semiconductor companies and presents estimates for U.S. captive R&D spending.

In comparing the yearly rate of change of U.S. merchant R&D spending with the yearly rate of change of U.S. merchant capital spending, one feature stands out—the rate of change of R&D spending is much more stable than that of capital spending. The reasons for R&D spending stability go right to the heart of the developmental process and the nature of competition in the semiconductor industry. This article examines the reasons for relative stability in the growth of R&D spending.

Semiconductor R&D Spending

Semiconductor R&D spending for U.S. merchant and captive semiconductor companies rose 13 percent to $3.7 billion in 1990 (see Table 1). This total includes only company-funded spending and does not include R&D funding from noncompany sources.

Time to market and technology are at the heart of today's industry, and they come together in the R&D process.

Total spending for U.S. merchant and captive R&D represented 14 percent of revenue in 1990 (see Table 2). In comparison, U.S. merchant and captive capital spending in 1990 was $4.3 billion and 17 percent of revenue. Dataquest expects U.S. merchant and captive R&D expenditures to increase by 11 percent in 1991 to $4 billion.

Table 1
U.S. Semiconductor R&D Expenditures (Millions of Dollars)

Company	1989	1990	1991
Advanced Micro Devices	202	204	215
Altera	9	11	15
Analog Devices	64	73	77
California Micro Devices	3	3	3
Chips & Technologies	39	49	55
Cypress	48	55	69
Harris	65	76	75
IDT	38	44	49
IMP	12	13	14
Intel	365	465	585
LSI Logic	42	60	75
Linear Technology	7	9	11
Micron Technology	24	41	46
Motorola	289	330	363
National Semiconductor	250	251	200
SEEQ Technology	9	9	8
Siliconix	19	17	19
Texas Instruments	327	357	364
VLSI Technology	46	54	60
Xicor	13	20	16
Others	647	746	809
Total Merchant	2,520	2,883	3,126
Percent Change	11	14	8
Captive Companies	706	785	852
Percent Change	13	11	8
Total Merchant and Captive	3,226	3,668	3,978
Percent Change	12	14	8

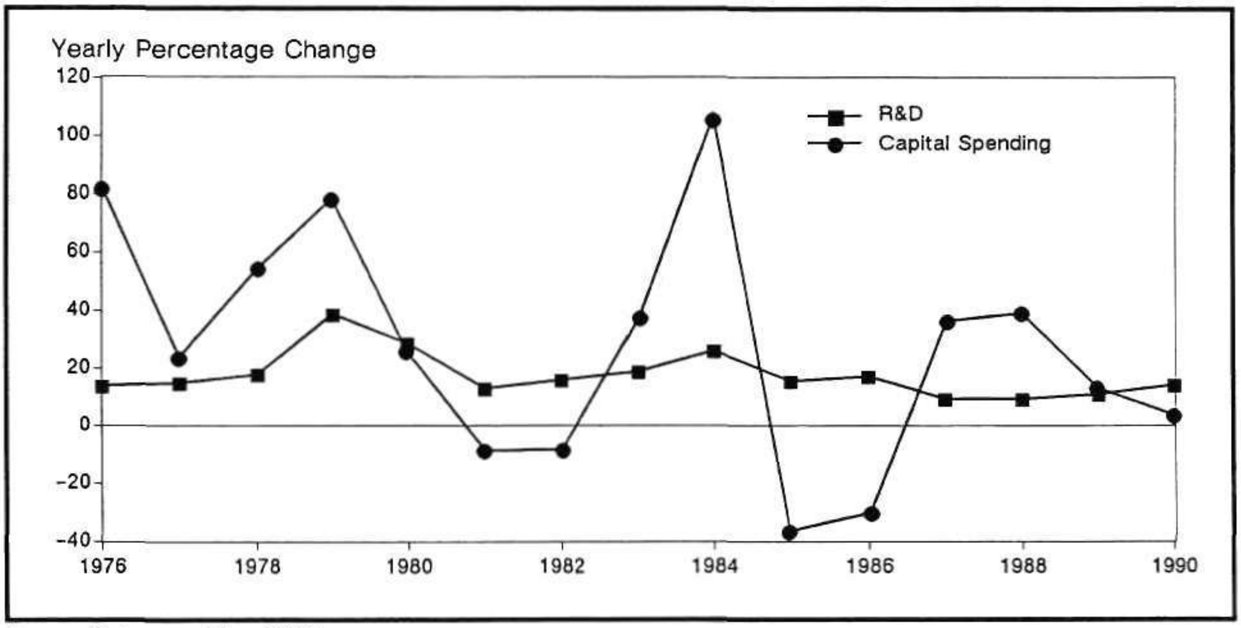
Source: Dataquest (May 1991)

Table 2
U.S. Semiconductor R&D Expenditures (Percentage of Revenue)

	1989	1990		1989	1990
Advanced Micro Devices	19	19	Micron Technology	6	14
Altera	16	13	Motorola	9	9
Analog Devices	18	19	National Semiconductor	15	15
California Micro Devices	11	10	SEEQ Technology	18	17
Chips & Technologies	16	19	Siliconix	16	14
Cypress	24	25	Texas Instruments	12	14
Harris	8	10	VLSI Technology	16	17
IDT	18	21	Xicor	14	20
IMP	23	23	Others	12	14
Intel	15	15	Total Merchant	13	14
LSI Logic	8	10	Captive Companies	17	17
Linear Technology	10	11	Total Merchant and Captive	13	14

Source: Dataquest (May 1991)

Figure 1
U.S. Merchant Semiconductor R&D and Capital Spending: Yearly Percent Change



Source: Dataquest (May 1991)

Of the merchant semiconductor companies' company-funded expenditures, we estimate that Intel spent more than any other company in 1990: $465 million. Intel was followed by Texas Instruments with $357 million and Motorola with $330 million. The top five U.S. merchants (Motorola, Texas Instruments, Intel, National Semiconductor, and Advanced Micro Devices) accounted for 56 percent of U.S. merchant company-funded R&D spending in 1990.

R&D goals typically were new product and process development. Process development goals included working with sub-0.5-micron processes, experimentation with processing on larger-size wafers, and shortening the developmental process.

R&D: The Seed Corn of Our Industry

A striking characteristic of R&D spending is the stability of its rate of change. This is especially evident when yearly changes in R&D are compared with yearly percentage changes in capital spending (see Figure 1). In the 1980s, there were four years when U.S. merchant semiconductor capital spending actually declined from the previous year. The dollar amount of merchant semiconductor R&D spending, by contrast, has increased every year since 1975.

Because R&D spending is the seed corn from which future products (and profits) will be harvested, it is very unlikely that aggregate R&D spending will decline in the foreseeable future.

The reason for this difference is simple: Capital expenditure can be deferred in times of uncertainty or during a downturn; if properly timed, deferring capital spending only results in a loss of excess capacity, not market share. On the other hand, when a company defers its R&D expenditure, it runs the risk of falling behind its competitors in the technology race. R&D is programmatic; semiconductor companies plan to develop new products, new technologies, and new processes in a predictable and controllable fashion.

New technologies, processes, and products are the "seed corn" from which a company's future will be harvested. An interruption in the growth of a company's developmental program will lengthen its developmental cycles for new technologies, processes, and products.

Lengthened developmental cycles will in turn lengthen the time it takes a company to get a product to market. Time to market is a crucial competitive advantage; those companies that are slower getting product to market are at a competitive disadvantage. Companies that get to market first establish credibility in their customers' minds and gain invaluable learning-curve advantages over companies that arrive later into the market. This is especially true in high-volume, commodity markets such as DRAMs.

A company that has introduced a product first is usually farther down on the cost curve, because it has produced more units and learned from that production experience. A company that is first to market is also farther down on the quality curve; that is, with more volume and learning, a company has better control over its process parameters and, therefore, is likely to have lower defect densities and higher quality than its competitors.

Dataquest Perspective

Because R&D spending is the seed corn from which future products (and profits) will be harvested, it is very unlikely that aggregate R&D spending will decline in the foreseeable future. It is also highly likely that the relative stability of R&D spending compared with capital spending will continue.

Time to market and technology are at the heart of today's industry, and they come together in the R&D process. R&D is crucial to both the giant, established semiconductor manufacturer and the little start-up looking for credibility and a technological edge.

Because it is so crucial, Dataquest believes that it is possible, indeed likely, that the R&D intensity of the industry will increase. The increasing complexity of both device and process, and the competitive nature of the industry, will drive companies to spend a larger percentage of revenue on R&D. ■

By George Burns

Conferences and Exhibitions

Dataquest's 10th Annual SEMICON/West Seminar

As a reminder, the 10th annual SEMICON/West seminar sponsored by Dataquest's Semiconductor Equipment, Manufacturing, and Materials service will be held on May 22, 1991. This seminar will focus on trends affecting the semiconductor equipment and materials industry.

The title and theme of this year's seminar is Status 1991. Attendees will hear Dataquest speakers provide a report on the electronic equipment, semiconductor, and semiconductor equipment and materials industries. The presentations will stimulate thought-provoking questions in each of these areas. The topics to be discussed are listed as follows:

- An overview of the worldwide electronic equipment industry (Ultimately, the demand for semiconductor equipment and materials is derived from electronic equipment demand.)
  - What is the forecast for electronic equipment demand, and what are the key electronic equipment segments that are driving semiconductor demand?
- Semiconductor industry overview and forecast, ASIC trends, and how ASIC manufacturing impacts semiconductor equipment manufacturers
- Key issues relating to semiconductor devices, including DRAM pricing and capacity and market trends in microprocessors and ASICs
  - Where are we in the DRAM product life cycles?
  - What is the worldwide semiconductor forecast?
- Microprocessor, ASIC, and DRAM processing strategies
  - What is the impact of these advanced devices on semiconductor manufacturing, and how will advanced semiconductor processing affect wafer fab equipment and materials?

- Characteristics of IC production fabs by parameters such as capacity, wafer size, and linewidth capability and how these characteristics affect capital spending and the wafer fab equipment and materials markets
- Trends in the semiconductor materials industry
  - What is happening in the key materials segments, and what are the pricing pressures facing the materials vendors?
- Trends in the wafer fab equipment industry
  - What is the status of the worldwide wafer fab equipment industry, and where are the areas of opportunity?

Table 1 shows Dataquest's 1991 Conference Schedule. For reservations or for further information call London, 895-835050; San Jose, (408) 437-8245; Tokyo, 3-5566-0411.

We look forward to seeing you at the seminar. ■

By Jeff Seerley

Table 1
1991 Dataquest Conference Schedule

Topic	Date	Location
North America		
SEMICON/West	May 22	Redwood City
Computer Storage	June 19-20	San Jose
Document Management	June 27-28	San Francisco
Personal & Wireless Communications	August 12-13	Monterey
Portable Computing	September 11-12	San Jose
Semiconductor	October 14-15	Monterey
Europe		
Semiconductor	May 29-31	Marbella
Printer	June 11-12	Amsterdam
Colour Market	June 12-13	Amsterdam
Copying & Duplicating	June 13-14	Amsterdam
Telecommunications	November 7-8	London
Japan and Asia		
Computer & Telecommunications	June 25-26	Tokyo
Strategic Industry	September 24-25	Taipei
Peripherals	October 1-3	Tokyo

Source: Dataquest (May 1991)

In Future Issues

The following topics will be featured in future issues of the *Dataquest Perspective:*

- Specialty gas market analysis for North American Wafer inspection
- U.S. regional capital spending, including Japanese manufacturers in the United States

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Dataquest Perspective

Semiconductor Equipment, Manufacturing, and Materials

Vol. 0, No. 2 **April 29, 1991**

0010221

Market Analysis

Flat FZ Wafer Market

The worldwide demand for float zone (FZ) silicon wafers is estimated to grow at less than a 5 percent annual compound growth rate (CAGR) during the next five years. High-power discrete devices, which currently account for the bulk of the FZ wafer demand, are expected to to grow more slowly than the total power discrete market. In addition, the development of improved-quality thick films is allowing many of the higher-power transistors to move away from FZ to epitaxial films, eroding the growth opportunities for FZ wafers in this segment. Low- to medium-power discretes, which make up the bulk of the discrete device unit sales, generally use epitaxial films, which are more cost-effective.

Market Trends

Power discrete devices fall into three general categories—thyristors, power diodes, and power transistors. Dataquest estimates that these product segments had worldwide revenue of $617 million, $1,340 million, and $2,360 million, respectively, in 1990 (see Table 1). Power diodes make up the largest unit volume with an estimated 12.6 billion sold in 1990; power transistors accounted for 4.9 billion units and thyristors for 1.2 billion units (see Table 2). About 80 percent of the power transistors currently produced are bipolar, although the MOS market is starting to develop.

Although total power discrete revenue is expected to have a 10.5 percent CAGR during the next five years, the revenue trend masks the true growth potential for FZ wafers. FZ wafers are sold into the high-power discrete applications. The high-power segment is a small subset of the power discrete market, accounting for only 1.96 billion units or 10.5 percent of the total power discrete unit consumption in 1990 (see Table 2).

Moreover, the growth opportunity in each of the three device categories is in the low- to medium-power device segment. Low- to medium-power devices are typically used in a broad range of consumer electronic equipment such as hair dryers and televisions. High-power devices are typically used in more durable products such as automobiles, motor controls, and elevators. Dataquest estimates that the high-power device revenue will grow at only a 5 to 7 percent CAGR during the next five years versus the low- to medium-power segment, which is estimated to grow at a 10 to 12 percent CAGR. The difference in growth rates reflects the end-use applications into which these devices are being sold.

Table 1
Estimated Worldwide Consumption of Power Discrete Devices (Millions of Dollars)

Device	1990	1991	1992	1993	1994	1995	CAGR (%) 1990-1995
Thyristors	617	671	725	774	811	821	5.9
Power Diodes	1,340	1,508	1,700	1,900	2,022	2,097	9.4
Power Transistors	2,360	2,700	3,140	3,625	4,000	4,185	12.1
Total	4,317	4,879	5,565	6,299	6,833	7,103	10.5

Source: Dataquest (April 1991)

Table 2
1990 Worldwide Unit Consumption of Power Discrete Devices (Billions of Units)

Device	Total	Low to Medium	High	Percentage High (%)
Thyristors	1.20	1.04	0.16	13.3
Power Diodes	12.6	11.26	1.34	10.6
Power Transistors	4.9	4.44	0.46	9.4
Total	18.7	16.74	1.96	10.5

Source: Dataquest (April 1991)

Production Trends

High-power thyristors and diodes are fabricated almost exclusively from high-resistivity FZ wafers using a double-sided diffusion process to provide the semiconductor junction. With these devices, voltage is applied between the front and back sides of a wafer, and the current flows through the wafer using metal electrodes placed on both sides. Relatively thin doped FZ wafers are used; the overall processing is very straightforward compared with planar devices. Czochralski (CZ) wafers cannot be used, mainly because of the problems in obtaining a high-quality, high-resistivity wafer.

The fabrication process for high-power (planar) transistors on an FZ wafer is fairly complex and involves an initial long (deep) two-sided diffusion step. One side is then ground back to the high-resistivity material and polished prior to carrying out the further diffusion steps needed to form the transistor. In order to leave the fabricated wafer with a manageable thickness, especially for the larger diameters, the starting wafer has to be relatively thick. Long diffusion times are needed to get a low-resistivity diffusion layer with the required thickness.

The alternative fabrication method is more straightforward. An epitaxial film is deposited onto a doped CZ wafer and the transistor fabricated in the film. A lengthy diffusion step is eliminated and relatively thin starting wafers, which are readily available in large CZ wafer diameters, can be used. The difficulty with this process is getting a thick, good-quality epitaxial film onto which reliable higher-powered transistors can be fabricated. To date, most device manufacturers have stayed with the FZ despite the complex processing involved.

Dataquest expects this situation to change during the next five years as more reliable thick films are developed to be used for emerging bipolar and MOSFET applications. There is a definite move toward the use of epitaxial films for the emerging higher-performance transistor, and it is generally believed that most of the new power devices will use epitaxial films rather than FZ wafers.

Dataquest Perspective

Because of product mix and a relative difference in the use of epitaxial wafers, Dataquest believes that the number of FZ wafers consumed in Europe is approximately twice that of North American consumption (see Table 3). Again, because of the size of the discrete market and a product mix that tends to favor FZ over epitaxial wafers, the volume of FZ wafers consumed in Japan is estimated to be about four times that of North America. Demand for FZ silicon in Asia/Pacific is estimated to be small relative to other regions.

Table 3
Estimated 1990 FZ Wafer Consumption (Millions of Square Inches)

Country	Square Inches
North America	11-13
Japan	43-45
Europe	23-25
Asia/Pacific	5-6
Total	82-89

Source: Dataquest (April 1991)

Historically, volume growth of silicon wafers has lagged revenue growth of the integrated circuit market by about 5 to 6 percent. Although the same amount of difference in growth rates is not anticipated for discrete devices, it may be assumed that silicon volume growth for power discretes will fall short of the corresponding discrete revenue growth rate.

Dataquest forecasts power discrete devices to have a 10.5 percent CAGR in the next five years. The high-power segment is estimated to grow even more slowly, at a 5 to 7 percent CAGR. This trend, along with the fact that many new power transistors will probably use epitaxial films, points to a future FZ market CAGR less than 5 percent from 1990 to 1995.

By Mark FitzGerald

CD SEM Equipment

Smaller Geometries Lead to Larger Market

Summary

The critical dimension scanning electron microscope (CD SEM) equipment market has experienced robust growth during the past five years and, as Figure 1 shows, now exceeds the optical CD equipment market by a sizable margin. Dataquest's preliminary estimate of the 1990 CD SEM equipment market is $100.6 million, up almost 25 percent from its 1989 level of $80.6 million. This healthy growth is all the more impressive when measured against a 1990 total wafer fabrication equipment market expected to be down a few percentage points from its 1989 level. This article examines several factors behind the emergence and acceptance of CD SEM measurement equipment in today's semiconductor manufacturing environment.

Why CD SEM?

In the latter half of the 1980s, the field of CD measurement diversified into a multitude of technologies. Historically, conventional CD tools have been white-light microscopy systems. These systems are considered adequate for measurements down to about 1.0-micron geometries. Several of these systems have been enhanced with sophisticated image processing capabilities to extend performance. In addition, laser-based measurement systems, confocal scanning laser microscopy (CSLM), and coherence-probe imaging (CPI) technologies have been developed to perform CD measurements in the submicron regime. CSLM and CPI systems have received only modest market acceptance to date because of the significant effort required to characterize the equipment for measurement of CDs in a production environment.

At the same time, SEM tools, traditionally relegated to the analytical lab, have been redesigned to meet the needs of submicron manufacturing for the production environment. The SEM tools designed for IC metrology are low-voltage systems because of the concern regarding damage to the wafer at higher levels of electron irradiation. In addition, equipment manufacturers have designed the tools to be more user friendly than their analytical counterparts by simplifying the operator control panel.

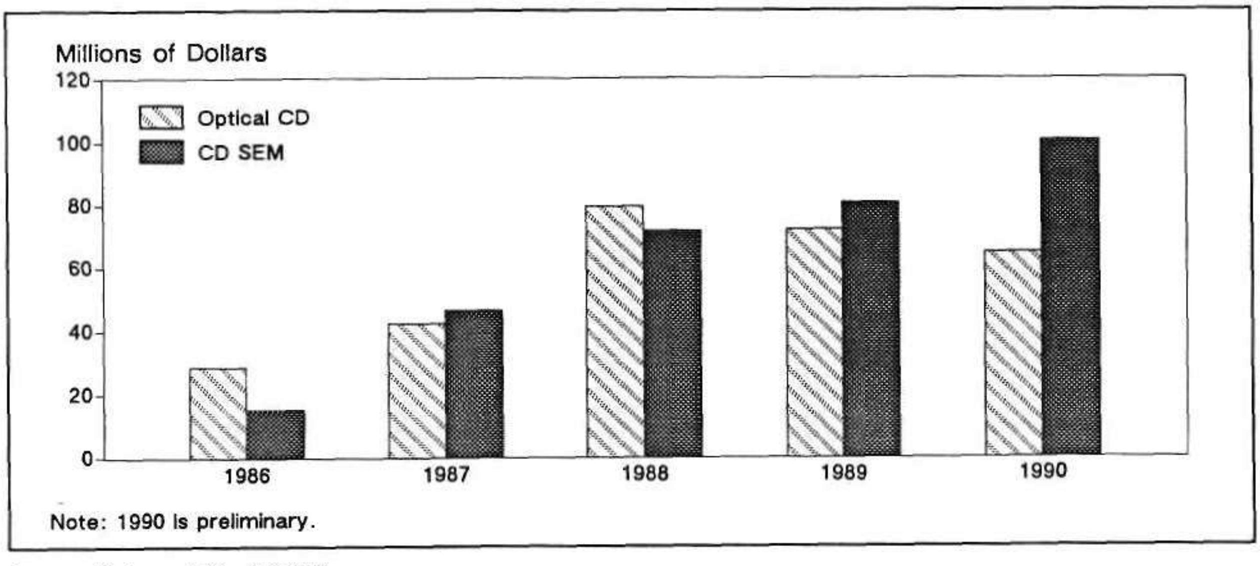
CD SEM Advantages

The advantages of CD SEM equipment include better measurement resolution and depth of focus than optical tools. Some manufacturers report better-than-0.2-micron measurement capability; however, most agree that today's CD SEM tools are fully characterized for production only down to about 0.5-micron geometries. CD SEM equipment, like the advanced optical techniques of CSLM and CPI, also has the ability to capture three-dimensional information of the line profile. The slope of the sidewalls becomes increasingly important in linewidth measurement as manufacturers move to submicron geometries and features with higher-aspect ratios necessitating tighter CD control.

Throughput

Throughput of CD SEM tools remains a major issue. Compared with optical tools, most CD SEM tools still have relatively low throughput, typically on the order of 8 to 12 wafers per hour at five measurement sites per wafer. This is because in most systems, wafers are processed serially between load lock and measurement chamber. Several companies have specifically incorporated throughput enhancement features in their design to overcome this factor. Opal (a subsidiary of printed circuit board inspection manufacturer, Optrotech) increases system throughput by measuring one wafer while a second wafer is pumped down in the load lock. An internal exchange unit allows the first wafer to move aside on completion of CD

FIGURE 1
Optical CD and CD SEM Equipment Markets



Source: Dataquest (April 1991)

measurements so that the second wafer can be moved from the load lock to the measurement chamber. Opal claims a throughput of about 20 wafers per hour and expects it to be even higher in the future. Nanoquest (Vickers Instruments operation acquired by BioRad in 1989) takes a different approach; its system accepts a full cassette of wafers into the load lock rather than a single wafer. The full cassette is pumped down, and a wafer transport mechanism is used to move individual wafers into the measurement chamber.

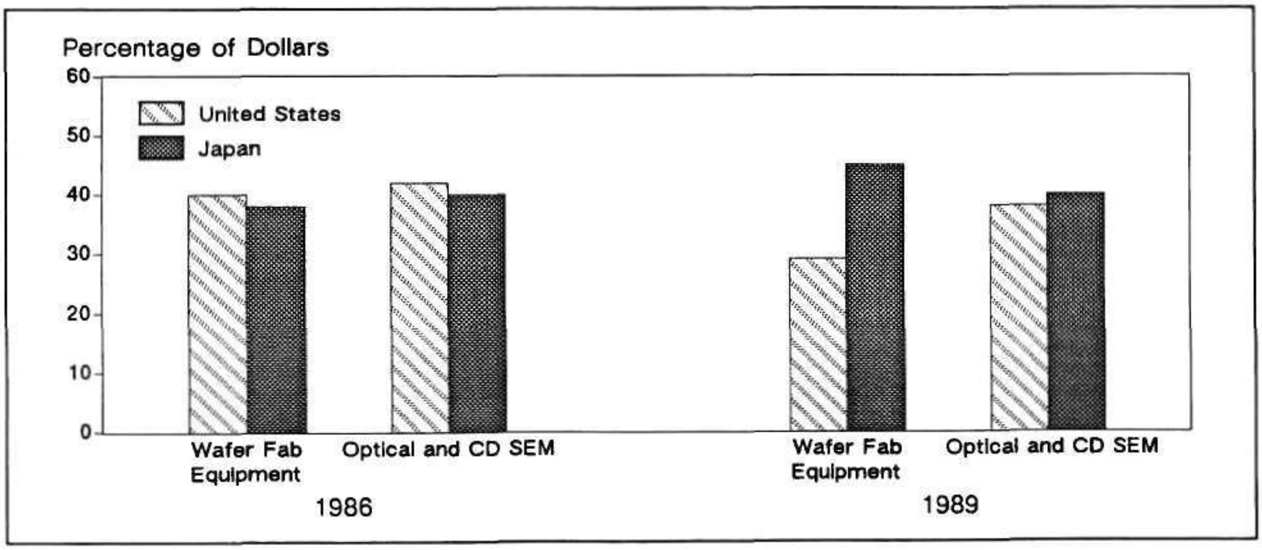
Regional Manufacturing Practices

One of the interesting aspects of the CD measurement equipment market is that some semiconductor manufacturers tend to perform less measurement and inspection than other companies. These companies have adopted a manufacturing philosophy to completely characterize and understand their process in the R&D environment prior to moving a device to high-volume production. Once a device is fully characterized for production, only minimal measurement and inspection is performed to monitor the fabrication process. Thus, fewer measurement tools are needed. This is in contrast to characterizing the process in a production mode, which requires more measurements and adjustments on the fly more frequently.

Figure 2 illustrates that in the last several years, regional variations have emerged in the use of CD measurement equipment. In 1986, manufacturers in the United States and Japan accounted for almost equal share of the worldwide wafer fab equipment market as well as almost equal share of the combined optical and CD SEM equipment market. By 1989, however, this situation had changed substantially. Although the United States as a region accounted for 29 percent of the wafer fab equipment market, it represented 38 percent of all spending on CD measurement systems. In contrast, Japan accounted for 45 percent of the wafer fab equipment market, but only 40 percent of the CD equipment market.

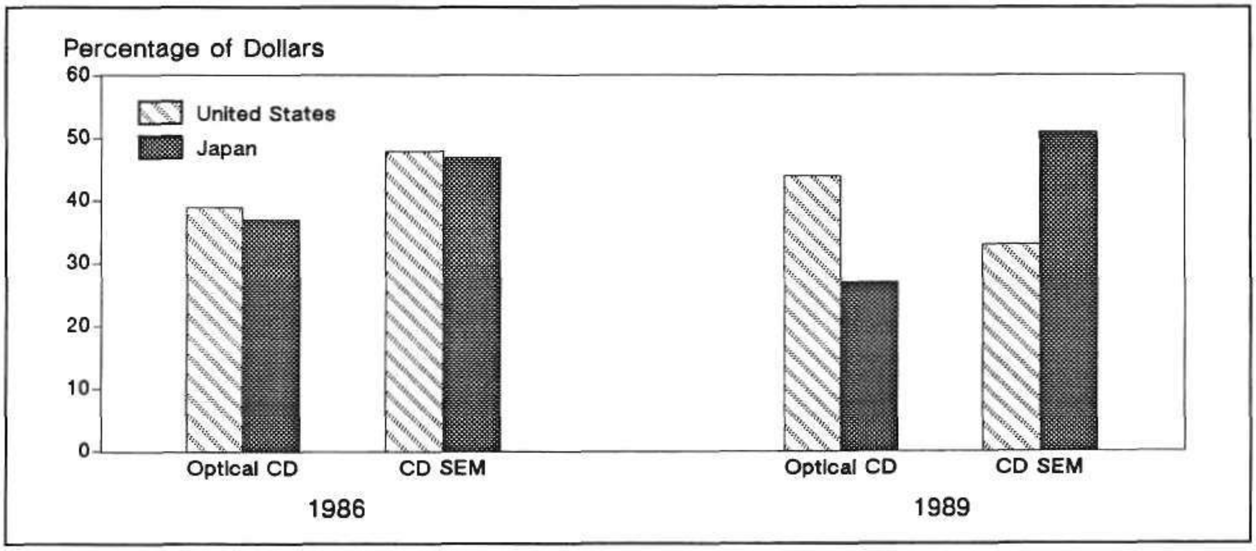
Even further regional manufacturing distinctions exist within the category of CD measurement equipment. Manufacturers in Japan use significantly more CD SEM systems than do their counterparts in the United States. Figure 3 shows that in 1986, semiconductor manufacturers in Japan and the United States accounted for approximately equal share of both the optical CD and CD SEM equipment markets. In 1989, the United States spent more on optical CD measurement equipment with 44 percent share of the world market, while Japan had only 27 percent share. Japan, however, accounted for over one-half of the CD SEM equipment market in 1989 with 51 percent share, in contrast with U.S. share of 33 percent.

FIGURE 2
Regional Equipment Market Trends
United States and Japan, 1986 and 1989



Source: Dataquest (April 1991)

FIGURE 3
Regional Trends—CD Equipment Market United States and Japan, 1986 and 1989



Source: Dataquest (April 1991)

The Japanese manufacturers' move to CD SEM equipment is due, in part, to the prevalence of DRAM manufacturing in Japan, which is the technology driver for processing submicron geometries. Dataquest believes, however, that Japanese semiconductor manufacturers have chosen to leapfrog advanced optical CD measurement technologies and move directly to SEMs because they are not convinced yet that advanced optical technologies can be pushed to or beyond the 0.5-micron processing regime. There are also concerns that advanced optical tools have not been characterized fully for the semiconductor production environment. Finally, semiconductor manufacturers in Japan historically have been supported by a strong domestic vendor base in CD SEM.

CD SEM Companies

Many companies currently are pursuing the CD SEM equipment market, including the following U.S. companies: Amray, Angstrom Measurements, Metrologix, Nanometrics, Nanoquest, and Opal. Japanese CD SEM companies include Akashi Beam Technology (recently acquired by Toshiba), Hitachi, Holon, and JEOL. This market includes well-established equipment companies as well as start-ups. Hitachi, however, held and maintained dominant market share throughout much of the 1980s. Dataquest estimates that Hitachi commanded 75 percent of world market share in 1990 (see Table 1). In 1986, when the world market for CD SEM equipment was only $15.4 million, Hitachi still accounted for over half of the market with 56 percent share. We believe that Hitachi's success is due, in part, to the company's extensive experience in e-beam technology for electronics and other applications, as well as its early product focus on developing a user-friendly CD-SEM tool for semiconductor production applications.

New Opportunities—Cluster Tool Processing

As linewidth geometries continue to shrink, the overall market opportunities for CD SEMs are growing. One interesting opportunity in the CD SEM equipment market comes from the developing market for cluster tools. CD SEM measurement equipment is particularly well

TABLE 1
1990 CD SEM Equipment Company Preliminary Market Share (Millions of Dollars)

Company	Revenue	Percent Share
Hitachi (Japan)	75.5	75.0
Holon (Japan)	9.4	9.3
Nanoquest (U.S.)	6.9	6.9
Nanometrics (U.S.)	3.1	3.1
Opal (U.S.)	2.4	2.4
Others	3.3	3.3
Total	100.6	100.0

Source: Dataquest (April 1991)

suited for a cluster tool vacuum environment designed for etch, strip, and deposition processes. Linewidth measurement would be performed on a wafer after etch/strip processing. The wafer then would move directly to a deposition module, thus eliminating the need to remove the wafer from the cluster tool for CD measurement prior to deposition. Metrologix, acquired by venture capital firm Nazem and Company in July 1990, is well suited to pursue this strategy because of its association with Tegal. Tegal, another company funded by Nazem, is well established in the plasma etch and strip equipment markets.

Dataquest Forecast

Dataquest anticipates that CD SEM tools will continue to experience healthy growth as a larger percentage of the semiconductor device product mix moves into the submicron processing regime. CD SEM measurement technology has already gained widespread acceptance in Japan, the largest semiconductor manufacturing region in the world. CD SEM equipment is establishing a presence in front-end manufacturing in other manufacturing regions of the world as well. We expect the CD SEM equipment market to be approximately $245 million by 1995, reflecting a 19.5 percent CAGR between 1990 and 1995.

We note, however, that optical CD measurement tools are not likely to disappear entirely. Several advanced optical tools have been designed specifically for submicron measurement performance and thus will compete directly with CD SEM. Conventional optical CD tools still provide a cost-effective, high-throughput option for measurement of 1.0-micron geometries and larger. Finally, optical CD tools still will be required to perform overlay measurements in most applications. CD SEM equipment is not particularly well suited for overlay measurement because of the physics of the measurement procedure. An optical tool can "see" through transparent film to alignment marks on an underlying layer. CD SEM measurement technology primarily relies on secondary electrons scattered off the wafer surface to determine its measurement signal, and thus, in most applications, is restricted to measurement of surface features. Therefore, optical CD tools with joint linewidth and overlay measurement capabilities or dedicated overlay tools will continue to be purchased in the 1990s. We forecast the optical CD equipment market to be $105 million in 1995, reflecting a five-year CAGR of 10.1 percent.

Dataquest Perspective

A single company has dominated the CD SEM equipment market to date. The other nine companies in this market segment face significant challenges. They must overcome the "play it safe" attitude of semiconductor manufacturers that chose to buy from the market leader. They must establish a market presence strong enough to allow them to generate a sufficient income stream to invest in future technology development. At the same time, they must expand their international operations. Partnerships and alliances with larger equipment companies can provide the support that some of these companies will need to nurture long-term growth. For U.S. equipment vendors of CD SEM tools, the Japanese market will be particularly difficult to penetrate because of the overwhelming strength of the domestic vendor base and the significant cost of doing business in Japan. Opportunities, however, always exist for a company able to sell, service, and support its equipment in an increasingly demanding customer base. ■

By Kunio Achiwa
Peggy Marie Wood

Semiconductor Manufacturing

Wafer Size and Manufacturing Costs

The Push to Larger Wafers

Introduction

Dataquest believes that large manufacturing cost gains can be made by using larger wafers in high-volume production. We believe that this is true today, as manufacturers begin to move from using 6-inch wafers to using 8-inch wafers, and it will be true in the year 2000, when the industry moves from 8- to 12-inch wafers.

This article highlights the manufacturing gains associated with using larger wafer sizes in volume production (20,000 wafer starts per month in today's state-of-the-art facility). Our analysis shows that the increased output outweighs any increases in capital costs associated with using larger wafers.

Historical Fab Costs and Capacity

In 1970, the initial capital cost (facility and equipment) of a high-volume, state-of-the-art fab

Table 1
Fab Cost per Monthly Square Inch of Capacity

Year	Fab Cost (Millions of Dollars)	Monthly Capacity: Wafers	Monthly Capacity: Square Inches	Fab Cost per Square Inch ($)
1970	30	10,000 (3-inch)	71,000	422
1987	225	20,000 (6-inch)	565,000	398
1990	295	20,000 (6-inch)	565,000	522

Source: Dataquest (April 1991)

Table 2
Wafer Size and Area

Wafer Size (Inches)	Area (In^2)	Ratio of Area to 6-Inch Wafer Area
6	28	1.0
8	50	1.8
10	79	2.8
12	113	4.0

Source: Dataquest (April 1991)

was $30 million. By 1987, this cost had risen to $225 million (see Table 1). During this same period, typical fab capacity as measured in square inches of silicon per month rose from $70 million to $565 million—a rate of increase slightly exceeding the growth of initial fab costs. The ratio of initial fab cost to monthly square-inch capacity decreased from $422 per square inch to $398 per square inch—a decrease of 6 percent. In other words, although the capital cost of a new fab increased dramatically from 1970 to 1987, capital cost per unit of capacity actually decreased, albeit slightly.

This decrease in initial capital cost per unit of capacity, in spite of increasing process complexity, was due to doubling the number of wafers a fab could produce and doubling the size of the wafer. Increasing wafer size dramatically increases the area of a wafer (see Table 2). Thus, from 1970 to 1987, wafer size doubled from 3 to 6 inches, and wafer capacity also doubled from 10,000 to 20,000 wafers per month. This doubling of both wafer size and capacity offsets the increasing costs of capital because of increasing process complexity.

However, since 1987, initial fab costs for 6-inch wafer fabs have continued to rise while capacity has typically remained constant. As a result, the ratio of initial fab costs to square-inch capacity has increased since 1987. (See Dataquest's SEMMS newsletter entitled "Technology Trends and Fab Costs," November 1990.)

Costs and Wafer Size

However, semiconductor manufacturers need not be helpless in the face of increasing capital costs. Our analysis indicates that if semiconductor manufacturers increase the size of their wafers, they will slow the rise in initial fab cost per square inch of silicon capacity. And, perhaps more important, using larger wafers will lower manufacturing cost per die.

Initial Capital Cost and Larger Wafer Sizes

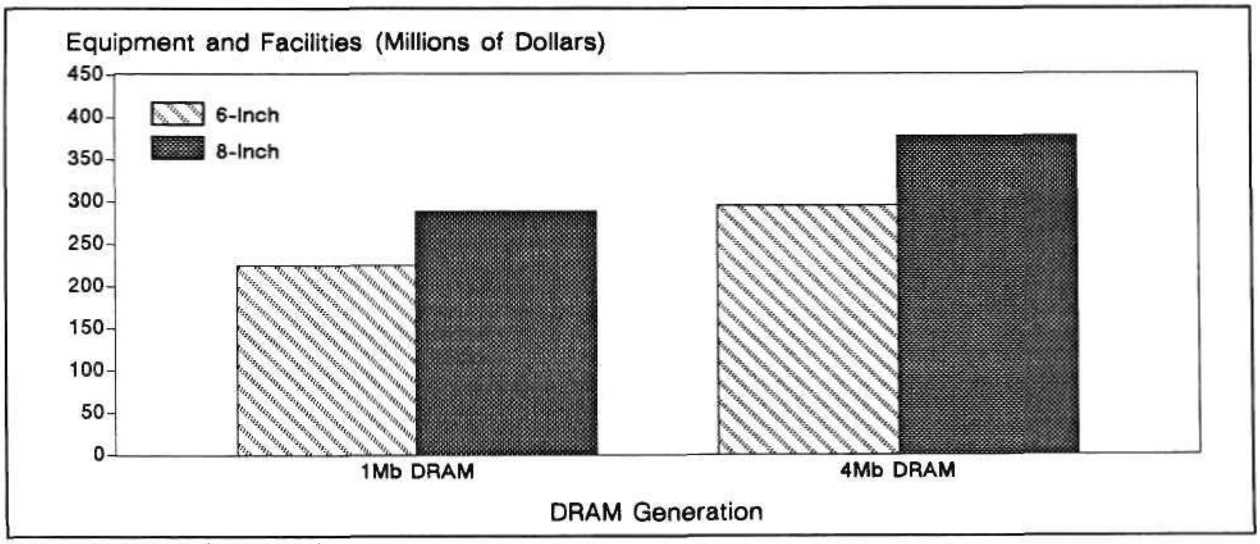
Our estimates of 1Mb and 4Mb DRAM fab costs are shown in Figure 1. We have provided initial fab costs for 6- and 8-inch fabs for both generations of DRAMs. We have normalized fab capacity for both 6- and 8-inch fabs to 20,000 wafer starts per month. As would be expected, fab costs rise with each generation of DRAMs. Fab costs also rise within a DRAM generation as larger wafers are used.

As Figure 2 shows, however, within a DRAM generation, fab costs per square inch of capacity decline as larger wafers are used. For example, initial facility and equipment cost per square inch of capacity for a 20,000-wafer-start-per-month fab making 4Mb DRAMs is over $500 per square inch if 6-inch wafers are used, but falls to under $400 per square inch if 8-inch wafers are used. Because the area of the wafer increases much faster than does capital cost, initial capital cost per square inch of silicon capacity decreases when larger wafers are used.

Manufacturing Cost per Die and Wafer Size

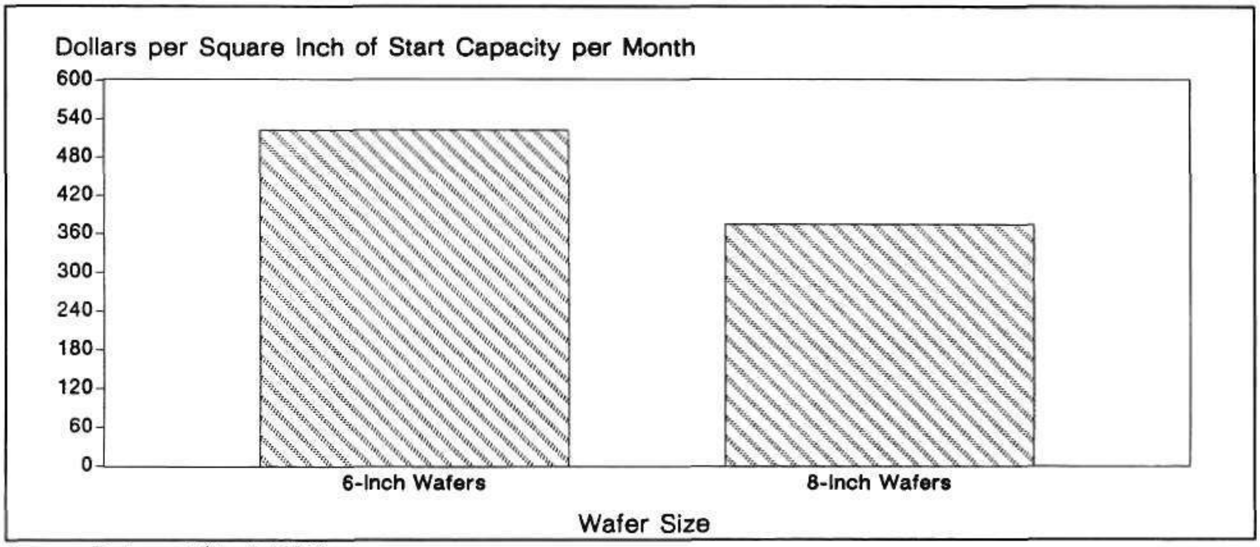
Dataquest has a DRAM manufacturing cost model capable of analyzing DRAM die cost manufactured on 6-, 8-, or even 10-inch wafers.

FIGURE 1
DRAM Fab Costs by Wafer Size



Source: Dataquest (April 1991)

FIGURE 2
Capital Cost/In^2 of a 20,000 Wafers/Mo. 4Mb DRAM Fab by Wafer Size



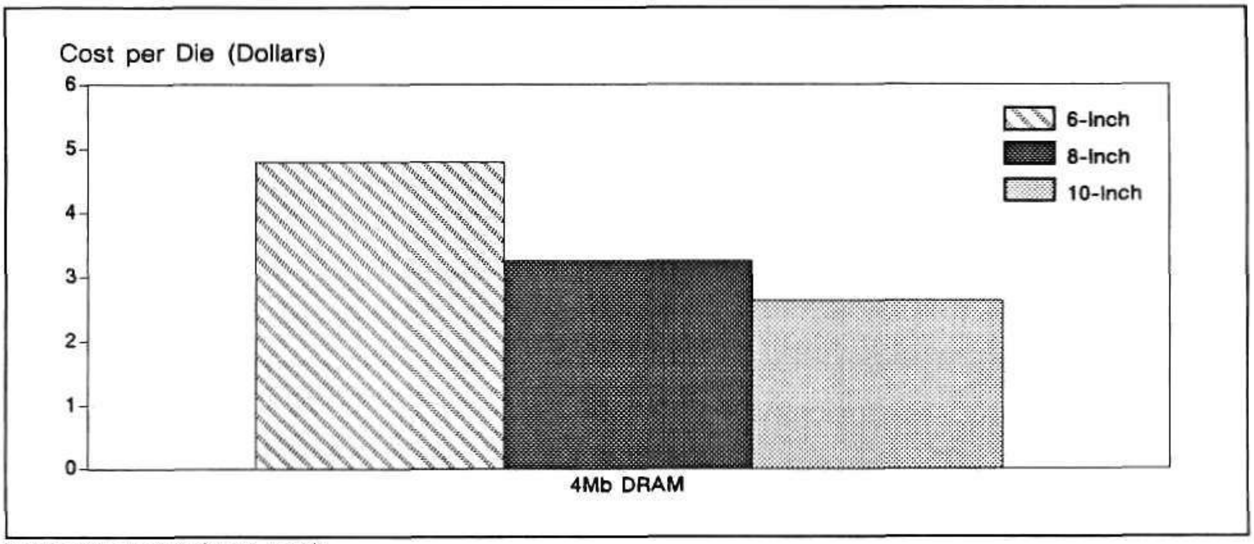
Source: Dataquest (April 1991)

Manufacturing cost (for example, labor, materials, and overhead) per good die at a given yield is shown in Figure 3 for 6-, 8-, and 10-inch wafers. Although no 10-inch 4Mb DRAM lines exist (and it is unlikely they ever will), we ran the model using 10-inch wafers for the sake of illustration. Manufacturing cost per good die declines as wafer size increases, because the number of die at a constant yield increases with wafer size much more rapidly than materials cost, depreciation, or any other manufacturing cost variable. The manufacturer that can maintain yields and move to larger wafer sizes will have a tremendous cost advantage over those that stay with smaller wafers.

Increasing Wafer Size Increases Process Complexity

The main focus of this article has been on the cost advantages of moving to larger wafer sizes.

FIGURE 3
DRAM Cost per Die by Wafer Size



Source: Dataquest (April 1991)

However, such a move is not easy; some major processing hurdles have to be overcome. For example, stepper depth of focus is sensitive to variations in flatness across the greater areas of larger wafers. The surface area of a larger wafer also presents uniformity problems for deposition, diffusion, and etch equipment. Robotics and wafer-handling capabilities for all equipment have to be reconfigured and upgraded in order to handle wafers that are both larger and substantially heavier.

Solving these and other problems will cost equipment and materials vendors time, effort, and money and require much effort. Additionally, after the equipment and materials are available, semiconductor manufacturers will have to transfer their working processes to the larger wafers, which also requires time, effort, and money. It is an unfortunate but true fact that semiconductor manufacturers that are the leaders in moving to a larger wafer size pay a price for leadership: an initial loss of yield.

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This time, effort, and money are necessary to transfer a successful process to a larger wafer size; yet, because substantial savings are involved, we believe that a move to larger wafer sizes is inevitable. Semiconductor manufacturers can achieve substantial savings in initial fab cost per square inch of capacity and in manufactured cost of a yielded die by using larger wafers.

Although for years IBM was the only major manufacturer using 8-inch wafers, today others are announcing plans to build 8-inch facilities. The industry is continuing its historic move to larger wafers. Indeed, by the mid-1990s, Dataquest expects to see 10-inch or, more likely, 12-inch pilot fab lines announced. Because there was a time lag of three to five years between the first appearance of 8-inch wafers and their widespread use, we do not expect to see widespread use of 12-inch wafers until about the year 2000.

Because it takes six to seven years to develop a new process, those companies (materials suppliers, equipment vendors, and leading-edge semiconductor manufacturers) that wish to stay ahead of the competition should be looking to the next wafer size today.

In addition to pushing so many other limits (for example, lithography, interconnect, deposition, contamination) by the end of this decade, the industry will be fabricating devices on a 12-inch wafer—a surface that is 225 percent larger than an 8-inch wafer surface. It is a much larger playing field, and its size will also be reflected in the size of R&D budgets in the coming years. ■

By George Burns

Company Analysis

A Quick Look at Advanced Micro Devices

This article provides a quick look at Advanced Micro Devices' (AMD's) semiconductor capital spending, R&D spending, capacity by line geometry, planned facilities, and recent company highlights as related to semiconductor manufacturing. This article is part of the "Quick Look" series from Dataquest's Semiconductor Equipment, Manufacturing, and Materials Service (SEMMS).

Semiconductor Capital Spending and R&D Spending

Figure 1 graphically illustrates the dollar amount of AMD's semiconductor capital spending and semiconductor R&D spending expressed as a percentage of semiconductor revenue by year from 1975 to 1990.

Manufacturing Facilities

Additions to AMD's facilities in 1990 are shown in Table 1. Figure 2 illustrates the percentage distribution of AMD's existing worldwide semiconductor capacity by line geometries.

Company Highlights

The following discussion highlights significant events for AMD.

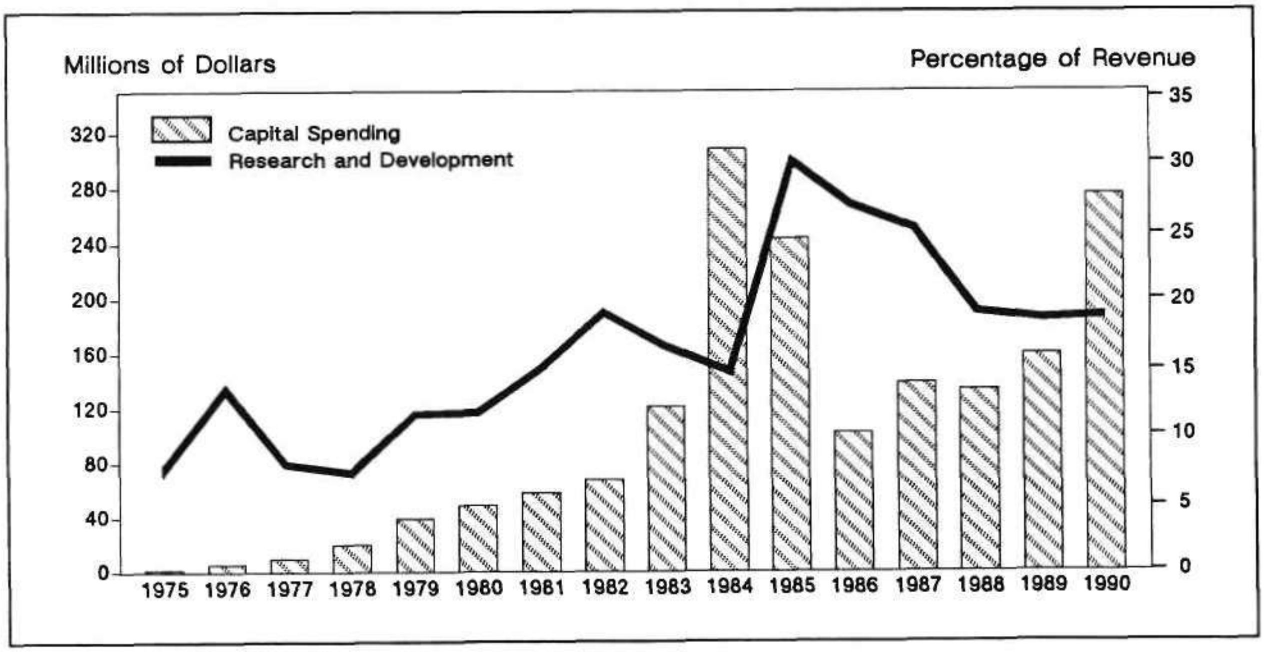
- Sunnyvale, California (SDC)

  AMD began processing product wafers at its new Submicron Development Center (SDC) in September 1990. The SDC is one of the most advanced R&D lines in the world. The SDC is a paperless fab with a wafer-start capacity of 3,000 wafers per week. Of these, 2,400 will be product wafers and 600 will be R&D wafers; therefore, the SDC is both an R&D facility and a production line. The facility was designed to be able to process wafers down to 0.25 micron by the end of the decade. Air cleanliness is Class 0.1. AMD's investment in the SDC was nearly $200 million.

- San Antonio, Texas (bipolar facilities)

  AMD sold its bipolar facilities in San Antonio to Sony for $55 million.

Figure 1
AMD—Capital Spending and R&D Spending by Year



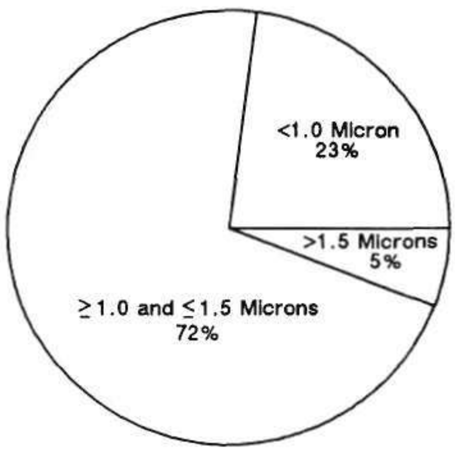
Source: Dataquest (April 1991)

TABLE 1
Additions to Advanced Micro Devices' Facilities—1990

Location	Products	Wafer Size	Year
Sunnyvale, California (SDC)	Technology development fab	6-inch	1990
Austin, Texas*	EPROM, logic, MPUs, PLDs, and SRAMs	5-inch	1990

*CMOS capacity expansion
Source: Advanced Micro Devices

FIGURE 2
AMD—Existing Capacity by Line Geometry (Percentage of Distribution)



Note: Capacity is measured in square inches of silicon.

Source: Dataquest (April 1991)

- Austin, Texas (Fab 10)

  Fab 10, which produces 80286 MPUs and PLDs, originally was an NMOS fab. AMD has expanded capacity by 40 percent to produce CMOS PLDs.

- Bangkok, Thailand (assembly and test facility)

  AMD began ramping up its new state-of-the-art 157,000-square-foot automated assembly and test facility.

- Capital spending in 1991

  AMD expects its capital spending in 1991 to be substantially less than in 1990—from approximately $300 million in 1990 to $130 million in 1991. ■

By George Burns

In Future Issues

The following topics will be featured in future issues of *Dataquest Perspective:*

- U.S. merchant R&D
- 1990 U.S. bulk gas market
- The role of consortia in semiconductor manufacturing
- Dry strip equipment: 1990 market in review

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