1991 SEMMS Newsletters and Bulletins

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1991 SEMMS Newsletters and Bulletins

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Research Newsletter

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.

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- 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.

Rebecca Henderson, Ph.D.
Assistant Professor
Sloan School of Management
Massachusetts Institute of Technology

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Research Newsletter

FINAL 1990 SEMICONDUCTOR MARKET SHARES

INTRODUCTION

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 will eventually see their business decline and their market share decrease as rapidly as they had previously grown. The 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) in 1990, allowing other companies to move up in the ranking list.

MICROCOMPONENTS: THE 1990 MARKET DRIVER

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 1990 semiconductor revenue from MOS memory products. In 1990, this ratio slipped by 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. Figure 1 compares 1989 and 1990 reliance on MOS memory by these companies.

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. These comparisons can be seen in Figure 2.

The effect of MOS microcomponents on the industry as a whole can be seen in Figure 3, which shows that were it not for the dramatic growth of microcomponents, the semiconductor industry would have declined by 2 percent in 1990, rather than growing 2 percent.

DIFFERENCES IN REGIONAL COMPANIES

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/opto (36 percent) and analog (30 percent); their revenue from the fastest-growing segments of the semiconductor industry (in the long term)—MOS memory and microcomponents—totaled only 21 percent of their semiconductor revenue. Asia/Pacific companies' revenue was very heavily skewed in favor of memory, with 63 percent of their revenue coming from that product category.

Figure 4 illustrates the product portfolios by regional company base. From this analysis, it appears that the most evenly balanced portfolios belong to the North American and Japanese companies, with percentage point spreads of only 13 and 16 percentage points, respectively, between the largest and smallest categories.

Although it might initially appear that European companies' portfolios are less well balanced, their targeted application markets differ from North American and Japanese companies in that a higher percentage of their output is aimed at the consumer

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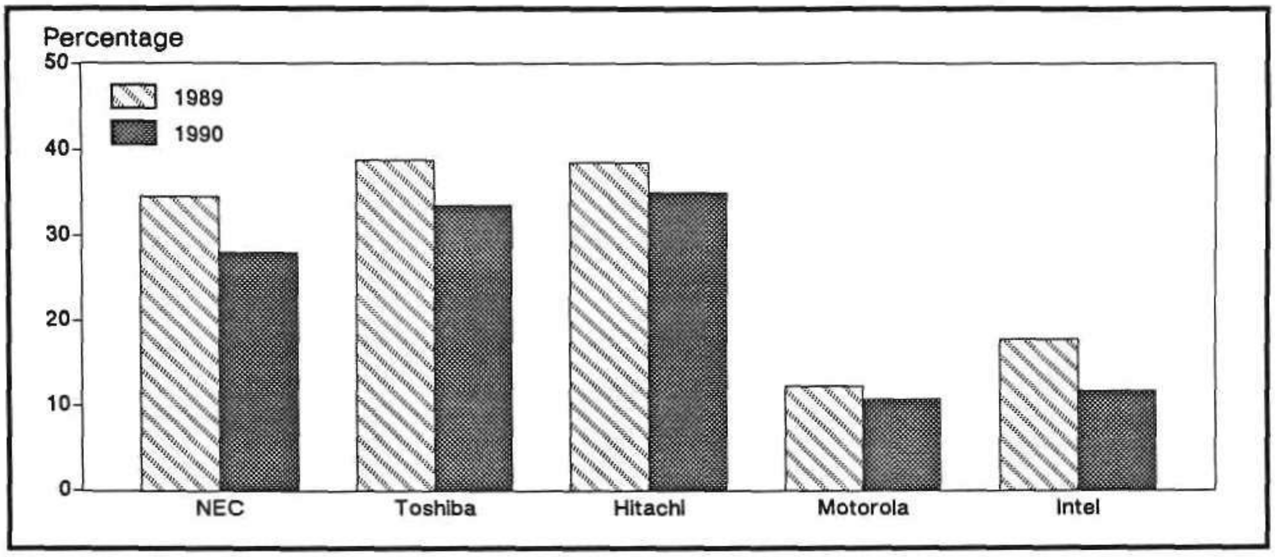
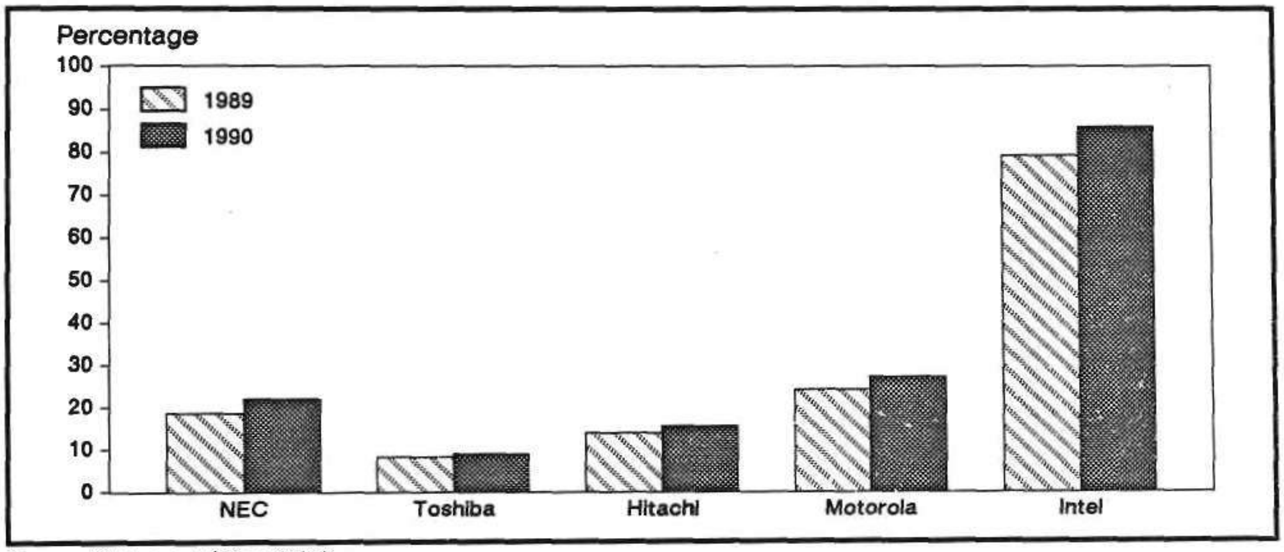
FIGURE 1
Top Five 1990 Semiconductor Suppliers' Reliance on MOS Memory (Percentage of Total Semiconductor)



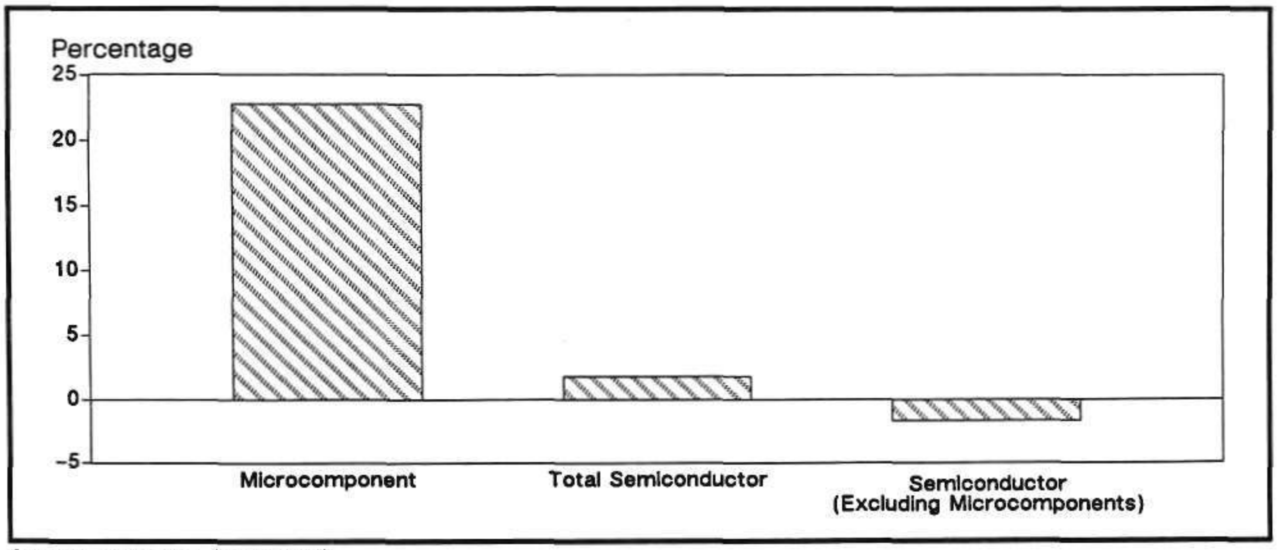
Source: Dataquest (May 1991)

FIGURE 2
Top Five Semiconductor Suppliers' Reliance on MOS Microcomponents (Percentage of Total Semiconductor)



Source: Dataquest (May 1991)

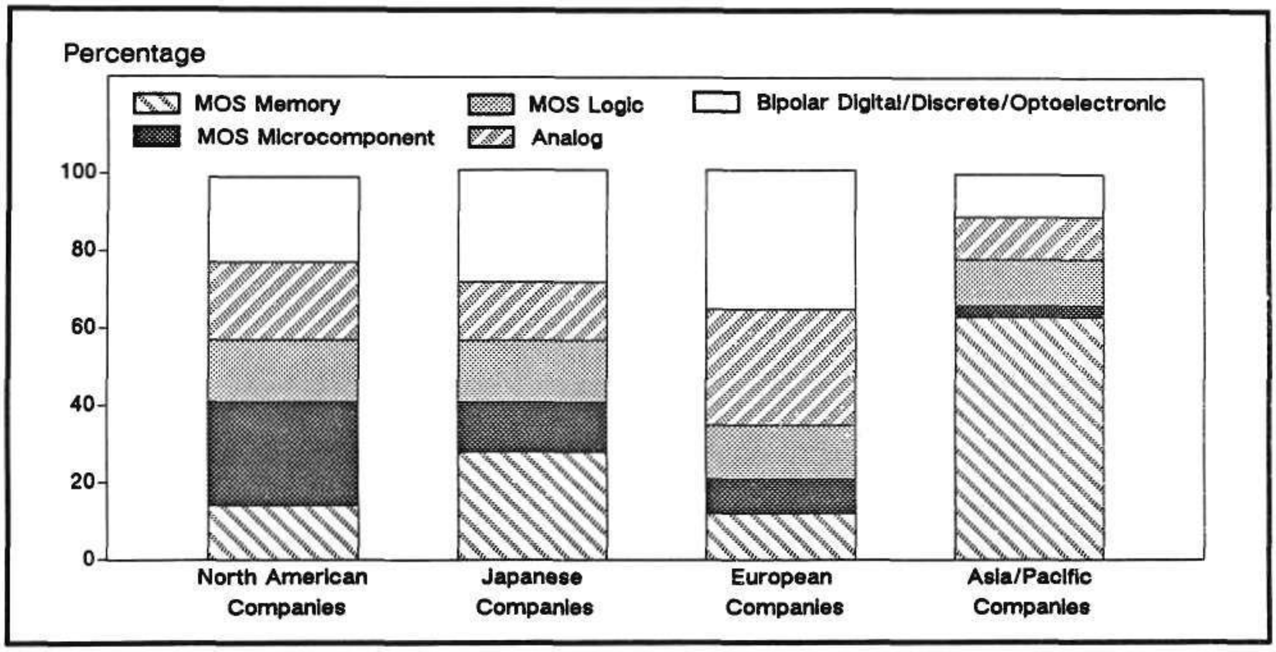
FIGURE 3
MOS Microcomponents: The Industry Driver
(Percent Growth in 1990)



Source: Dataquest (May 1991)

Source: Dataquest (May 1991)

FIGURE 4
1990 Product Portfolios by Company Base
(Percentage of Dollar Revenue by Product Category)



Source: Dataquest (May 1991)

and telecommunications industries, which use large quantities of discrete and analog chips.

The Asia/Pacific company statistics are skewed by Samsung, whose sales account for 62 percent of this group. Because Samsung has become one of the world's largest DRAM suppliers, it is not surprising that MOS memory accounts for 63 percent of Asia/Pacific company semiconductor revenue.

1990 RANKINGS AND MARKET SHARE

Table 1 is an analysis of the worldwide semiconductor market by regional supplier base and regional consumption market. This table shows that in 1990 North American companies held 37 percent of the worldwide semiconductor market, Japanese companies held 49 percent, European companies held 11 percent, and Asia/Pacific companies held 4 percent.

Table 2 is a breakdown of the semiconductor market by product category for 1989 and 1990. The market grew a total of only 1.8 percent, but as previously alluded to, MOS microcomponents grew by 22.8 percent. Analog ICs, the second fastest-growing market, grew 12.6 percent. (We have included mixed-signal analog/digital ICs in the analog category.)

Table 1
Estimated Final 1990 Semiconductor Market Share Analysis (Factory Revenue in Millions of U.S. Dollars)

Company:	Each Regional Base
Product:	Total Semiconductor
Region of Consumption:	Each
Distribution Channel:	NM
Application:	All
Specification:	All

	Regional Market				
Company Base	North America	Japan	Europe	Asia/ Pacific-ROW	World
North America ($M)	11,942	2,402	4,492	2,701	21,537
Percent of Regional Market	69	11	42	35	37
Percent of Company Sales	55	11	21	13	100
Japan ($M)	3,777	19,825	1,814	2,961	28,377
Percent of Regional Market	22	88	17	39	49
Percent of Company Sales	13	70	6	10	100
Europe ($M)	1,074	164	4,117	851	6,206
Percent of Regional Market	6	1	39	11	11
Percent of Company Sales	17	3	66	14	100
Asia/Pacific ($M)	593	117	238	1,157	2,105
Percent of Regional Market	3	1	2	15	4
Percent of Company Sales	28	6	11	55	100
World ($M)	17,386	22,508	10,661	7,670	58,255
Percent of Regional Market	100	100	100	100	100
Percent of Company Sales	30	39	18	13	100

NM = Not meaningful
Source: Dataquest (May 1991)

TABLE 2
Estimated Semiconductor Consumption
(Factory Revenue in Millions of U.S. Dollars)

Company:	All
Product:	Each
Region of Consumption:	Worldwide
Distribution Channel:	NM
Application:	All
Specification:	All

	1989	1990	Percent Change
Total Semiconductor	57,213	58,225	1.8
Total Integrated Circuit	46,924	47,303	0.8
Bipolar Digital	4,510	4,440	-1.6
Bipolar Memory	540	459	-15.0
Bipolar Logic	3,970	3,981	0.3
MOS Digital	33,024	32,292	-2.2
MOS Memory	16,361	13,091	-20.0
MOS Microcomponent	8,202	10,068	22.8
MOS Logic	8,461	9,133	7.9
Analog	9,390	10,571	12.6
Discrete	7,662	8,235	7.5
Optoelectronic	2,627	2,687	2.3

NM = Not meaningful
Source: Dataquest (May 1991)

The top 40 semiconductor companies' worldwide rankings and revenue are shown in Table 3.

DATAQUEST CONCLUSIONS

The memory market 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.

Patricia S. Cox

Note: Detailed market share data books have been completed and mailed to binderholders of the SIS, JSIS, ESIS, ASETS, and NASM services.

TABLE 3
Estimated Market Share Ranking
(Factory Revenue in Millions of U.S. Dollars)

Company:	Top 40
Product:	Total Semiconductor
Region of Consumption:	Worldwide
Distribution Channel:	NM
Application:	All
Specification:	All

1990 Rank	1989 Rank		1989 Revenue	1990 Revenue	Percent Change	1990 Market Share (%)
1	1	NEC	5,015	4,898	-2	8.4
2	2	Toshiba	4,930	4,843	-2	8.3
3	3	Hitachi	3,974	3,893	-2	6.7
4	4	Motorola	3,319	3,694	11	6.3
5	8	Intel	2,430	3,171	30	5.4
6	5	Fujitsu	2,963	2,880	-3	4.9
7	6	Texas Instruments	2,787	2,574	-8	4.4
8	7	Mitsubishi	2,579	2,319	-10	4.0
9	10	Philips	1,716	2,011	17	3.5
10	9	Matsushita	1,882	1,942	3	3.3
11	11	National Semiconductor	1,618	1,719	6	3.0
12	13	SGS-Thomson	1,301	1,463	12	2.5
13	12	Sanyo	1,365	1,381	1	2.4
14	15	Sharp	1,230	1,325	8	2.3
15	14	Samsung	1,260	1,315	4	2.3
16	16	Siemens	1,194	1,224	3	2.1
17	19	Sony	1,077	1,146	6	2.0
18	17	Oki	1,154	1,074	-7	1.8
19	18	Advanced Micro Devices	1,100	1,053	-4	1.8
20	20	AT&T	873	861	-1	1.5
21	21	Harris	830	800	-4	1.4
22	22	Rohm	740	774	5	1.3
23	23	LSI Logic	512	598	17	1.0
24	26	Sanken	387	407	5	0.7
25	NM	GEC Plessey	0	390	NM	0.7
26	28	Fuji Electric	362	385	6	0.7

(Continued)

TABLE 3 (Continued)
Estimated Market Share Ranking
(Factory Revenue in Millions of U.S. Dollars)

Company:	Top 40
Product:	Total Semiconductor
Region of Consumption:	Worldwide
Distribution Channel:	NM
Application:	All
Specification:	All

1990 Rank	1989 Rank		1989 Revenue	1990 Revenue	Percent Change	1990 Market Share (%)
27	29	Analog Devices	357	381	7	0.7
28	25	ITT	390	371	-5	0.6
29	31	VLSI Technology	286	324	13	0.6
30	30	Telefunken Electronic	299	295	-1	0.5
31	24	Micron Technology	395	286	-28	0.5
32	32	Hewlett Packard	269	279	4	0.5
33	35	Chips & Technologies	240	265	10	0.5
34	40	International Rectifier	190	225	18	0.4
35	39	Cypress Semiconductor	196	223	14	0.4
36	42	General Instrument	170	214	26	0.4
37	27	Seiko Epson	368	213	-42	0.4
38	NA	Shindengen Electric	NA	209	NA	0.4
39	33	NMB Semiconductor	247	201	-19	0.3
40	43	Rockwell	165	200	21	0.3
		All Others	7,043	6,399	-9	11.0
		North American Companies	19,978	21,537	8	37.0
		Japanese Companies	29,809	28,377	-5	48.7
		European Companies	5,443	6,206	14	10.7
		Asia/Pacific Companies	1,983	2,105	6	3.6
		Total Market	57,213	58,225	2	100.0

NA = Not available
NM = Not meaningful
Source: Dataquest (May 1991)

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Research Newsletter

WILL INDUSTRY ECONOMICS DEFY "MOORE'S LAW"?

"In the long run, financial pressures may force semiconductor companies to slow down the pace of technological development."

—Dr. Gordon E. Moore
Dataquest's 1987 Semiconductor Industry Conference

SUMMARY

Dataquest believes that the semiconductor industry is facing a slowdown in the historical pace of integrated circuit (IC) price/performance improvements. The factors affecting this slowdown have less to do with technical limitations than with the costs of overcoming them. As the semiconductor industry enters the final decade of the 20th century, it faces the critical question of whether the cost of continuing its improvements in device complexity will set the deciding limits to future declines in the cost per function of semiconductor ICs.

A slowdown in IC price/performance improvements has enormous implications: Such a slowdown could ultimately slow the rate of semiconductor market growth, lower the industry's return on investment, and reduce technical improvements because of reduced R&D spending. The net result of diminished price/performance improvements could well be the lengthening of product life cycles in leading-edge devices—a phenomenon that would in turn have a profound impact on the electronic systems industry! The best analogy of this situation is that of a vicious circle taking the form of a tightening noose.

This newsletter is the first in a series that explores global industry issues. This first installment reviews the basic tenets underlying "Moore's Law" and examines cost issues that Dataquest believes are fundamentally altering the price/performance dynamics of the semiconductor industry.

MOORE'S LAW REVISITED

The electronics industry's notions of price/performance improvements were best defined almost three decades ago, when Intel Corporation's cofounder and chairman of the board, Dr. Gordon E. Moore, observed that the "complexity of integrated circuits has approximately doubled every year since their introduction, (and) *cost per function has decreased several thousandfold*" (author's italics). Dr. Moore's observation has become a generally accepted semiconductor industry canon known as "Moore's Law." Over a nearly 20-year period from the introduction of the first planar transistor to the mid-1970s, the semiconductor industry achieved a nearly 800-fold increase in device complexity, which Dr. Moore attributed to exponential progress in the following areas:

- Die size—In a 20-year period, IC die size for the most complex integrated circuits increased by a factor of 20.
- Linewidth—During the same period, reductions in linewidth and space improved by a factor of approximately 32.

In combining these factors, Dr. Moore was able to account for an overall 640-fold increase in device complexity, leaving a factor of about 100 to account for. This factor, according to Dr. Moore, was "cleverness"—the contribution of circuit and device advances to the achievement of higher device density. "It is noteworthy," Dr. Moore observed, "that this contribution to complexity has been more important than either increased chip area or finer lines."

OF TECHNOLOGY AND CEREAL PRIZES

Moore's law, it may be argued, is the most fundamental observation of how the semiconductor

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industry has added value during the more than 40 years since the invention of the transistor. It is the basis for bit-density improvements in semiconductor memories, gate-count improvements in logic devices, and the basic explanation for how an industry can deliver miracles on a timetable basis. The semiconductor industry has made possible the fact that consumers worldwide have an unshakable expectation that electronics products will continuously deliver greater functionality and performance at lower cost. Equally important, Moore's Law has been the basis of profitability (however marginal at times) for an industry that appears perpetually poised to cannibalize itself. The fact that a leading-edge device such as the 4Mb DRAM can drop from a price of $460 to less than $10 in a six-year period fuels, through increased application, a level of demand that to some degree offsets such drastic erosions in price.

A powerful example of price/performance improvements in the semiconductor industry—one that moves us from the realm of abstraction to consumer reality—is the liquid crystal display (LCD) electronic watch. In 1975, the LCD watch represented electronics industry state of the art in a number of areas—the electronic timing semiconductor chip, the CMOS processing that made it possible, LCD technology, the small lithium battery, and the quartz crystal oscillator. Less than 20 years later, these very technologies are being delivered as a plastic giveaway in a box of breakfast cereal. Not only that, all of these impressive technologies of 1975 are now routinely manufactured at low cost in Asia and assembled in mainland China at a likely cost of less than 60 cents. The plastic watch case may be as much of a cost factor as the semiconductors it contains!

WHERE ARE THE LIMITS?

Although the semiconductor industry has granted the same veracity to Moore's Law that one might accord to Newton's Third Law of Motion, it must be remembered that Moore's Law is essentially an observation of the dynamics of an industry based on *past* performance. Numerous industry leaders, including Dr. Moore himself, have cautioned against an extrapolation of device complexity trends through a strict linear progression based on Dr. Moore's insight of three decades ago. In short, there are limits beyond which Moore's Law cannot logically apply. At Dataquest's 1987 Semiconductor Industry Conference, the coinventor of the integrated circuit, Jack Kilby, commented that such a straight-line extrapolation of device complexity to the year 2027 would suggest a range of 100 billion to 10 trillion transistors on a 12-inch square chip—at a price of $3 per chip!

The mind-boggling impossibility of Jack Kilby's extrapolation appears obvious even to an industry accustomed to enormous technological strides. During the 1987 conference, Dr. Moore identified a more fundamental limit to silicon-based semiconductor technology when he observed that progress in dimension reduction, the most important aspect of the industry's technological progress, "doesn't show any signs of abating until we reach a physical limit probably near 0.1-micron"—a limit that the industry will most likely encounter 20 years from now.

In an update of his original analysis 30 years ago, Dr. Moore observed that packing efficiency in ICs had progressed by a factor of four between 1959 and the mid-1970s. At that time, however, he observed, "I am inclined to suggest a limit to the contribution of circuit and device cleverness of another factor of four (improvement) in component density." With cleverness diminishing as a chief contributor to device complexity, Dr. Moore speculated that the slope of the Moore's Law complexity curve could slow to a doubling of complexity every two years rather than every year. Although this has not yet proven to be the case, there are clearly limits to how far the industry can go in improving such factors as defect density and yield.

THE PRICE OF THE FUTURE

While acknowledging the technical challenges of following Moore's Law into the submicron era, one must also acknowledge that the history of the semiconductor industry is replete with examples of overcoming technical limitations. However, there are laws other than those of physics that affect the future pace of the semiconductor industry's price/performance improvements. A greater obstacle to the continuation of Moore's Law may be the law of economics—a law more harsh in its effects on companies than any they may face in the R&D lab. Put another way, a question facing the industry is: "Which do we run out of first, cash or creativity?" The economic forces arrayed against Moore's Law have to do with the price of industry progress: the costs of designing, marketing, and manufacturing leading-edge ICs. Some of the most fundamental cost issues currently facing the semiconductor industry are reviewed in the following paragraphs.

Lithography Discontinuity

In a recent meeting with Dataquest semiconductor analysts, Dr. Moore expressed his current doubts that industry progress toward the limits of device physics would proceed unabated. His earlier conviction that dimension reduction could follow its current exponential slope until it reaches the 0.1-micron level has been tempered by a concern that the industry will encounter serious obstacles in getting past the 0.35- to 0.25-micron range, the feature size requirement for production of 64Mb and 1-gigabit DRAMs! Production manufacturing of circuits with 0.25-micron geometries will be feasible, from Dr. Moore's current perspective, only if it can be done with optical lithography technology. The industry faces an enormous discontinuity at the point that optical lithography is abandoned. The issue, however, is not so much the technical achievement of manufacturing devices with feature sizes below 0.25 micron; it is the cost of doing so given the investments that will have to be made in the technological alternatives to optical lithography.

Design Costs

Dataquest believes that design cost, whether measured by per bit, transistor, or gate, now costs about one-fortieth of what it cost in the early 1970s. Numerous factors lie behind this tremendous progress, most of these having to do with the switch from physical layout and "hand analysis" to computer-aided design (CAD) advances in schematic capture, auto-routing, and simulation. On the other hand, chip density has increased 2,000-fold in the last 20 years, making the cost of design higher on a per-device basis. As a rule of thumb, design and/or development costs have gone up with the square root of density despite the offsetting benefits of CAD technology. Look at the history of microprocessor development: In the past decade, according to Intel, development costs rose from $25 million for the 8086 to $250 million for the 80486. As a whole, Dataquest estimates that design costs have risen 45 times during the last two decades.

Manufacturing Costs

In the near future, Dataquest sees a number of process trends that threaten to drive up the per-wafer cost of semiconductor manufacturing. The most critical of these are as follows:

- An increased number of mask steps—from 5 for a 16K device to between 25 and 30 for a 64Mb DRAM.
- An increase in interconnect levels—1Mb SRAMs, 4Mb SRAMs, and 16Mb DRAMs will use two levels of metal. ASICs, which lead interconnect technology, will have four or five levels of metal.
- An increase in the number of process steps—each interconnect level involves many deposition and etch steps and drives up process complexity as well as requiring expensive equipment. On average, the total number of process steps per wafer will increase from 200 for the 1Mb DRAM to approximately 800 for the 64Mb DRAM.
- The increase in process complexity will cause a decrease in wafer throughput, resulting in lower factory productivity. In addition, increases in process complexity will mean higher work-in-process inventory costs.

Marketing Costs

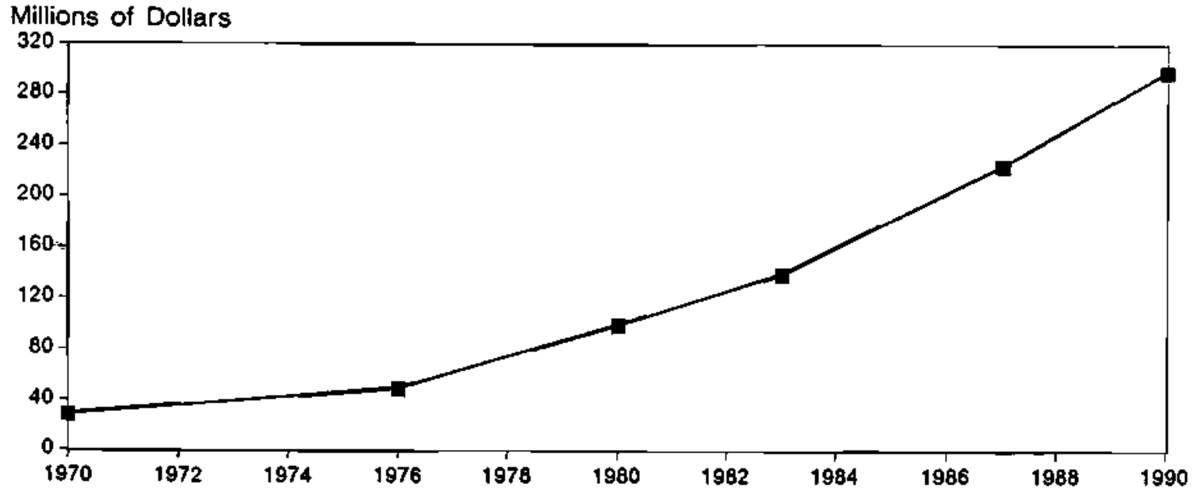
The costs associated with marketing ICs have increased as a function of the increase in market size and the industry's movement to worldwide markets. Dataquest estimates that the former accounts for about an 8 times increase in marketing costs and the latter about a 3 times increase—or about 25 times altogether. Increasing competition among suppliers at the applications level will tend to push these costs up still further.

Wafer Fab Costs

According to Dataquest's Semiconductor Equipment, Manufacturing, and Materials Service (SEMMS), the cost of a state-of-the-art fab has risen from $30 million in 1970 to $300 million today, as illustrated in Figure 1. Equipment costs for a single station routinely exceed $1 million and are increasing rapidly. As a result, process equipment costs have risen from 40 percent of the total fab cost to approximately 70 percent.

Based on discussions that SEMMS analysts have had with several semiconductor manufacturers in Japan and the United States, the cost estimates

Figure 1
Building plus Equipment Costs for a High-Volume Fab Line



Source: Dataquest (April 1991)

for a 64Mb DRAM fab range from $500 million to as high as $1 billion. Assuming the more conservative end of this range, we would still be looking at fab costs rising at a compound annual growth rate (CAGR) of 15 percent from 1990 to 1996 compared with a CAGR of 12 percent from 1970 to 1990. With both fab financing and fab productivity becoming equally critical, a slow ramp in production would be disastrous to suppliers both in terms of carrying cost and market prices. If this was true in the past, it will be more so in the future.

The Limits of Productivity

Up until now, the semiconductor industry has been doing a remarkable job of meeting the manufacturing challenge of increasingly complex devices with increased productivity. Clearly, the industry has responded to manufacturing complexities and costs with increases in die and wafer size and improvements in device yield. At Dataquest's 1987 Semiconductor Industry Conference, Dr. Moore happily remarked that the semiconductor industry had exhibited "the ability to improve products in all dimensions simultaneously by making them smaller with essentially no trade-offs."

A number of factors have contributed to the industry's success in continuing its dramatic price/performance improvements. CAD, for one thing, has not only enabled the industry to design significantly more complex products with greater efficiency but also to model "real-world" conditions of advanced wafer manufacture without incurring all of the attendant learning-curve costs. The industry has also witnessed a qualitative shift in technology development toward zero defects in the sense that defect elimination is occurring more rapidly than new generations of technology are turning over. As a result of improvements in defect density, there have been corresponding improvements in yield and therefore in process complexity (in terms of the number of mask levels) and wafer size.

Nevertheless, there are limitations to this progress as well. As Dr. Moore observed four years ago, "as the defect density is reduced to a tenth of a defect per square centimeter or lower, the yield approaches 100 percent." Although the industry has made great gains in improving average yields from 20 percent to better than 80 percent, there simply is not another factor of four left in yield improvement. Thirty years ago, Dr. Moore noted a limitation to increases in die size: "Extension to larger die size depends principally upon the continued reduction in the density of defects...(and) their density can be reduced as long as such reduction has sufficient economic merit to justify the effort." The operative words in this statement are *economic merit.*

Paying the Piper

With the industry reaching some serious limits in the ability of productivity gains to offset rising wafer capital and processing costs, it is clear that chip costs will rise. The consequence of this increase will be a marked slowdown in the rate of price/performance improvement. Historically, data show that when costs (and prices) stop falling, they do so rather abruptly. This is true because of the compounded effects of slower market growth, lower return on investment, and reduced technical improvements resulting from reduced R&D spending—less market, less investment, less opportunity.

The semiconductor memory market is already showing signs of slower growth, at least as measured in compounded annual bit growth. From 1980 to 1985, compounded bit growth in semiconductor memories proceeded at a 114 percent annual pace. Between 1985 and 1989, Dataquest observed a slowdown in the rate of bit growth to 62 percent. For the time being, the market is continuing its 60 to 70 percent growth rate, but we believe that growth will be far slower in the future.

This forecast does not imply that the market will not continue to grow in dollar terms; the semiconductor market will see healthy growth in the foreseeable future. Dataquest does expect, however, that product lifetimes will lengthen and new product introductions—generation turnover—will come slower. As a speaker pointed out during a speech at the 1990 Dataquest Semiconductor Industry Conference, "For 20 years I have been a proponent of the industry's experience curve. No longer. Moore's Law is dead or dying. This will be plainly evident in two to three years." The critical questions now before the industry concern the consequences of a slowdown in the rate of price/performance improvement and how the industry might adjust to these consequences.

George Burns
Michael J. Boss

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THE EFFECTS OF THE GULF WAR ON SEMICONDUCTOR CAPITAL SPENDING

The eruption of the crisis in the Persian Gulf in August sent a shock through the world's economic system. Consumer and business confidence plummeted. The U.S. economy, already sinking under the weight of a budget deficit, a trade deficit, and the S&L crisis, finally submerged beneath the waves of a recession.

EFFECTS OF THE GULF WAR

Dataquest has discussed the war's end with several major U.S. semiconductor manufacturers. We believe that, with the war's end, the negative consequences of the Gulf Crisis will now be reversed and there will be positive short- and long-term consequences for the semiconductor industry.

Short-Term Consequences

From our discussions with industry representatives, we believe that the following short-term consequences of the war's end are likely:

- The war's end will eliminate a major source of instability and uncertainty.
- The war's end will increase consumer and business confidence.

Long-Term Consequences

Important as the short-term consequences are, many in the industry believe that, because of the spectacular success of high technology in the war, the long-term consequences of the war's successful conclusion will be even more substantial. The following long-term consequences are expected:

- Increased awareness on the part of the U.S. government, including the executive branch, of the strategic importance of high technology in general and semiconductors in particular
- Stable level of military IC procurement, or at least less of a decrease than had been originally projected with the thawing of the cold war
- Increased support from the U.S. government for high-technology and semiconductor R&D, including direct funding, tax credits, and support for consortia
- Increased likelihood of support for an industrial/trade policy supportive of high technology

DATAQUEST CONCLUSIONS

We believe that increased confidence on the part of both business and consumers could signal an early end to the current recession. An end to the recession would buoy up semiconductor capital spending in 1991. Increased confidence and the return of general economic growth would also lead to continued growth in 1992 and 1993. At the end of the last general economic recession (in November 1982) semiconductor capital spending enjoyed (in 1983 and 1984) two record years of growth, partly due to the PC boom but also due to a resurgence of business and consumer confidence. Although Dataquest does not expect capital spending to grow as much in percentage terms as it did in 1983 and 1984, we do expect rebounding confidence on the part of business and consumers to lead to vigorous growth in capital spending. (Our current forecast looks to growth of 24 percent and 23 percent, respectively, in 1992 and 1993.)

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High technology has been a key component of U.S. defense strategy for decades. Because of its success in the Gulf War, insiders in Washington D.C. report that they have never seen enthusiasm for high technology at such a high level. The likelihood that this enthusiasm will jell into support and funding for R&D in high technology and semiconductors is now stronger than it has been for years.

There have been debate and questions for years in the United States about whether or not the U.S. government could support high technology and, if so, how to go about this. A major consequence of the Gulf War may very well be that high technology in the United States will win substantial support for its long-term health and growth from the U.S. government.

George Burns

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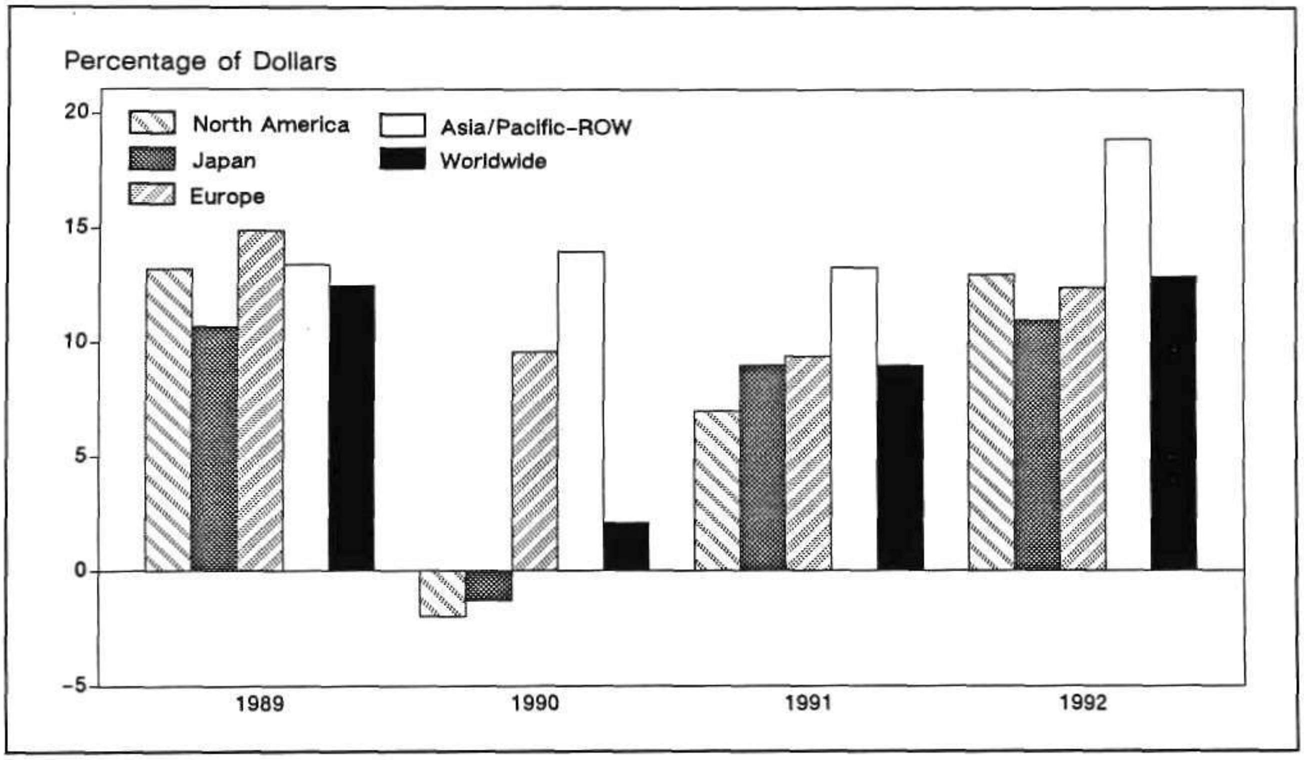
Research Newsletter

FIRST QUARTER 1991 WORLDWIDE SEMICONDUCTOR INDUSTRY OUTLOOK: EMBATTLED, BUT NOT BOMBED OUT

INTRODUCTION

In spite of a U.S. recession and the threat of war, the worldwide semiconductor industry grew in the fourth quarter of 1990 in both bookings and billings. The Persian Gulf war, which began on January 16, 1991, when the allied forces started bombing Baghdad, might be expected to cast a pall over the entire world economy to the detriment of the semiconductor industry. However, Dataquest believes that the industry will continue to grow, albeit modestly, through 1991. We expect quarterly growth to be stronger in 1992. Our annual growth forecast by region is shown in Figure 1. Overall, we expect 9 percent growth in 1991 and 13 percent growth in 1992.

FIGURE 1
Annual Semiconductor Industry Growth Rates by Regional Market (Percentage of Dollars)



Source: Dataquest (January 1991)

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The reasons for our relative optimism are as follows:

- Our monthly survey of major OEM semiconductor procurement managers continues to support improvement in the systems market outlook.
- Semiconductor inventories at OEMs are less than 20 days and within 8 days of target.
- Many semiconductor manufacturers are reporting strong bookings for the month of January.
- WSTS statistics show both bookings and billings on an upward trend through November, the last worldwide actuals available.
- Increasing pervasiveness of semiconductors in electronics and consumer goods and increasing functionality per chip will continue to raise chip average selling prices and allow the semiconductor industry to grow faster than the electronic equipment industries.
- Telecommunications equipment production continues to do well, due in part to demand from eastern Europe. This will continue to drive semiconductor consumption in Europe.
- There is evidence—in the huge approval rating of U.S. President George Bush, the large U.S. stock market rallies, and signs of improvement in the index of leading indicators—that U.S. consumer confidence has increased dramatically since the bombing of Baghdad began.
- U.S. allies have pledged $45 billion toward the cost of the war thus far, thereby alleviating a potentially onerous financial burden on one nation.

To be sure, there are also possible hazards on the horizon:

- Protraction and/or major expansion of the war in the Persian Gulf could sabotage world economies.
- Increased political and economic instability in the Soviet Union could become a very explosive situation with worldwide repercussions.
- Lack of soundness of the U.S. financial system could damage the U.S. economy if massive bank failures were to occur. This possibility can be averted by effective action on the part of the Federal Reserve Board, Congress, and the Bush administration.
- A trade war, brought on by patriotic fervor in the United States, could disrupt world economies enough to adversely affect the semiconductor industry. This possibility is avoidable if the U.S. government and its allies actively control events that might result in protectionist U.S. policies.

OUTLOOK FOR 1991 AND 1992

We have looked at several different scenarios for semiconductor industry growth this year and next. They range from highly optimistic to highly pessimistic. We believe that the most likely scenario is somewhere in between, with worldwide growth of 9 percent in 1991 and 13 percent in 1992.

In the final months of 1990, both bookings and billings were well ahead of the same period in 1989, at 13 and 14 percent, respectively. The same trend holds when looking at the three months ended November 1990 versus the three months ended November 1989. Because of this trend and because of renewed confidence levels since fighting began in the Gulf, we believe that the first and second quarters of 1991 are going to show growth, with most of it in the second quarter. We are forecasting modest growth in the third and fourth quarters of 1991. We think quarterly growth will be considerably higher in 1992 for the following reasons:

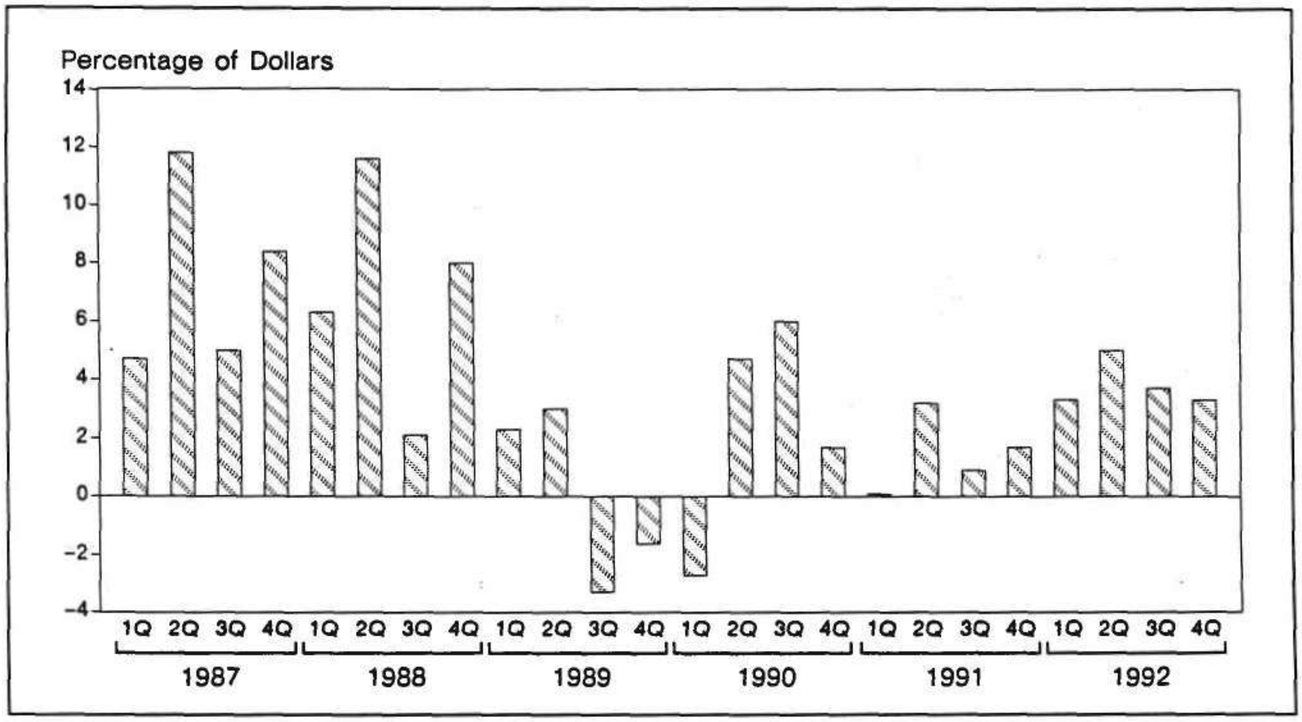
- We believe that the war will have been resolved.
- We believe that the U.S. savings and loan and banking crisis will be in the solution phase.
- We believe that psychology will play a strong role: Just as low consumer confidence contributed strongly to the U.S. recession in the fourth quarter of 1990, a positive mind frame in the electronics industry can buoy up the semiconductor industry.

Figure 2 shows our sequential quarterly growth history and forecast worldwide. Figure 3 shows worldwide growth by quarter versus the same quarter a year ago.

Regionally, we expect to see the following trends in 1991:

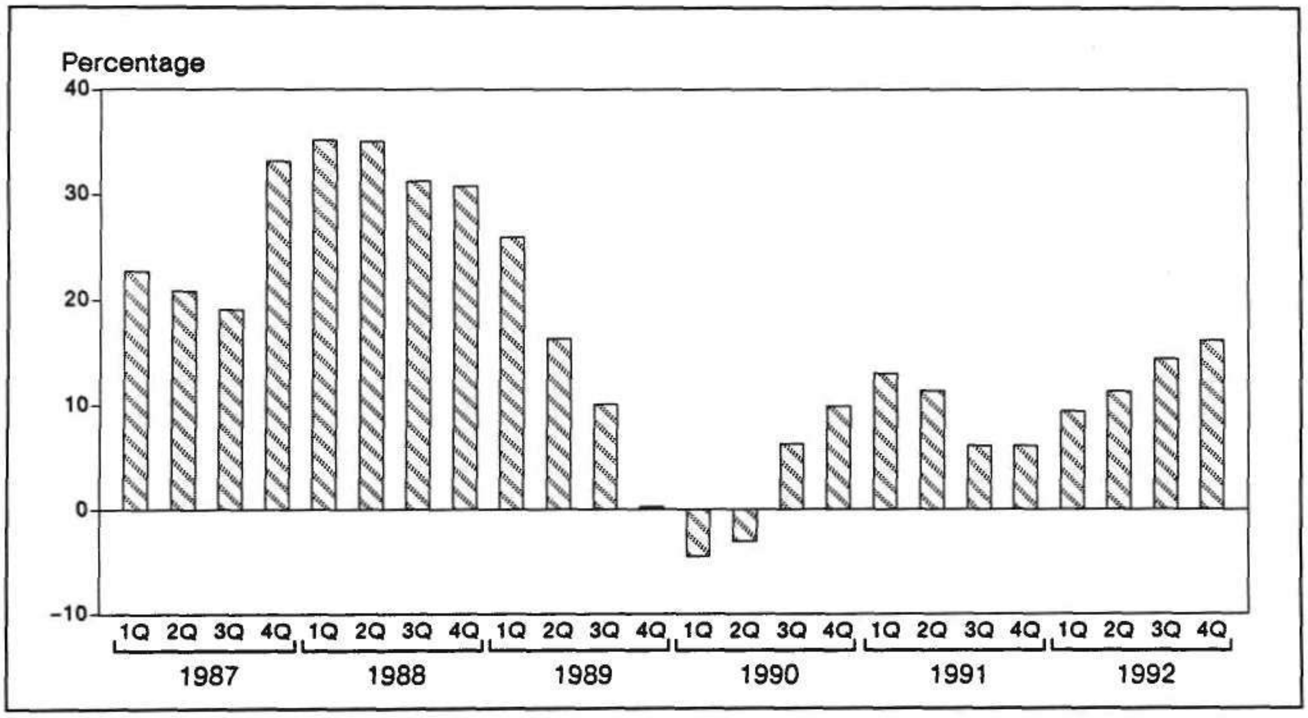
- North American market growth will be strongest in the second quarter.
- European market growth will be strongest in the first quarter. European semiconductor consumption benefited in 1990 from a boom in TV and VCR production, which we do not believe will be repeated this year.

FIGURE 2
Worldwide Semiconductor Industry Growth by Sequential Quarters



Source: Dataquest (January 1991)

FIGURE 3
Worldwide Semiconductor Industry Growth versus the Same Quarter One Year Ago



Source: Dataquest (January 1991)

- Japan will show the weakest quarterly growth of any region this year, largly due to the unprecedented economic challenges it is facing in its stock market and real estate market and the slowdown in consumer spending in the United States, upon which a large part of Japan's semiconductor consumption depends.
- The Asia/Pacific-Rest of World (ROW) market, which slowed in the fourth quarter of 1990 due to a falloff in clone demand, will resume growth in the second quarter of 1991.

In general, the outlook for the Asia/Pacific markets continues to be brighter than that for other regions for the following reasons:

- The Asia/Pacific countries' GDPs in general continue to grow at high single-digit rates.
- Much of the Asia/Pacific semiconductor demand will come from products to be sold within the country of manufacture. In fact, Japanese companies are now producing goods in Asian countries for sale there rather than for export to other regions.
- This market is still the smallest, least mature regional market; therefore, it can support a higher percentage growth than can other regions.

Our 1992 outlook calls for Asia/Pacific-ROW to remain the fastest-growing regional market, followed, in order of growth, by North America, Europe, and Japan.

DATAQUEST ANALYSIS

Never before has Dataquest forecast semiconductor industry growth during a global conflict that could affect worldwide economic powers. We believe that enough positive factors exist to result in modest industry growth both this year and next. The war could have either a significantly positive effect or, conversely, a significantly depressing effect on the semiconductor industry. We have chosen a scenario in which most volatile effects are counterbalanced by other influences, and life continues on, though perhaps not at the frenetic pace of the 1980s.

Patricia S. Cox

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Research *Bulletin*

REGIONAL WAFER FABRICATION EQUIPMENT MARKET FORECAST

SUMMARY

An understanding of regional market trends and driving forces is essential to forecasting the growth of the worldwide wafer fabrication equipment market. This newsletter provides Dataquest's forecast for the regional wafer fabrication equipment markets. In our January 1991 newsletter, we forecast the worldwide wafer fabrication equipment market to grow at a compound annual growth rate (CAGR) of 14.4 percent from $5.6 billion in 1990 to $10.9 billion by 1995. The different regional wafer fabrication equipment markets have unique characteristics and are expected to have widely different growth rates during the next five years.

Dataquest believes that the Asia/Pacific-ROW (Rest of World) and European wafer fab equipment market growth rates will substantially outpace the U.S. and Japanese market growth rates during the next five years. The continuing globalization of the semiconductor industry, the emergence of vigorous capital spending by the newly industrialized countries of the Pacific Rim, and the race by semiconductor manufacturers to achieve a manufacturing presence in each continent will have profound effects on regional market trends within the wafer fab equipment industry.

REGIONAL WAFER FABRICATION EQUIPMENT MARKET FORECAST

Table 1 displays the regional wafer fabrication equipment market forecast. Through sheer size and momentum, the Japanese wafer fabrication equipment market is expected to continue to prevail as the largest market during the next five years, although it will grow at the slowest rate among the four major geographical markets. Many Japan-based device manufacturers are rapidly shifting their capital investments to offshore fabs in their pursuit of globalization. However, leading-edge technologies such as 8-inch 16Mb DRAM fabs will continue to be built and ramped up in Japan before transfer to offshore clone fabs.

The U.S. market is expected to continue to be the second-largest wafer fab equipment market in the world. The influx of offshore Japanese fabs, together with 8-inch submicron fabs built by leading U.S. captive and merchant semiconductor manufacturers, will contribute to the momentum of the U.S. equipment market. However, U.S. semiconductor manufacturers have largely retreated from commodity-device markets such as the DRAM and SRAM markets. Instead, they have focused on high-margin, value-added designs,

TABLE 1
Regional Wafer Fabrication Equipment Market Forecast
(Millions of Dollars)

	1990	1991	1992	1993	1994	1995	CAGR (%) 1990-1995
North America	1,691	1,835	2,239	2,700	2,936	3,053	12.5
Japan	2,414	2,651	3,171	3,785	4,029	4,216	11.8
Europe	689	834	1,068	1,340	1,517	1,655	19.2
Asia/Pacific-ROW	768	890	1,211	1,657	1,935	1,977	20.8
Worldwide Total	5,562	6,211	7,689	9,482	10,417	10,901	14.4

Source: Dataquest (February 1991)

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which fetch higher revenue streams per dollar of capital investment because of their relatively higher average device prices. Many new niche-oriented U.S. device companies have elected to go the fabless route in order to escape the crippling expenses of submicron fabs. Dataquest expects a significant shift in the ownership mix of U.S.-based fabs through the 1990s.

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 to large blocs of Eastern European countries. In effect, European semiconductor manufacturers will face steeply escalating competition in their own backyards.

The Asia/Pacific-ROW market is in a transition from being an export-driven market to becoming an inwardly focused, consumer-oriented market. South Korea and Taiwan continue their strategic government-backed capital investments in leading-edge DRAMs, ASICs, and foundry businesses. In addition, Japanese semiconductor companies are building fabs in other low-labor-cost Asian countries such as Malaysia, Thailand, and China in order to cater to more mature device product demands.

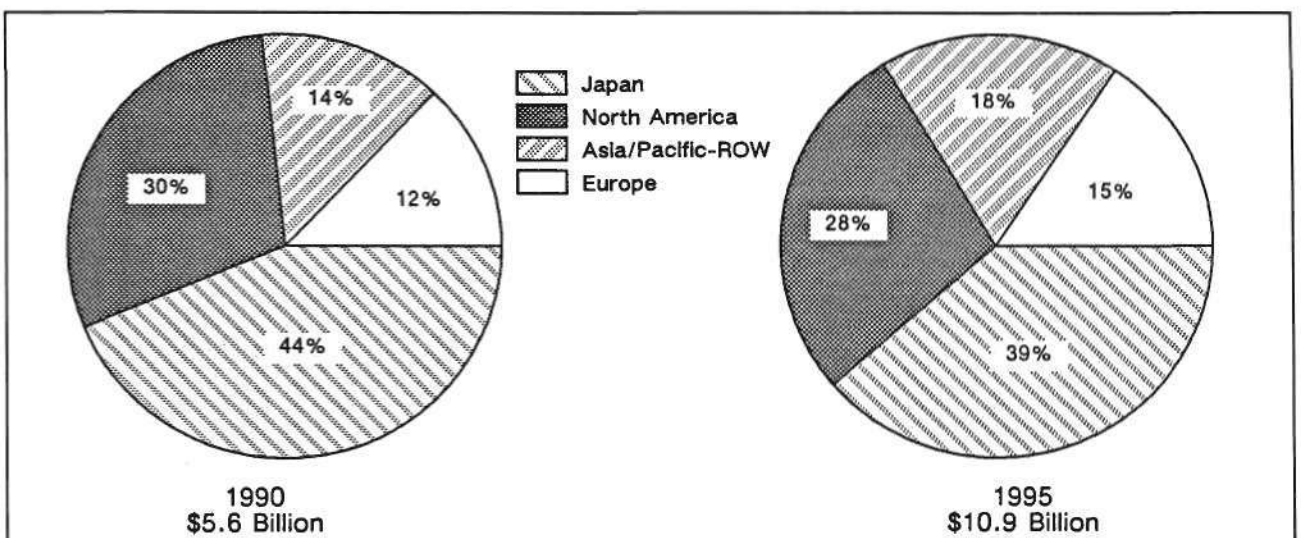
Figure 1 illustrates the relative proportions of the regional wafer fabrication equipment markets in the world market between 1990 and 1995. The rapid growth of the European and Asia/Pacific-ROW equipment market between 1990 and 1995 is readily apparent.

DATAQUEST CONCLUSIONS

Semiconductor manufacturing is emerging as a truly global industry; nevertheless, important regional differences are emerging between the various geographical wafer fabrication equipment markets. Dataquest believes that it is important to understand the forces and end-use applications driving the various regional wafer fab equipment markets. The wafer fab equipment markets are experiencing rapid change as they develop in order to support global semiconductor producers. We expect European and Asia/Pacific fab equipment markets to grow at the fastest rates during the next five years as those regions act swiftly to balance chip demand-and-supply forces. The Japanese equipment market is expected to continue its role as a high-volume, DRAM-driven leading-edge market. Captive U.S. chip producers, together with value-added merchant U.S. chip companies and offshore plants, are expected to maintain the U.S. equipment market as the second largest in the world.

Krishna Shankar

FIGURE 1
Regional Wafer Fab Equipment Markets



Source: Dataquest (February 1991)

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Research *Bulletin*

1991 SILICON WAFER FORECAST

The worldwide market for silicon wafers (prime polished, test, and epitaxial wafers) grew 11.9 percent in 1990. Dataquest's preliminary estimate of worldwide consumption is 2,028 million square inches (msi) for the calendar year. Demand grew in all regions except Europe; demand in Europe remained flat (see Table 1).

The Asia/Pacific region continued its explosive demand for wafers, led primarily by semiconductor plants located in South Korea and Taiwan. Demand for silicon wafers totaled 169 msi in 1990, up 32.8 percent from 1989. Based on the silicon wafer consumption trend, it is evident that South Korean semiconductor manufacturers, which focus heavily on MOS memory (it is about 60 percent of their production on a revenue basis), increased their device production in spite of falling memory prices with the objective of winning more market share.

Dataquest expects future growth in demand for silicon wafers in Asia/Pacific to outstrip growth in other regions of the world. The five-year forecast compound annual growth rate (CAGR) for Asia/Pacific is 19.8 percent. Consumption will increase 248 msi, a unit growth surpassed only by Japan. In the long term, China looks especially promising. Dataquest believes that recent announcements by Japanese semiconductor companies of plans to build front-end facilities on the mainland signal the beginning of an investment cycle that will result in rapid growth of silicon wafer demand in China.

Total European consumption was flat in 1990 because several European semiconductor manufacturers saw flat growth in MOS and bipolar products. Only the analog, discrete, and optoelectronic device markets grew in 1990; however,

Table 1
Silicon Consumption Forecast by Region
(Millions of Square Inches)

	1989	1990	1991	1992	1993	1994	1995	CAGR (%) 1990-1995	Delta msi 1990-1995
United States	560	620	662	733	847	861	855	6.6	235
Percent Growth	13.0	10.7	6.8	10.7	15.5	1.7	(0.7)		
Japan	909	1,022	1,101	1,221	1,400	1,434	1,447	7.2	425
Percent Growth	17.7	12.5	7.7	10.9	14.7	2.4	0.9		
Europe	216	217	244	285	343	368	395	12.8	178
Percent Growth	10.2	0.1	12.6	17.0	20.2	7.4	7.3		
Asia/Pacific	127	169	221	273	338	389	417	19.8	248
Percent Growth	29.4	32.8	30.6	23.6	23.9	15.1	7.0		
Total	1,812	2,028	2,228	2,512	2,928	3,053	3,114	9.0	1,086
Percent Growth	16.0	11.9	9.9	12.8	16.6	4.3	2.0		

Source: Dataquest (January 1991)

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Table 2
Semiconductor Production Forecast
(Millions of Dollars)

	1989	1990	1991	1992	1993	1994	1995	CAGR (%) 1990-1995
United States	21,919	21,868	23,829	27,690	33,915	36,545	38,461	12.0
Percent Growth	8.7	(0.2)	9.0	16.2	22.5	7.8	5.2	
Japan	30,275	28,390	29,353	32,875	39,593	42,176	44,255	9.3
Percent Growth	13.4	(6.2)	3.4	12.0	20.4	6.5	4.9	
Europe	6,789	7,604	9,244	11,353	14,327	15,849	17,515	18.2
Percent Growth	17.3	12.0	21.6	22.8	26.2	10.6	10.5	
Asia/Pacific	2,472	3,169	4,097	5,116	6,466	7,667	8,286	21.2
Percent Growth	32.3	28.2	29.3	24.9	26.4	18.6	8.1	
Total	61,455	61,031	66,523	77,034	94,301	102,237	108,517	12.2
Percent Growth	12.7	(0.7)	9.0	15.8	22.4	8.4	6.1	

Source: Dataquest (January 1991)

because these markets are small, the growth had little impact on the demand for silicon wafers. Even so, demand is forecast to have a 12.8 percent CAGR through 1995, the second fastest growth rate, because of the increased level of investment in fabs by U.S. and Japanese companies. Demand for silicon is forecast to be up 178 msi during the five-year period.

The demand for silicon wafers was up 12.5 percent in Japan, reaching 1,022 msi in 1990. The fact that demand for silicon wafers in Japan grew at the same time that device revenue fell 2.1 percent is attributable to the severe pricing pressures in MOS memory, which is a large segment of the Japanese market. Dataquest expects silicon wafer demand in Japan, currently the largest market in the world, to continue to grow during the next five years at a 7.2 percent CAGR. Although the growth rate is modest, Japan will far surpass the other regions of the world in terms of unit growth; consumption is estimated to increase by 425 msi during the forecast period.

Growth of 10.7 percent in the U.S. market in 1990 was a little below worldwide average growth. However, demand for epitaxial wafers exploded; merchant shipments grew over 25 percent, reaching 70 msi. Much of the demand for epi wafers was due to strong growth in microprocessor production and MOS memory devices using trench technology. Prime polished and test wafers accounted for most of the 620 msi of silicon consumed in the United States; these products grew in the 7 to 9 percent range. Dataquest's five-year forecast estimates that silicon wafer demand will have a moderate 6.6 percent CAGR.

Dataquest is currently conducting its worldwide silicon study, which will be completed by the beginning of second quarter. At that time, we will publish a more detailed breakout of the 1990 worldwide silicon wafer market and an update to our forecast. The silicon forecast is based on a semiconductor device forecast (see Table 2). Please note when comparing the two forecasts that the device forecast is reported in U.S. dollars and therefore is impacted by exchange rates and changes in device prices. Consequently, correlation between the forecast trends in the two tables may not be obvious.

Mark FitzGerald

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WAFER FAB EQUIPMENT MARKET NEAR-TERM FORECAST

SUMMARY

Dataquest is cautiously optimistic about the near-term outlook for the wafer fabrication equipment market. We expect the worldwide front-end equipment market to grow by 12.0 percent in 1991 compared with 1990. The short-term outlook is clouded by current worldwide macroeconomic and political uncertainties. In the long term, however, Dataquest believes that the wafer fabrication equipment market will enjoy healthy growth at a compound annual growth rate (CAGR) of 14.4 percent, from $5.6 billion in 1990 to $10.9 billion in 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.

ASSUMPTIONS IN THE FORECAST

Dataquest's wafer fabrication equipment forecast assumes that major world economies do not slide into a major, sustained recession in 1991. We also assume that the Middle East political crisis is resolved without a shooting war. If either of these events happen, capital spending on property, plant, and equipment will almost certainly be scaled back in the short term. Although the 1991 outlook is fraught with political and economic uncertainty, Dataquest is bullish about the long-term growth prospects for the wafer fabrication equipment industry. We will revisit our capital spending and wafer fab equipment forecast in the second quarter of 1991.

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 escalate dramatically. Lithography, deposition, and etch/clean equipment continue to be technology drivers that fuel the wafer fabrication equipment industry's growth. The wafer fabrication equipment market will exhibit robust growth over the next five years because of both unit shipment increases to support additional production and increased average selling prices driven by increased process complexity.

In 1990, the regional market growth trends were varied. In 1990, the U.S. and Japanese wafer fabrication equipment markets remained relatively flat compared with 1989 levels. The European market grew significantly because of offshore U.S. and Japanese fabs being built in Europe. However, the Asia/Pacific-ROW regional market, which enjoyed spectacular growth in 1988 and 1989, experienced a severe contraction in 1990. Dataquest expects wafer fab equipment spending in Asia/Pacific to resume healthier growth in 1991.

WAFER FABRICATION EQUIPMENT COMPANIES

Dataquest continues to observe consolidation and globalization in the worldwide wafer fabrication equipment industry. The large global companies are continuing to grow, while many small, regionally focused companies are struggling to survive. In 1990, U.S. and European equipment companies reported a disparate mixture of positive and negative growth rates relative to 1989. In contrast, Japan-based equipment companies uniformly reported flat or positive growth in 1990 due to the relatively strong domestic Japanese economy and offshore expansion of Japan-based device companies. The 1990s will see significant changes in the balance of power between European, Japanese, and U.S. equipment companies as they hasten to follow their increasingly globalized semiconductor manufacturers.

Krishna Shankar
Peggy Marie Wood

Dataquest Incorporated, 1290 Ridder Park Drive, San Jose, CA 95131-2398 / (408) 437-8000 / Telex 171973 / Fax (408) 437-0292

Table 1
Worldwide Wafer Fab Equipment Market Forecast
(Millions of Dollars)

	1990	1991	1992	1993	1994	1995	CAGR (%) 1990-1995
Lithography							
Contact/Proximity	17	16	16	15	15	14	(3.8)
Projection	80	86	99	112	119	122	8.8
Steppers	1,115	1,264	1,576	1,970	2,145	2,251	15.1
Direct-Write Lithography	75	85	105	131	154	173	18.2
Maskmaking Lithography	81	94	116	145	167	173	16.4
X-Ray	4	10	15	31	50	70	77.3
Total Lithography	1,372	1,555	1,927	2,404	2,650	2,803	15.4
Autom. Photoresist Proc. Eqp.	311	348	425	523	569	593	13.8
Etch and Clean							
Wet Process	278	312	385	465	500	520	13.3
Dry Strip	110	120	150	190	210	220	14.8
Dry Etch	610	690	845	1,068	1,180	1,252	15.5
Total Etch and Clean	998	1,122	1,380	1,723	1,890	1,992	14.8
Deposition							
CVD	550	630	770	970	1,070	1,140	15.7
PVD	360	405	490	600	650	690	13.9
Silicon Epitaxy	60	55	85	74	105	110	12.9
MOCVD/MBE	109	119	142	166	182	195	12.3
Total Deposition	1,079	1,209	1,487	1,810	2,007	2,135	14.6
Diffusion	300	330	400	500	550	575	13.9
Rapid Thermal Processing	26	30	45	60	70	80	25.2
Total Ion Implantation	444	490	632	774	835	789	12.2
Process Control							
CD (Optical and SEM)	166	192	239	290	320	330	14.7
Wafer Inspection	98	109	136	165	181	191	14.3
Other Process Control	368	391	483	574	619	644	11.8
Total Process Control	632	692	858	1,029	1,120	1,165	13.0
Factory Automation	205	225	275	340	375	400	14.3
Other Equipment	195	210	260	320	350	370	13.7
Total World Fab Equipment	5,562	6,211	7,689	9,483	10,416	10,902	14.4
Percent Change	(6)	12	24	23	10	5	

Source: Dataquest (January 1991)

Technology Trends

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Research Newsletter

A GLIMPSE AT FUTURE 64Mb DRAM TECHNOLOGIES

SUMMARY

The IEEE International Solid State Circuits Conference (ISSCC) held every February is a good barometer of future trends in device technology and applications. The 1991 conference featured several experimental versions of 64Mb DRAM devices. Although these devices are at least five years away from volume production, they provide a glimpse of future high-volume process technologies. In this newsletter, Dataquest analyzes key implications of these prototype 64Mb DRAM technologies for the semiconductor equipment, manufacturing, and materials industries in the years ahead.

64Mb DRAM TRENDS

Table 1 illustrates the key features of experimental 64Mb DRAMs unveiled by Fujitsu, Matsushita, Mitsubishi, and Toshiba at ISSCC 1991. Dataquest believes that DRAM companies will continue to push optical lithography to 0.4-micron geometries for the 64Mb DRAM. All of the 64Mb DRAM devices were characterized by multiple levels of poly/polycide and double-level interconnect technology. Gate and capacitor dielectric thickness values are expected to be in the 50- to 100-angstrom range. All four companies used variations of a stacked-capacitor cell scheme.

U.S.-based DRAM manufacturers have traditionally favored a trench capacitor-based memory cell. In contrast, Japan-based DRAM companies favor the simple stacked capacitor scheme over the more complex trench capacitor scheme with its attendant problems of trench etch damage and trench sidewall leakage currents. Toshiba appears to have the most aggressive 64Mb DRAM design. Toshiba's use of excimer laser lithography, together with the asymmetric stacked trench capacitor design, yields the smallest cell size ($0.9 \times 1.7\ um^2$) and the fastest speed (33ns).

LITHOGRAPHY TRENDS

All of these 64Mb DRAMs were fabricated with 0.4-micron design rules using optical lithography tools. Fujitsu and Mitsubishi opted for i-line steppers and Matsushita and Toshiba chose excimer laser steppers. The astonishing progress of optical lithography in combination with technology such as phase-shift masks pushes X-ray lithography even further out into the future. Semiconductor manufacturers have a huge installed base of investment and experience in optical lithography that they are reluctant to throw away. Japan-based DRAM companies are racing to convert development results in phase-shift masks into commercially useful technologies to extend the lifetime of optical lithography tools through the 64Mb DRAM generation and potentially to the 256Mb DRAM generation.

Issues such as global and local planarization, depth of focus, wafer flatness, and intrafield focus on large fields may yet force semiconductor manufacturers to eventually migrate to X-ray lithography, which has far higher depth-of-focus latitude. However, X-ray lithography has to contend with the challenges of 1X mask technology. The prohibitive costs associated with synchrotron orbital rings (SORs) for X-ray lithography, together with the technical challenges of 1X mask materials, mask fabrication, inspection, and repair, have prompted 64Mb DRAM manufacturers to stay with the evolutionary, incremental advantages of optical lithography.

Dataquest believes that the extension of optical lithography using i-line and excimer laser steppers in combination with phase-shift mask technology may enable the 64Mb DRAM device to follow the traditional decrease in the cost-per-bit curve. Given the extension of optical lithography to the 64Mb DRAM generation, lithography equipment companies need to focus on high-throughput, wide-field steppers that can offer better productivity in

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TABLE 1
Key Features of 64Mb CMOS DRAMs at ISSCC 1991

Company	Minimum Feature size (Microns)	Lithography	Poly/ Polycide Levels	Metal Levels	Gate Oxide Thickness (Angstroms)	Capacitor Type	Cell Size um x um	Chip Size mm x mm	Access Time (ns)
Fujitsu	0.4	I-line Phase-shift	4	2	NA	Double-fin stacked	1.0 x 1.8	11.27 x 19.94	40
Matsushita	0.4	KrF excimer laser	3	2	120	Tunnel stacked	1.0 x 2.0	10.85 x 21.60	50
Mitsubishi	0.4	I-line	3	2	120	Dual-cellplate stacked	1.0 x 1.7	12.5 x 18.7	45
Toshiba	0.4	KrF excimer laser	4	2	50	Asymmetric stack trench	0.9 x 1.7	9.22 x 19.13	33

NA = Not available
Source: ISSCC/Dataquest (March 1991)

spite of higher average selling prices (ASPs). Significant opportunities exist for companies to target new business areas such as i-line and excimer laser photoresists, ancillary lithography chemicals, phase-shift masks, mask coatings, mask etch, and mask inspection/repair equipment.

ETCH/CLEAN TRENDS

Dataquest estimates that the number of mask/etch levels will almost double between the 1Mb DRAM (16 levels) and the 64Mb DRAM (about 30 levels). In fact, the number of wet clean/dry etch processes will exceed the number of masking processes because of the addition of more elaborate wet/dry vapor cleans as well as blanket (maskless) etchback steps such as trench refill etchback, LDD spacer etchback, and contact/via plug etchback, intermetal planarization etchback. The unique requirements of the 3-D stacked or trench 64Mb DRAM capacitor offer extraordinary challenges to the ability of wet chemical/vapor phase cleans to truly "clean" the wafer without adding additional particles and contamination.

Dry etch equipment has to offer extremely high selectivities, uniformity, critical dimension (CD) control across 8-inch wafers, and low ionization damage in order to etch 0.4-micron gate features. A variety of plasma sources are being considered in order to handle the stringent processing requirements of 64Mb DRAM dry etch processes. New gas chemistries such as bromine, NF_3, and other non-fluorocarbon processes offer significant processing challenges to gas suppliers and dry etch equipment companies.

DEPOSITION TRENDS

DRAM manufacturers have already switched from single-level metal to double-level metal for the 16Mb DRAM generation. The challenges associated with metal step coverage dramatically increase as contact and via dimensions approach the 0.4-micron level. CVD titanium nitride, CVD tungsten, and CVD polysilicon are being examined as viable candidates for contact plug processes. Meanwhile, the efforts to improve the step coverage of sputtered aluminum and refractory barrier metals such as titanium nitride continue vigorously. Many opportunities exist for materials companies to develop new sputtering materials and CVD source materials for interconnect applications in the 64Mb DRAM generation.

The polysilicon CVD equipment market is expected to grow dramatically over the next five years in order to cater to mushrooming applications for high-quality polysilicon films at multiple levels in the 64Mb DRAM process. For example, Toshiba is reportedly planning to use four levels of poly/polycide films in its 64Mb DRAM process. Stacked capacitors and trench capacitors will use multiple poly depositions to achieve the desired cell capacitor area. Many new types of poly CVD equipment such as improved vertical LPCVD poly tubes and integrated cluster tools incorporating rapid thermal oxidation/nitridation (RTO/RTN), low-pressure poly CVD, and low-pressure tungsten silicide CVD may emerge in response to these applications.

Interlayer dielectrics between poly and first-level metal and intermetal dielectrics between metal levels need to be highly planarized because of metal step coverage, bridging, depth of focus, resist uniformity, and over-etch considerations in 64Mb DRAM wafers. In addition to the familiar spin-on-glass planarization schemes, Dataquest believes that 64Mb DRAM companies will examine other global planarization techniques such as biased electron cyclotron resonance (ECR) CVD techniques, chemical-mechanical polishing, TEOS-based plasma-enhanced CVD oxide fill/etchback, and in-situ deposition/low-temperature reflow oxides. Tungsten, poly, aluminum, and copper CVD plugs are being explored for contact and via fills. The choice of the optimum planarization and back-end interconnect process will have profound effects on 64Mb DRAM speeds, yield, and reliability.

DIFFUSION/IMPLANT TRENDS

Vertical diffusion and LPCVD tubes will probably be used for all diffusion and oxidation processes on 8-inch 64Mb DRAM wafers. Vertical furnaces offer high-quality thin oxides, thermal nitride, and polysilicon. Vertical tubes are also more compatible with the automation and film uniformity requirements of 8-inch fabs. Load-locked vertical diffusion furnaces may be used to implement tube-to-tube transfer between oxidation, nitridation, and LPCVD poly/nitride processes.

The number of implant steps continues to rise significantly in order to precisely control the electrical behavior of 0.4-micron geometry transistors. In addition to the traditional requirements for dose uniformity and low particulates across 8-inch wafers, continuously variable tilt angles and parallel beam scanning are expected to become the norm for implanting 3-D 64Mb DRAM device structures.

Process Control Trends

CD and wafer-inspection equipment companies will enjoy major business opportunities at the 64Mb DRAM generation. The process of analyzing variations in critical dimensions at the 0.4-micron level across 8-inch wafers is a major challenge. The move toward integrated processes will lead to the loss of critical intermediate CD and wafer-condition information. Some equipment companies are evaluating the incorporation of in-situ metrology tools such as CD SEM measurement chambers and particle-detection/wafer-inspection chambers onto cluster tool platforms.

Thin films and resistivity measurement systems will face similar challenges in measuring thin oxides and shallow doped junctions. Electrical measurement techniques may be used to augment physical thin-film thickness and resistivity measurements.

Dataquest Conclusions

Dataquest believes that DRAM process technology will continue its evolutionary progress between generations. The extension of optical lithography and the stacked capacitor cell structure to the 64Mb DRAM devices are aimed at keeping the DRAM cost per bit on its historical decline. Dramatic increases in the complexity of lithography, interconnect, planarization, dry etch, and process-control processes may push the price tag of a 8-inch high-volume 64Mb DRAM fab to well over $600 million. At the 0.4-micron 64Mb DRAM level, interconnect process complexity and performance will be the limiting factors that control the device speed and cost per bit.

Krishna Shankar

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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Research Newsletter

EQUIPMENT AND CONTAMINATION IN THE 1990s

Process equipment costs today can exceed $2 million. Fab costs today are $300 million and will reach $1 billion by the year 2000. These sums of money are large, yet they can be jeopardized by particles smaller than one-tenth of a micron in size. This newsletter focuses on where these particles come from and their effect on process equipment and facilities in the future.

SOURCES OF PARTICLES TODAY

Eliminating particles as sources of contamination is important in semiconductor manufacturing because particles can cause "killer" defects in a device's circuits. Killer defects are defects that cause a device to malfunction. Particulates one-tenth of the size of the minimum linewidth of a device can cause a killer defect. For today's leading-edge devices (e.g., 4Mb DRAMs), this means that particles smaller than one-tenth of a micron can cause a killer defect. Defects impact yields, and yields impact the bottom line. Thus, an investment of $1 billion can be put at risk by a particle one one-thousandth the thickness of a human hair.

Dr. Venu Menon of Sematech said at a recent Microcontamination Conference that human beings and the clean room itself account for only approximately 25 percent of particulate contamination in today's state-of-the-art facility. Equipment and process account for approximately 75 percent. This percentage is very different from what it was 10 years ago. Then, human beings, clean room practices, and the clean room itself were major sources of contamination.

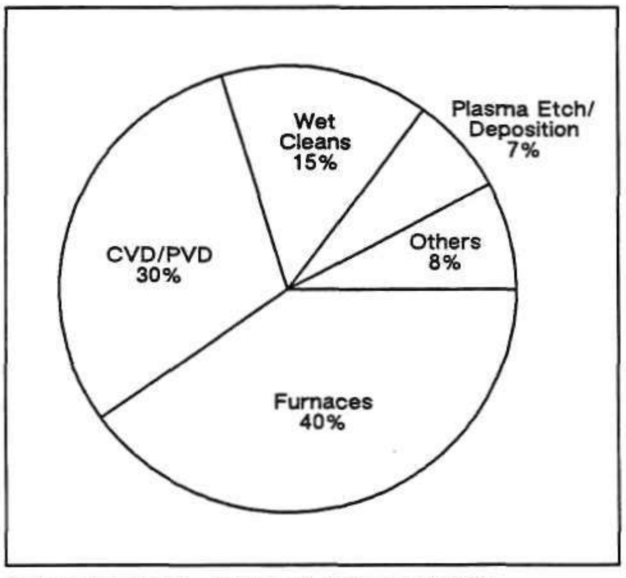
According to Dr. Menon, by 1995 the contribution of human beings and the clean room to particulate contamination will decline even further; only 10 percent of particulate contamination will be attributable to these sources. The reasons for this shift in importance of people and the clean room as sources of contamination are several: continuing improvements in clean room practices, increased use of automation, isolation of human beings from the wafer, use of microenvironments, and the advent of sub-Class 1 clean rooms.

PARTICULATE SOURCE BY EQUIPMENT TYPE

At the same conference, Dr. Menon also presented data on the source of particulate contamination by equipment type (see Figure 1). Although these data were specific to Sematech's fab in Austin, Texas, and therefore may not be representative of the industry as a whole, they were nonetheless instructive.

One further caveat to the data in Figure 1 is that particulate counts were measured by particles per bare wafer pass. This type of measurement is

FIGURE 1
Equipment-Sourced Particulate Contamination by Equipment Type



Source: Sematech, Dataquest (February 1991)

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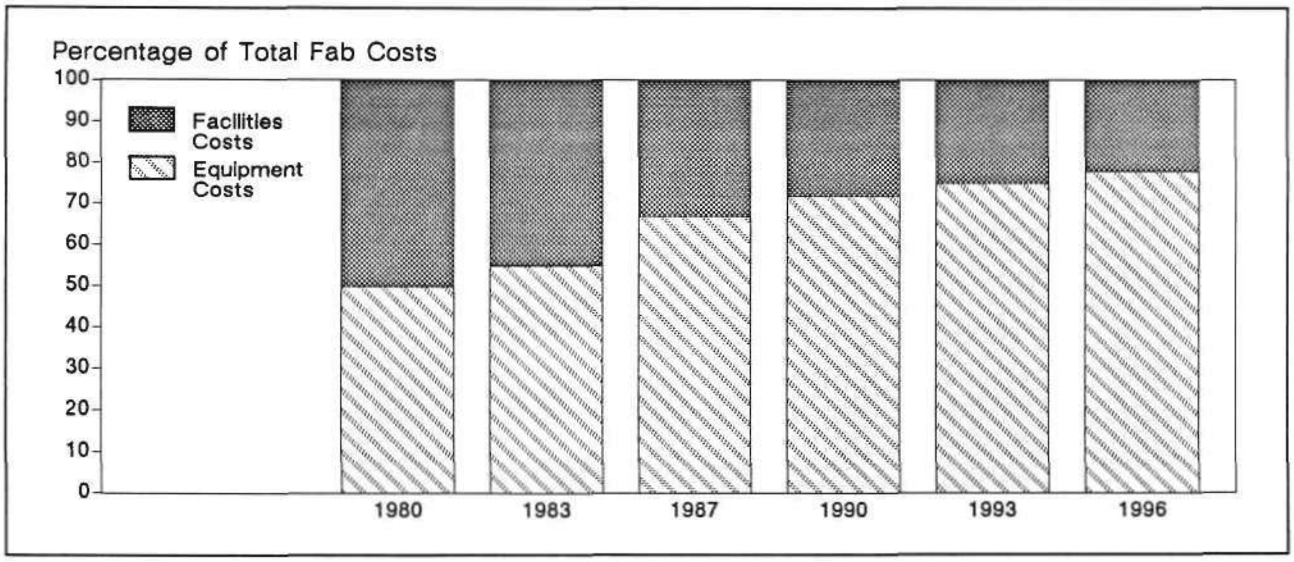
FIGURE 2
Fab Costs
Equipment and Facilities



Source: Dataquest (February 1991)

suitable for equipment used for wet cleaning; however, it does not capture the particles formed from process reactions during plasma etch and PVD/CVD.

It is ironic that the cleaning process, which after all is supposed to remove particulates, is itself a source of particulate contamination (i.e., 15 percent). Because of this fact, dry-wafer-cleaning technologies, which are cleaner than wet-cleaning technologies, will be the technology of choice for state-of-the-art fabrication by the mid-1990s. Dr. Menon estimates that wet processing will decline from over 80 percent of today's cleaning steps in a state-of-the-art fab to less than 35 percent by 1995. By the year 2000, all cleaning in a state-of-the-art fab will very likely be dry.

Because equipment and process will account for 90 percent of particulate contamination by 1995, in-situ equipment monitoring will become more important and prevalent. It will not only provide manufacturers with particulate measurement within the process chamber during a process, it will also allow for the real-time correction of process equipment problems.

DATAQUEST CONCLUSIONS

Contamination control engineers and semiconductor manufacturers will seek the sources of particulate contamination less in people and the clean room and more in equipment and process. Because dry-wafer cleaning is cleaner than wet-cleaning technologies, there will be a shift from wet-cleaning processes to dry-wafer-cleaning processes. By the end of the decade, virtually all cleaning in state-of-the-art manufacturing will be dry cleaning. Another result of the prominence of equipment and process as sources of particulate contamination is that in-situ monitoring will become increasingly important.

Equipment and process will continue to be major sources of particulate contamination in the 1990s. Therefore, equipment vendors not only will have to face the sub-half-micron challenges of resolution, etch, and deposition, they also will have to face the challenge of eliminating particles one-tenth the size of the technology they were designed to fabricate. This challenge will cost money.

To make their equipment cleaner, equipment companies' R&D expenses will continue to rise, as will the likelihood that the cost of manufacturing the equipment will escalate. The result will be cleaner equipment and processes—and more expensive equipment.

Finally, because both people and clean room contributions to particulate contamination will decline relative to equipment and processes, we can expect facility costs in the 1990s, while continuing to rise at a faster rate than in the past, to rise at rates slower than the growth of equipment costs for a new state-of-the-art fab. Therefore, as shown in Figure 2, equipment costs will continue to grow as a percentage of total fab costs.

George Burns

Company Information

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Research *Newsletter*

A QUICK LOOK AT
TEXAS INSTRUMENTS

This newsletter provides a quick look at Texas Instruments' (TI's) semiconductor capital spending, R&D spending, capacity by line geometry, planned facilities, and recent company highlights as related to semiconductor manufacturing. This newsletter is part of the "Quick Look" series of newsletters from Dataquest's Semiconductor Equipment, Manufacturing, and Materials Service (SEMMS).

SEMICONDUCTOR CAPITAL SPENDING AND R&D SPENDING

Figure 1 graphically illustrates TI's semiconductor capital spending and semiconductor R&D spending expressed as a percentage of semiconductor revenue by year from 1975 through 1990.

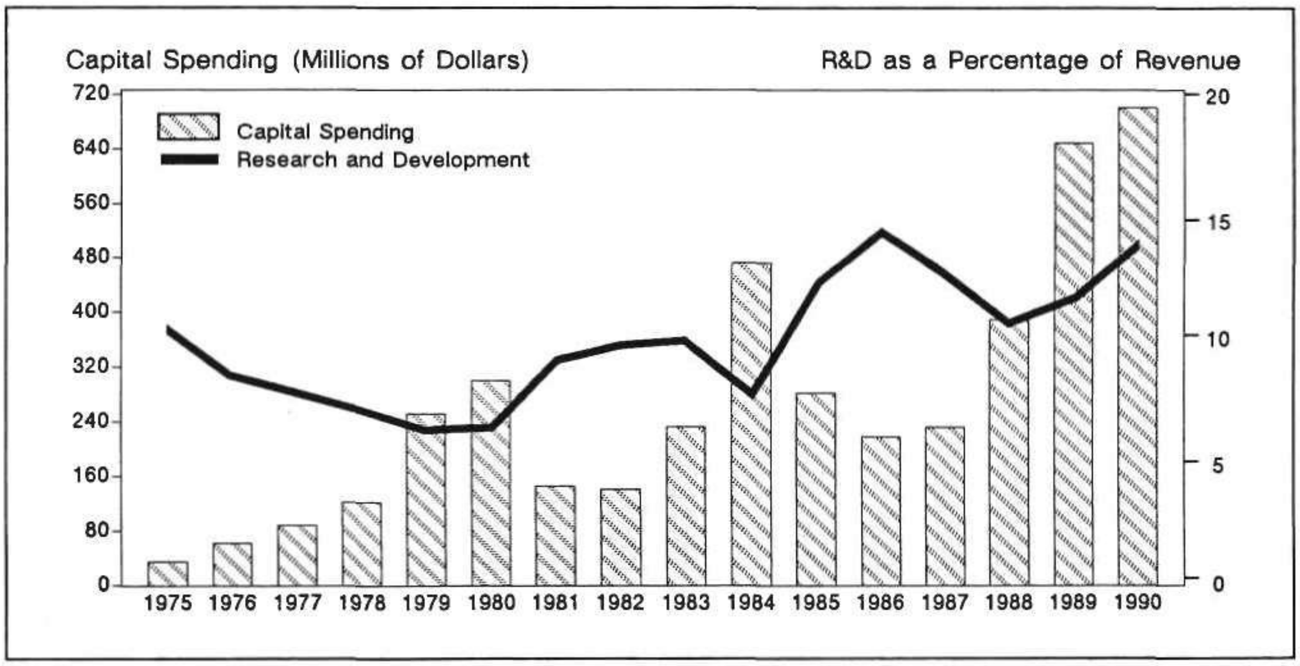
MANUFACTURING FACILITIES

Additions to TI's manufacturing facilities in 1991 and planned additions beyond 1991 are shown in Table 1. Figure 2 illustrates the percentage distribution of TI's existing worldwide semiconductor capacity by line geometries.

COMPANY HIGHLIGHTS

The following discussion highlights significant events for TI.

FIGURE 1
Texas Instruments—Semiconductor Capital Spending and R&D Spending by Year



Source: Dataquest (February 1991)

SEMMS Newsletters 1991 Company Information

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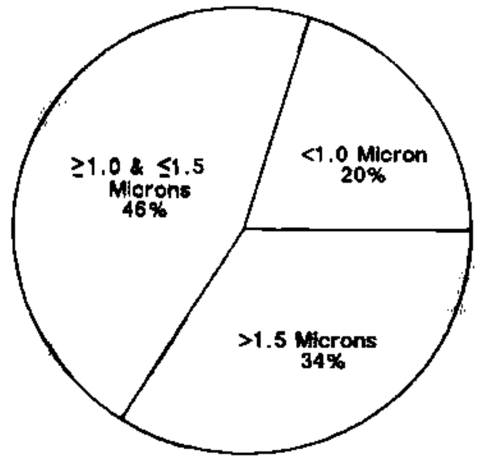
Table 1
Texas Instruments' Planned Facilities—1991-1993

Location	Products	Wafer Size	Year
Hiji, Japan	4Mb DRAMs, 1Mb SRAMs	8-inch	1991
Hsinchu, Taiwan[1]	4Mb DRAMs	6-inch	1991
Tsukuba, Japan	R&D facility	NA	1991
Avezzano, Italy	16Mb DRAMs	8-inch	1992
Hyogo, Japan[2]	VLSI logic, ASICs	8-inch	1992
Hiji, Japan	16Mb DRAMs, 4Mb SRAMs	8-inch	1993

NA = Not available
[1] Joint venture with Acer
[2] Joint venture with Kobe Steel
Source: Texas Instruments

Figure 2
Texas Instruments—Existing Capacity by Line Geometry
(Percentage of Distribution)



Note: Capacity is measured in square inches of silicon.

Source: Dataquest (February 1991)

- Avezzano, Italy

TI started pilot production of 4Mb DRAMs at its Avezzano location and plans to produce the bulk of its 4Mb DRAMs for the European market at Avezzano for the next few years. Initial investment cost of the fab is about $250 million. Over several years, $1.2 billion will be invested at Avezzano. This investment will include an additional fab and R&D center. The Italian government will contribute about $670 million to the total investment.

- Dallas, Texas

Recent events at TI's Dallas, Texas, facility include 16Mb DRAM samples and development and production in 1990 of a 0.8-micron BiCMOS 100,000-gate array. Also, TI is shifting some 1Mb DRAM capacity to digital signal processing (DSP) devices and advanced logic.

- Fresing, Germany

TI is in the process of upgrading its advanced logic line to submicron capability.

- Hsinchu, Taiwan

TI expects this joint-venture facility with Acer to produce first silicon of 4Mb DRAMs in the third quarter of 1991.

- Hyogo, Japan

Official ground breaking for this joint-venture facility with Kobe Steel occurred in February 1991, and first silicon is expected late in 1992.

- Miho, Japan

TI will start production of the 0.8-micron, 100,000-gate bipolar CMOS gate array developed at the Dallas facility. This fab already produces 1Mb and 4Mb DRAMs.

George Burns

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Research Newsletter

A QUICK LOOK AT NEC

This newsletter provides a quick look at NEC's semiconductor capital spending, R&D spending, capacity by line geometry, planned facilities, and recent company highlights as related to semiconductor manufacturing. This newsletter is part of the "Quick Look" series of newsletters 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 NEC's semiconductor capital spending by year from 1977 to 1990 and semiconductor R&D spending expressed as a percentage of semiconductor revenue by year from 1985 to 1989.

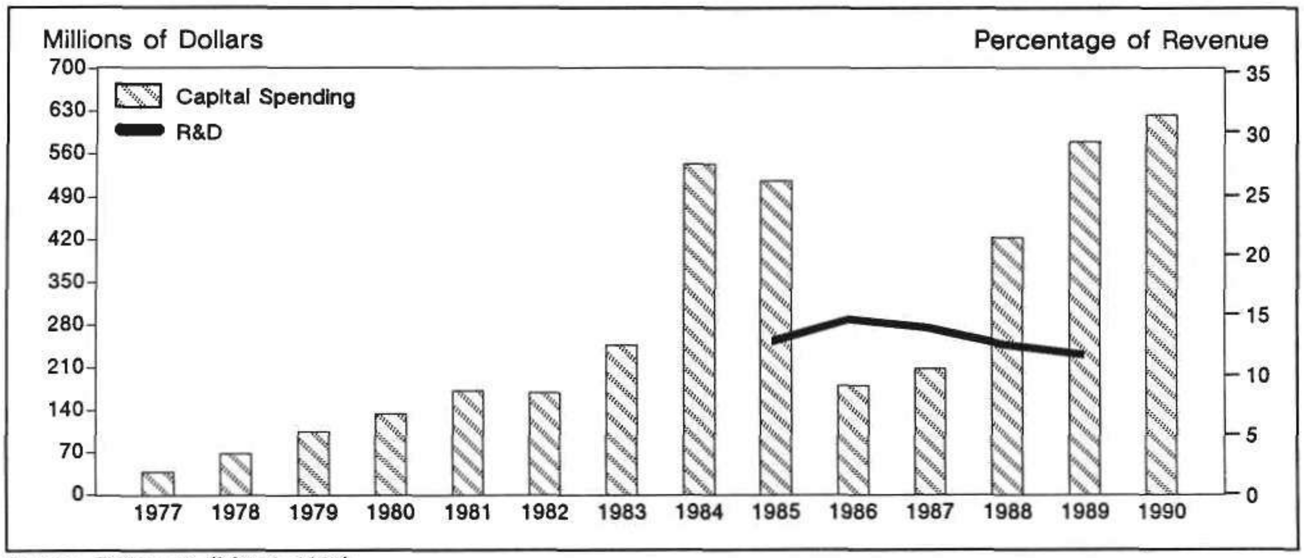
MANUFACTURING FACILITIES

Planned additions to NEC's facilities from 1991 to 1993 are shown in Table 1. Figure 2 illustrates the percentage distribution of NEC's existing worldwide semiconductor capacity by line geometries.

COMPANY HIGHLIGHTS

The following discussion highlights significant events for NEC.

FIGURE 1
NEC—Capital Spending and R&D Spending as a Percentage of Semiconductor Revenue



Source: Dataquest (March 1991)

SEMMS Newsletters Company Information

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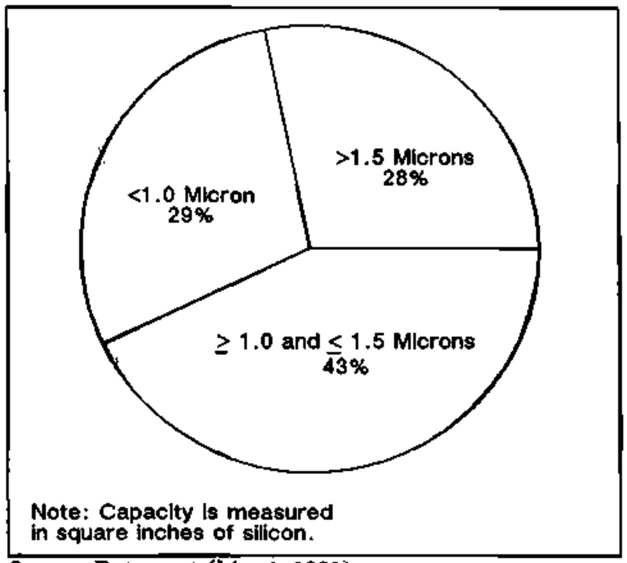
TABLE 1
NEC's Planned Facilities—1991 to 1993

Location	Products	Wafer Size	Year of Production
Livingston, Scotland	4Mb DRAMs, 1Mb SRAMS, MPUs	6-inch	1991
Roseville, California	4Mb DRAMs	6-inch	1991
Higashi-Hiroshima, Japan	4Mb DRAMs, 1Mb SRAMs, EPROMS	8-inch	1991
Kumamoto-Shi, Japan	16Mb DRAMs, 4Mb SRAMs, MPUs, gate arrays	8-inch	1992
Yamaguchi, Japan	16Mb DRAMs	NA	1993
Higashi-Hiroshima, Japan	4Mb DRAMs, 16Mb DRAMs	8-inch	1993 or 1994
Beijing, China (Joint venture with a Chinese company)	64K DRAM-level LSIs	NA	NA

NA = Not available
Source: Dataquest (March 1991)

FIGURE 2
NEC—Existing Capacity by Line Geometry (Percentage of Distribution)



Source: Dataquest (March 1991)

- NEC and AT&T Microelectronics have signed a five-year technology exchange agreement. The agreement calls for NEC to provide production technology for all of its CMOS gate array products to AT&T. In return, AT&T will supply CAD system technology to NEC.

- NEC is currently processing 9,000 6-inch wafers per month at its plant in the United Kingdom. NEC is in the process of installing $49 million in additional equipment, which will double its wafer starts to 18,000 6-inch wafers per month. This facility is producing 4Mb DRAMs and MCUs. NEC Semiconductor (U.K.) Ltd. will also start production in 1991 at a new plant in Livingston, Scotland, to produce 4Mb DRAMs for the European market.

- NEC's M-LINE fab at Roseville, California, will begin 4Mb DRAM production this year using a tool set similar to the one at the NEC Hiroshima fab.

- The NEC Hiroshima fab was completed at a cost of $425 million. This facility will be used to manufacture 4Mb DRAMs, 1Mb SRAMs, and EPROMs. This facility will eventually manufacture 16Mb DRAMs using a 0.6-micron CMOS technology.

- NEC will sell semiconductors to countries in eastern Europe for use in consumer goods and automobiles from its Berlin-based subsidiary NEC Electronic Germany GmbH.

- Within several years, NEC plans to establish a semiconductor plant in Beijing, China, to produce 64K DRAM-level ICs. The fab is a joint venture between NEC and Shoudu Iron and Steel Company.

Kunio Achiwa, Tokyo
Jeff Seerley, San Jose

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Research Newsletter

A QUICK LOOK AT
MOTOROLA

This newsletter provides a quick look at Motorola's semiconductor capital spending, R&D spending, capacity by line geometry, planned facilities, and recent company highlights as related to semiconductor manufacturing. This newsletter is part of the "Quick Look" series of newsletters from Dataquest's Semiconductor Equipment, Manufacturing, and Materials Service (SEMMS).

SEMICONDUCTOR CAPITAL SPENDING AND R&D SPENDING

Figure 1 graphically illustrates Motorola's semiconductor capital spending and semiconductor R&D spending by year from 1975 through 1990.

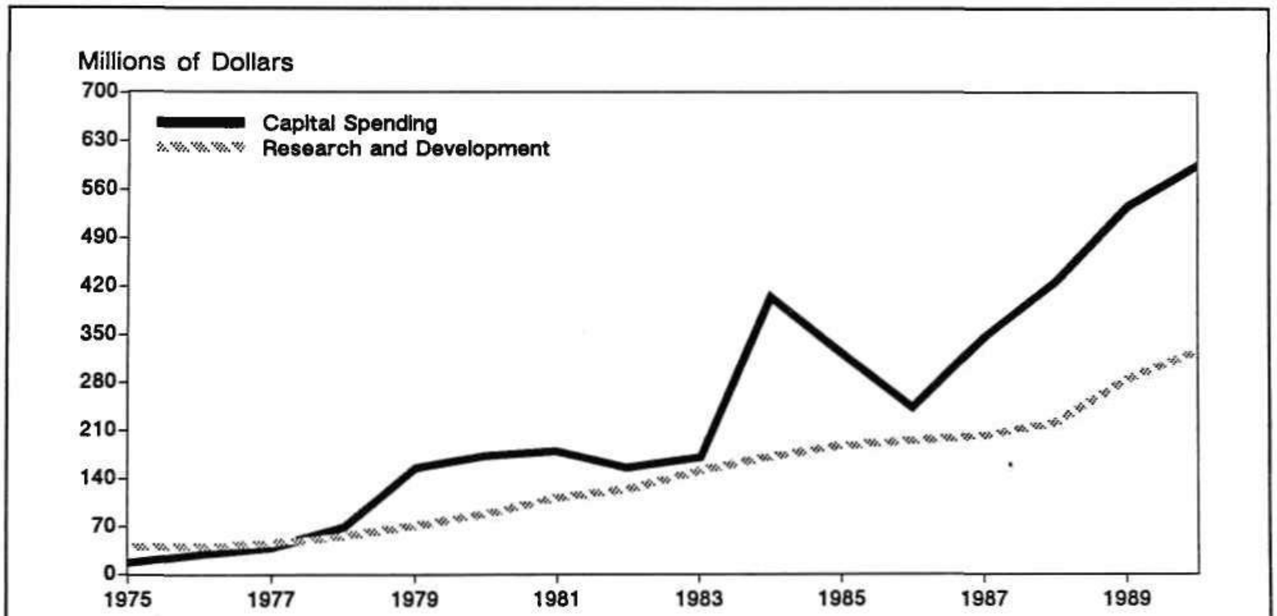
MANUFACTURING FACILITIES

Additions to Motorola's manufacturing facilities in 1990 and planned additions beyond 1990 are shown in Table 1. Figure 2 illustrates the percentage distribution of Motorola's existing worldwide semiconductor capacity by line geometries.

COMPANY HIGHLIGHTS

The following discussion highlights significant events for Motorola.

FIGURE 1
Motorola—Capital Spending and R&D Spending by Year



Source: Dataquest (November 1990)

SEMMS Newsletters 1990 Equipment Business Index

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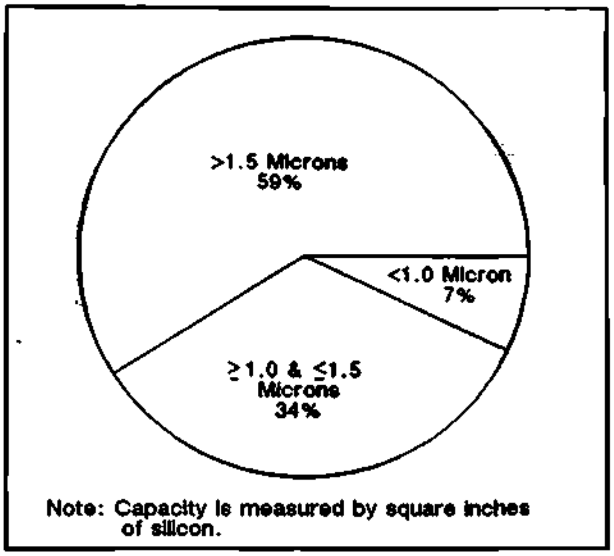
Table 1
Motorola's Planned Facilities—1990-1992

Location	Products	Wafer Size	Year
East Kilbride, Scotland[1]	DRAMs, SRAMs, MPUs	6-inch	1990
Seremban, Malaysia	Discretes, power	6-inch	1990
Hong Kong (Silicon Harbor)	Design, assembly, and test	NA	1990
Oak Hill, Texas	Memory, MPUs	8-inch	1991
Sendai, Japan[2]	4Mb DRAMs	6-inch	1991
Sendai, Japan	Assembly and test	NA	1991
Chandler, Arizona	ECL and BiCMOS, gate arrays	6-inch	1992
Chandler, Arizona	R&D line	6-inch	1992

NA = Not available
[1] Capacity expansion
[2] Motorola-Toshiba joint venture
Source: Motorola

Figure 2
Motorola—Existing Capacity by Line Geometry (Percentage of Distribution)



Source: Dataquest (November 1990)

- Oak Hill, Texas (MOS 11)

  This new fab is Motorola's first 8-inch wafer facility. It is scheduled to begin production of advanced memory and microprocessor devices in the latter part of 1991. Initial cost of this facility will be $250 million. Recent equipment orders for MOS 11 include Applied Materials CVD, etch, and implanter systems; Canon steppers; Lam Research plasma etchers; Silicon Valley Group track equipment and vertical reactors; and Varian implanters.

- Chandler, Arizona (R&D line and Bipolar 6)

  Bipolar 6, an ASIC fab designed for small lots and quick turns, will be built adjacent to Motorola's new ASIC R&D line. Motorola will be able to take devices from R&D to pilot to manufacturing, all within the same facility.

- Silicon Harbor

  The Silicon Harbor facility, located in Hong Kong, is a 326,000-square-foot facility that will house Motorola's Asia/Pacific headquarters, an advanced ASIC design center, and an assembly/test center.

- Plans for China facility

  Motorola is reported to be still interested in building an assembly/test facility in China—perhaps by 1992 in Tianjin.

- Toshiba joint venture

  Motorola's joint venture with Toshiba, Tohoku Semiconductor, is scheduled to begin production of 4Mb DRAMs at its Sendai plant in Japan in mid-1991. It is rumored that Motorola and Toshiba also will start construction of a joint-venture 4Mb DRAM plant in Europe in 1991.

George Burns

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Research Newsletter

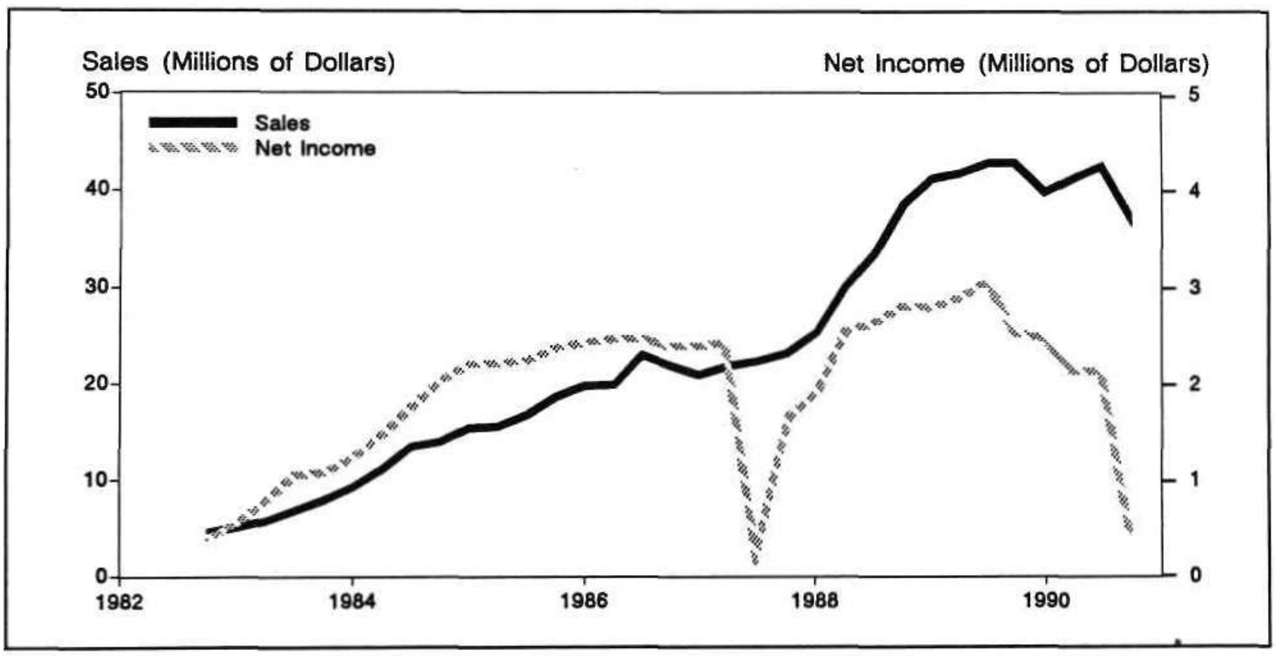
A QUICK LOOK AT
KLA INSTRUMENTS

This newsletter provides a quick look at the financial performance and recent company activities of KLA Instruments, a major supplier of semiconductor wafer fabrication equipment. This newsletter is one of the "Quick Look" series of newsletters from Dataquest's Semiconductor Equipment, Manufacturing, and Materials Service (SEMMS).

FINANCIAL REVIEW

Selected financial data for KLA are presented here with no comments or analysis. Figure 1 presents KLA's quarterly sales and net income through the quarter ending September 30, 1990. Table 1 provides a summary of fiscal year (ending 6/30) sales, net income, R&D expenditures as a percentage of sales, and return on assets (ROA) for KLA.

FIGURE 1
KLA Instruments—Sales and Net Income by Quarter (Millions of Dollars)



Source: KLA Instruments' Quarterly Reports, Dataquest (December 1990)

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TABLE 1
KLA Instruments—Fiscal Year Sales, Net Income, R&D as a Percentage of Sales, and ROA (Thousands of Dollars)

Fiscal Year (Ends 6/30)	Sales	Net Income	Ratio of Net Income to Sales (%)	Ratio of R&D to Sales (%)	ROA (%)
1982	16,162	1,510	9.3	15.0	8.4
1983	23,396	2,928	12.5	13.1	8.4
1984	42,873	5,664	13.2	14.3	8.7
1985	62,878	8,802	14.0	17.1	10.9
1986	82,526	9,854	11.9	12.3	10.0
1987	88,194	7,489	8.5	9.8	6.5
1988	112,851	8,827	7.8	12.2	6.6
1989	165,459	11,678	7.1	15.2	7.3
1990	167,916	9,380	5.6	18.4	5.2

Source: KLA Instruments' Annual Reports, Dataquest (December 1990)

COMPANY HIGHLIGHTS

The following discussion highlights significant events for KLA.

- KLA Instruments' business activities

Founded in 1975, KLA is a major manufacturer of automated optical inspection equipment primarily used by the semiconductor industry and manufacturers of printed circuit boards. The company's equipment product offerings are organized into four divisions: the Reticle and Photomask Inspection Division (RAPID), the Wafer Inspection System Division (WISARD), the Automated Test Systems Division (ATS), and the KLA Scanning, Inspection, and Classification Division (KLASIC). KLA's product-development activities are carried out in the United States (California), Germany, Israel, and Japan. Manufacturing operations are located in California, Germany, and Israel.

In the late 1970s, the company formed a relationship in Japan with Tokyo Electron Limited (TEL) to sell and service its semiconductor products. This early relationship in Japan proved to be a significant component in building the company's international presence. In 1980, international sales totaled 18 percent of total revenue, compared with 7 percent in 1979. By 1990, international sales accounted for 53 percent, more than one-half of the company's revenue.

The company's semiconductor equipment products perform optical defect detection on photomasks, reticles, and wafers; electrical defect detection on wafers and individual integrated circuits, linewidth and overlay measurements on wafers; and electrical probing on finished wafers. KLA's high-speed image-processing technology was the first to provide the semiconductor industry with automated defect detection of photomask, reticle, and wafer patterns. This achievement was significant because it allowed the subjective judgement of the operator to be eliminated from the inspection process.

- Recent significant announcements

In October 1990, KLA Instruments' WISARD division introduced its second-generation wafer inspection system, the KLA 2110. The 2110 has significantly increased throughput and improved defect sensitivity compared with its predecessors in the 20xx family of automated defect inspection systems. The 2110 has been designed specifically for defect inspection of repeating pattern arrays such as DRAMs, SRAMs, EPROMs, EEPROMs, and gate arrays. The company views the 2110 as complementary with its other 20xx product offerings, which have full-pattern capability for all device structures such as logic.

In September 1990, KLA and Nippon Mining of Japan announced that they had signed an agreement to form a new joint-venture company, KLA Acrotec Company, Ltd., for development of flat-panel display inspection equipment. The new company will be based in Japan and staffed by employees of KLA and Nippon Mining. The automated defect-detection technology of KLA is well suited for liquid-crystal and flat-panel display manufacturing, areas where it is critical to find and repair defects before processing is complete.

Joe Grenier
Peggy Marie Wood

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Research *Newsletter*

A QUICK LOOK AT
INTEL

This newsletter provides a quick look at Intel's semiconductor capital spending, R&D spending, capacity by line geometry, planned facilities, and recent company highlights as related to semiconductor manufacturing. This newsletter is part of the "Quick Look" series of newsletters from Dataquest's Semiconductor Equipment, Manufacturing, and Materials Service (SEMMS).

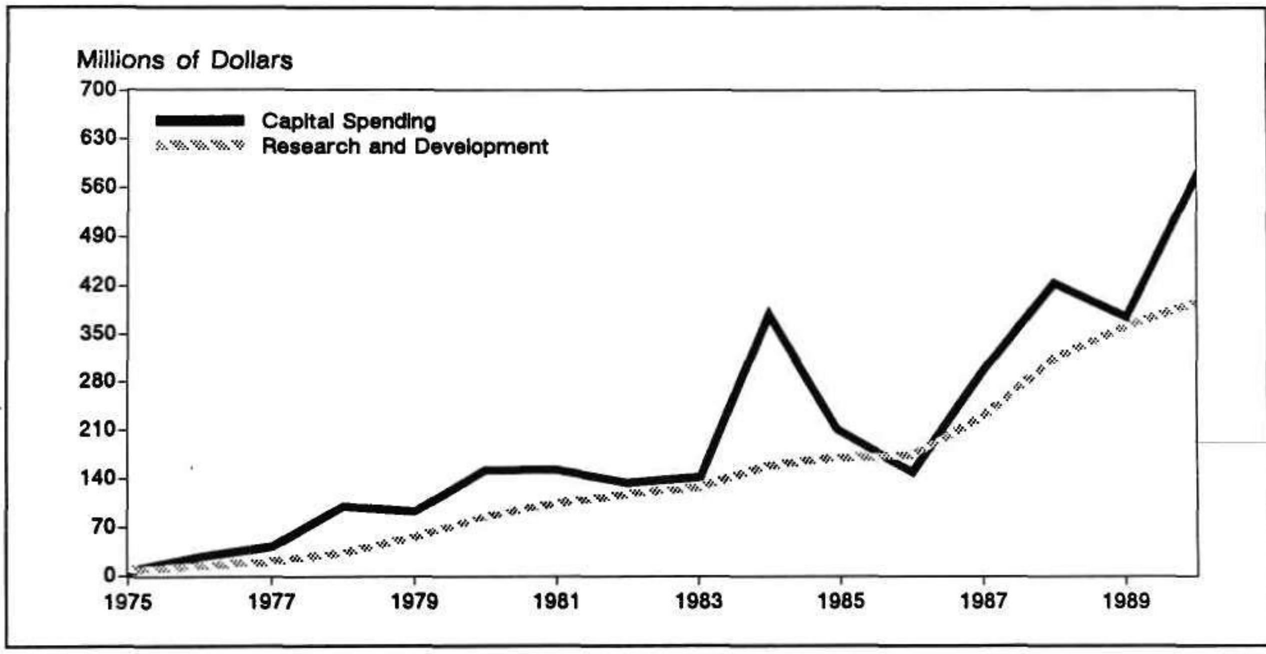
SEMICONDUCTOR CAPITAL SPENDING AND R&D SPENDING

Intel's semiconductor capital spending and semiconductor R&D spending by year is shown in Figure 1.

MANUFACTURING FACILITIES

A percentage distribution of Intel's existing worldwide semiconductor capacity by line geometries is shown in Figure 2. Additions to

Figure 1
Intel—Semiconductor Capital Spending and R&D Spending by Year (Millions of Dollars)



Source: Dataquest (December 1990)

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Intel's facilities in 1990 and planned additions beyond 1990 are shown in Table 1.

COMPANY HIGHLIGHTS

The following discussion highlights significant events for Intel.

- Santa Clara, California (D2)

  Intel's newest developmental fab, D2, is a memory and embedded control device development fab with 25,000 square feet of clean room. It was designed to develop the manufacturing processes to support three different technologies simultaneously: current generation down to 0.8 micron, 0.5 to 0.6 micron, and 0.2 to 0.3 micron. D2 was the first development fab in the United States to use Dr. Ohmi's submicron clean room concepts.

- Rio Rancho, New Mexico (Fab 9.1 and Fab 9.2)

  Intel added significant microprocessor and advanced logic capacity in 1990 to Fab 9.1. It also began equipping its submicron Fab 9.2 to produce microprocessors and other advanced logic devices. Intel expects to begin volume production in Fab 9.2 by the second quarter of 1991.

- Chandler, Arizona (assembly and test facility)

  Intel completed an assembly and test facility in Chandler, in 1990. It will be used to assemble and test R&D and prototype devices and leading-edge production devices.

- Livermore, California (Fab 3)

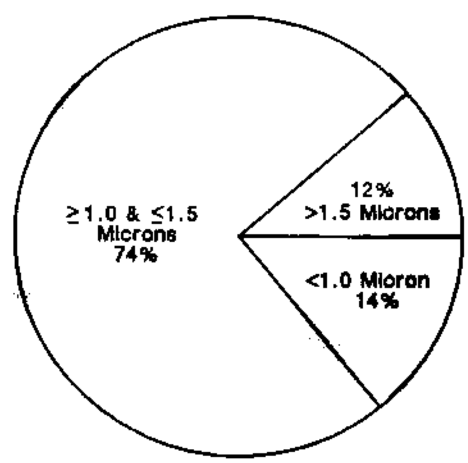
- Intel stated that its Livermore fab (Fab 3), which was going to be closed this year, will stay open an extra year to meet 80383SX demand.

- Leixlip, Ireland

  Construction of a systems manufacturing plant began at this site in 1990. Intel also plans to start construction of a wafer fab in 1991, which Dataquest expects to be an 8-inch facility. Chip production will begin in 1993.

George Burns

FIGURE 2
Intel—Existing Capacity by Line Geometry
(Percentage of Distribution)



Note: Capacity is measured by square inches of silicon.

Source: Dataquest (December 1990)

TABLE 1
Intel's Planned Facilities—1990-1993

Location	Products	Wafer Size	Year
Santa Clara, California (D2)	Nonvolatile memory technology development	6-inch	1990
Rio Rancho, New Mexico (9.2)	MPUs, EPROMs	6-inch	1991
Leixlip, Ireland	80486/80586 MPUs	8-inch	1993

Source: Intel

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Research *Newsletter*

A QUICK LOOK AT
ADVANCED MICRO DEVICES

This newsletter 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 newsletter is part of the "Quick Look" series of newsletters 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.

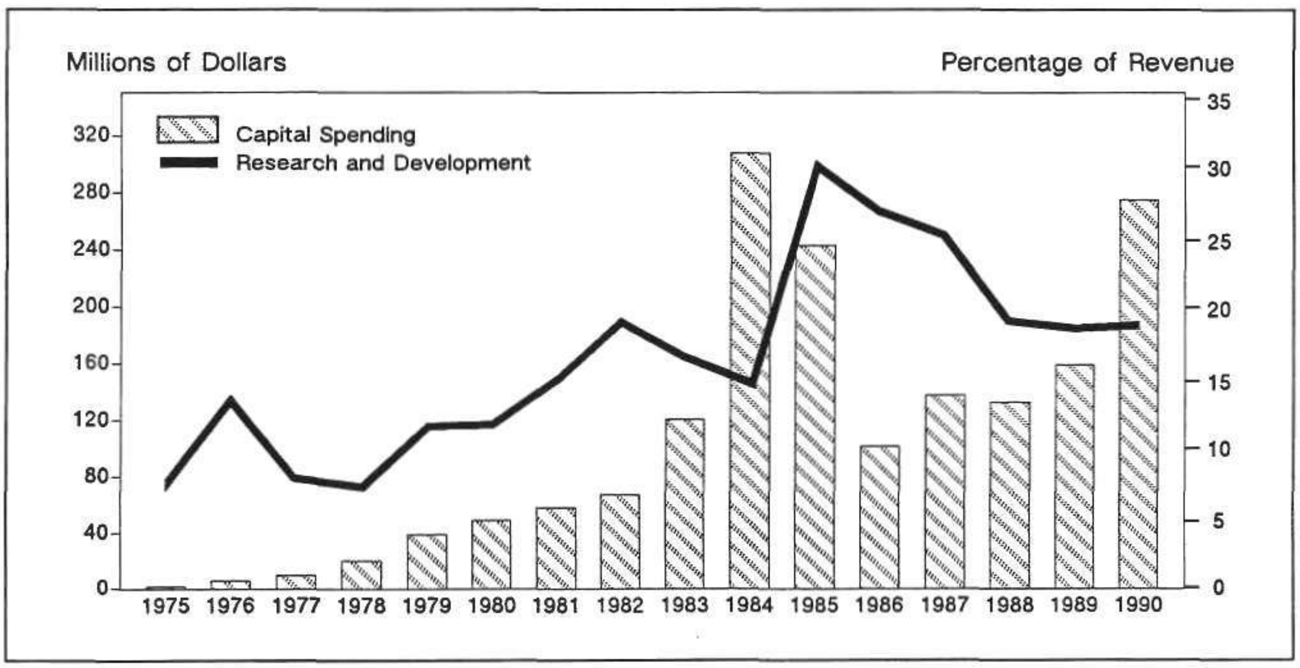
MANUFACTURING FACILITIES

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.

FIGURE 1
AMD—Capital Spending and R&D Spending by Year



Source: Dataquest (January 1991)

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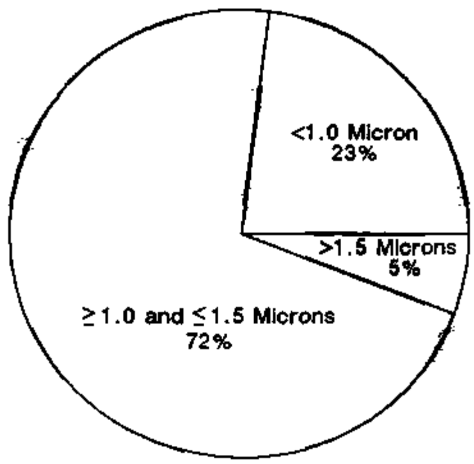
TABLE 1
Additions to Advanced Micro Device's Facilities—1990

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 (January 1991)

- 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.

- 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.

- San Antonio, Texas (bipolar facilities)

  AMD sold its bipolar facilities in San Antonio to Sony for $55 million.

- 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.

George Burns

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Research *Newsletter*

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.

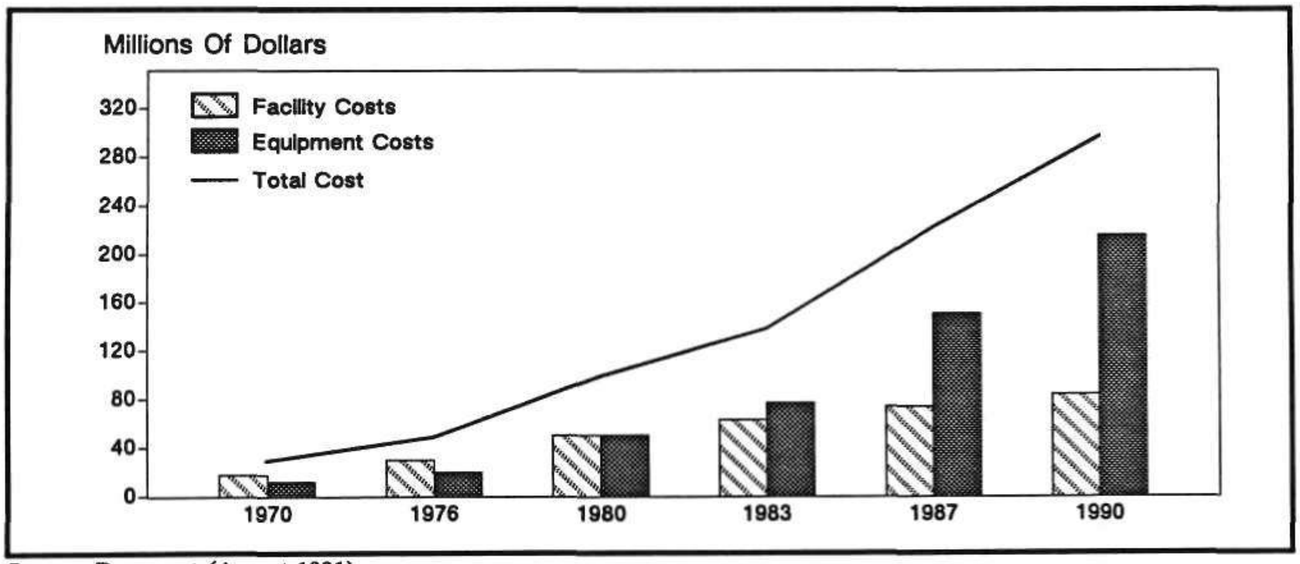
DEFINITION OF A MICROENVIRONMENT

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.

Figure 1
Building and Equipment Costs for a High-Volume Fab Line



Source: Dataquest (August 1991)

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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.)

Jeff Seerley
Don Briner

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Research *Newsletter*

ALLIANCES: LARGE COMPANY RIVALRIES SPAWN START-UPS

Small start-up semiconductor companies, conceived in response to exogenous technological changes, are born of the competitive rivalry among large incumbent companies. This view is contrary to the popularly held belief that large companies stifle the emergence of start-ups. However, according to Dr. Bruce Kogut, professor in the Department of Management of Wharton School, University of Pennsylvania, it is exactly the acceptance of strategic technological alliances by large companies that fosters the emergence of start-ups.

Dr. Kogut further believes that major companies strategically encourage start-up companies as a way to promote proprietary technologies into industry standards. In this manner, they may even consciously extend their competition with their major rivals.

Under Dataquest's sponsorship, Dr. Kogut and doctoral candidate Dong-Jae Kim, also of the Wharton School, have been analyzing data that have been collected from as long ago as 29 years on semiconductor company alliances. Between 1961 and 1989, there were about 1,975 alliances involving semiconductor companies, with 1,765 occurring after 1979 (see Figure 1). About 63 percent involved U.S. companies. Data for the study were compiled from Dataquest databases and unpublished studies by the Electronic Industries Association of Japan (EIAJ, 1987) and New York University (NYU, 1986).

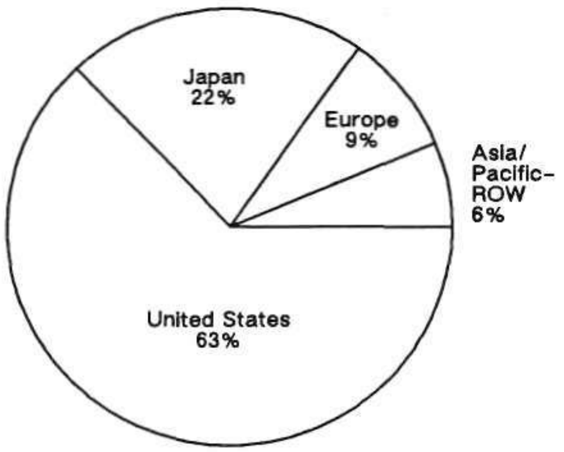
Dr. Kogut initially noted that the relationships implied some sort of network structure in the global semiconductor industry. But upon further examination he found that the companies tended to pursue strategic, hence long-term, relations. This tendency made the structure of the industry look more like an interrelated web. "A typical structure consists of one or more central players and affiliated satellite partners," he said.

He found that the central roles were most commonly played by the large, incumbent companies, while satellite roles were taken by the small, and often new, companies. Guided by this discovery, Dr. Kogut began exploring the role of large incumbent semiconductor companies in regard to the entry process of start-ups and the relationship between large and small semiconductor companies.

The traditional belief about the relationship among large and small companies competing in the same industry is characterized as antithetical. Many analysts believe that competition for market share between companies inhibits start-up activities.

The assumption of implicit hostility between large and small companies is reflected in policy debates on the very factors that sustain the health of the American economy. As per their debate in the *Harvard Business Review*, George Gilder, who supports small companies, and Charles Ferguson,

FIGURE 1
Alliances by Region (1961-1989)



Source: EIAJ, NYU, Dataquest (February 1991)

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who believes that large organizations are needed to sustain heavy capital and R&D requirements, represent the typical positions.

Mr. Gilder affirms that the American strength comes not from the law of complexity, but from the law of microcosm; the case in point being the down-scaling and technological development in the computing industry. He believes that the entrepreneur remains the driving force of economic growth in all vibrant economies, especially the U.S. economy.

In counterpoint to Mr. Gilder, Mr. Ferguson argues that high-technology industries require increasingly capital-intensive cost structures, dominated by R&D, computer networks, highly flexible production systems, and global marketing and customer support organizations. But based on what Dr. Kogut sees in the strategic alliance data, he says the argument between large and small is a mistake. "This mistake is by no means minor in light of the importance and magnitude of the decisions facing Eastern Europe and the Soviet Union regarding the dissolution of their large enterprises into thousands of small companies."

The notion that competing large companies deter small companies from entering the industry ignores evidence that the rivalry among large companies differs qualitatively from that between large and small companies. Small and large companies often do not compete directly, and competition within an industry is partitioned by size categories. However, the entrance of small companies does dramatically impact maturing but innovative industries such as the semiconductor industry. Both small and large companies appear to benefit substantially from each other. The innovative activities of the new small companies pushes out the boundaries into new subfields and even to new major branches.

Start-up companies seek protective alliances with large incumbent companies in order to enhance their chances for growth and survival. The large companies seek to establish central positions in brokering and sharing knowledge in the development of new subfields.

The evolution of the semiconductor industry has displayed a cyclical pattern of new entries to the industry. The first burst occurred in the 1950s and early 1960s after the invention of the transistor. The dominant vacuum tube companies failed to extend their positions into this new technology, so start-up companies such as Fairchild Semiconductor and Texas Instruments expanded rapidly through the creation and adoption of new processes and product innovations.

But internationally, the semiconductor industry displayed a different pattern during this period. Large Japanese companies gained early access to key patents and proprietary technologies needed to build a domestic industry. Because technology went to the large companies of Japan and there was a tendency against technology sharing at that time, few start-ups entered the market in Japan. In Europe, most of the initial semiconductor production occurred by U.S. companies' subsidiaries. Gradually, European companies entered the market, although mostly in niche areas.

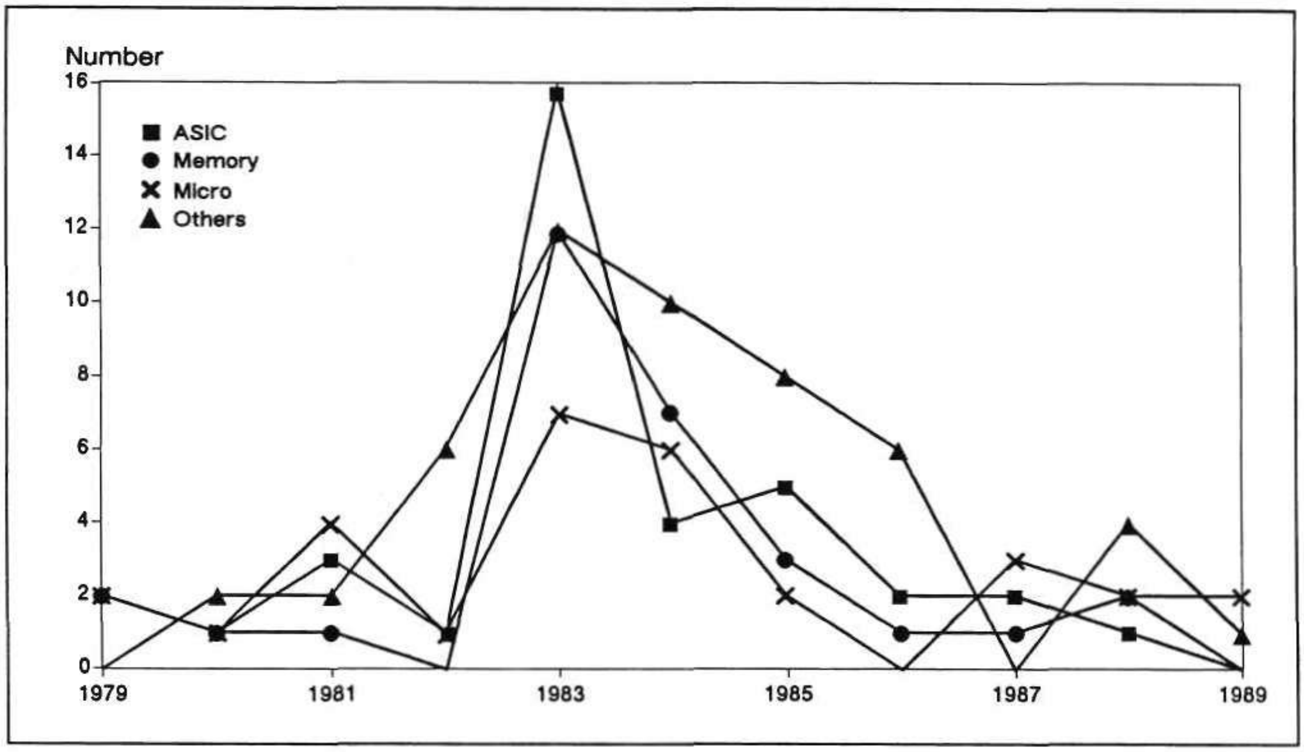
During the late 1960s and 1970s, start-up entries were slow. However, the computer industry in the United States grew, and the proliferation of desktop computers came later, which fostered a host of new specialty semiconductor opportunities. These opportunities led to a rash of start-up companies in the late 1970s and 1980s (see Figure 2). To a lesser extent, start-ups entered the semiconductor market in Europe and Japan during the same period. Many of the start-ups of this era were design centers without fabs.

As start-ups entered the subfields, they developed features that complemented existing products manufactured by established companies. For example, some of the semiconductors could increase microprocessor clock speeds. In order to take advantage of this feature, start-ups need access to proprietary information from the major companies. In establishing technology agreements with the major established companies, both the start-up company and the major company benefited. Start-up activity usually preceded the building of alliances by two or three years (see Table 1).

Major companies such as Intel or Motorola shared proprietary information with small companies because the technology of the small companies enhanced the performance of their own products. The large company could harness the higher niche R&D productivity of the smaller company, while the small company enhanced its chances for growth and survival. Both were betting on increased market share with the prospects of becoming an industry standard.

In strategic alliance development, it should be noted that not only must microcomponents be compatible with the microprocessor they support, but so must application-specific integrated circuits (ASICs) and various memory products such as SRAMs and EPROMs. This compatibility requires cooperation from the dominant company in order to acquire the proprietary knowledge and legal rights that result in a strategic alliance. The

FIGURE 2
Start-Ups by Device Type



Source: EIAJ, NYU, Dataquest (February 1991)

TABLE 1
Alliances Versus Start-Ups by Year

	'80	'81	'82	'83	'84	'85	'86	'87	'88	'89
Alliances	21	35	52	88	153	232	300	420	325	139
Start-Up Entries	5	10	8	47	27	18	9	6	9	3

Source: EIAJ, NYU, Dataquest (February 1991)

proliferation of these supporting products moves the primary product ever closer to becoming an industry standard, as have the Motorola 68XXX microprocessors/microcontrollers and Intel's 80X86 microprocessors.

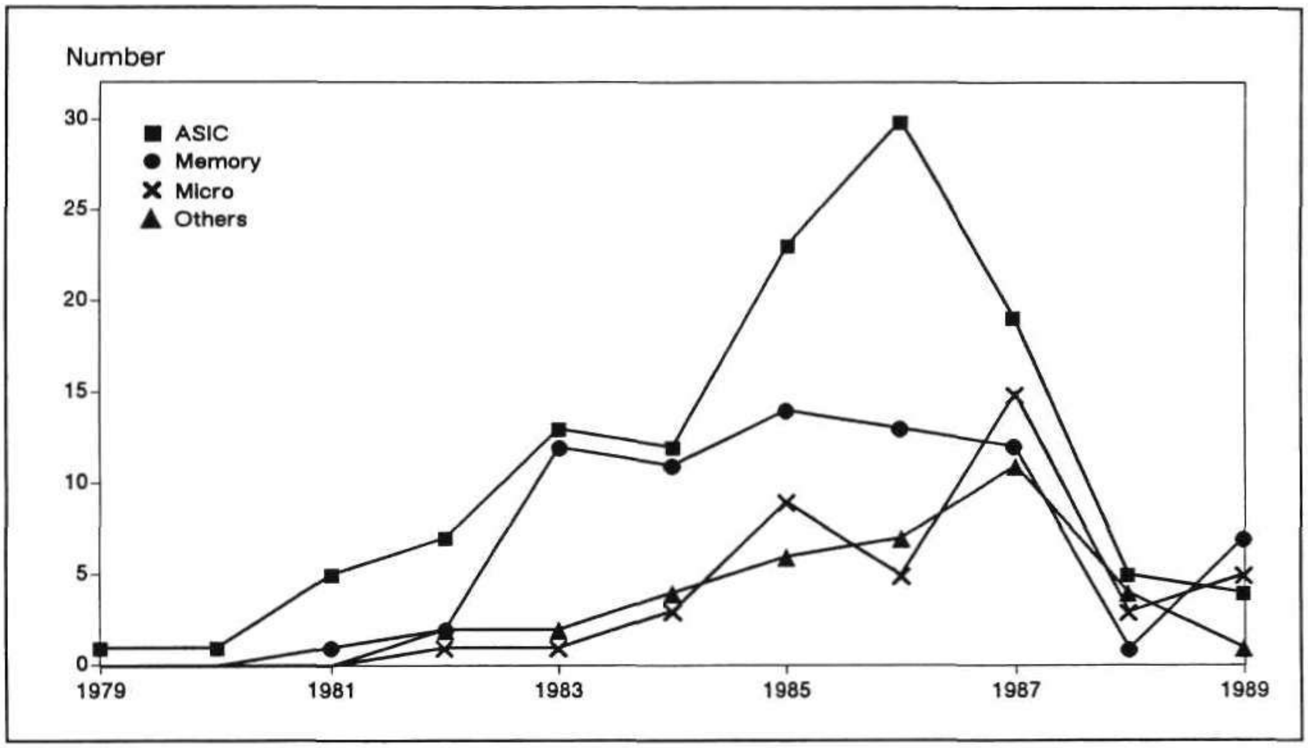
Given the depth of data, Dr. Kogut theorizes that alliances, through cooperation and centrality, have played a role in the evolution of the semiconductor industry as evidenced through the entry of start-ups. He tracked the entry of start-up companies by product type: ASIC, microcomponents, memory, analog, optoelectronics, discrete semiconductors, and gallium arsenide (GaAs).

By further tracking the pattern of alliances by type of product and establishing a network of centrality, Dr. Kogut captures the extent to which companies connect other companies to each other. He notes that in the 1980s he saw a combination of new microprocessor-related technologies that focused on customized integrated circuits (see Figure 3). He believes that this trend spawned an innovative wave that generated new opportunities for start-ups and established companies alike.

He suggests that the competitive uncertainty among the established companies spilled over into a race to encourage start-ups to innovate technologies compatible with their proprietary standards. By establishing cooperative relationships, incumbent companies signaled their willingness to share critical technologies or help new companies survive by providing manufacturing capacity. This, he says, induces the birth of new companies.

Dr. Kogut further suggests that the need for a major company to seek a strategic alliance diminishes as its product gains acceptance in the market and becomes an industry standard. For example,

FIGURE 3
Device-Specific Alliances by Year



Source: EIAJ, NYU, Dataquest (February 1991)

Intel and Motorola both have market acceptance of their microprocessors to the level of an industry standard. He says that these companies' dominant positions virtually have the industry locked into their standards, which is why their rate of strategic alliances is falling off. Barring new technological developments, the rate of strategic alliances will not increase (see Table 2).

National Semiconductor, by contrast, introduced a 32-bit microprocessor in the same time frame as did Motorola and Intel, but has not yet received the same level of market acceptance. National's rate of strategic alliance is still high, but there is a decreasing incentive for small companies to establish an alliance with National in this product area.

DATAQUEST ANALYSIS

Dataquest concurs with Dr. Kogut's analysis that large semiconductor companies do stimulate new company birth and development through the acceptance of strategic alliances. However, the relationship between small and large companies is delicate. Cooperation with start-ups and small

TABLE 2
Selected Companies' Alliance Shares (Percentage)*

Year	Intel	Motorola	National
1979	0	1.77	1.33
1980	0	1.87	1.49
1981	0.88	2.07	1.48
1982	1.81	2.04	1.13
1983	2.59	2.10	1.62
1984	3.46	2.06	2.81
1985	3.46	2.09	2.67
1986	2.87	2.01	2.57
1987	2.72	1.77	2.97
1988	2.50	1.61	3.42
1989	2.53	1.65	3.22

*Number of alliances of the company (cumulative)/total number of alliances (cumulative) x 100.
Source: EIAJ, NYU, Dataquest (February 1991)

companies as an extension of rivalry among large companies can be stable only as long as the rivalry persists under conditions of technological growth and innovation. As a dominant company emerges, cooperation is no longer a potent strategy for either the leader or the stragglers.

It also appears that the health of an industry and economy is the result of a delicate and evolutionary balance between cooperation and competition, between innovation and diffusion, and between small and large companies. Entry, growth, and exit are elements of the revival and persistence of industries and their subfields. These processes also reflect the ecological balance achieved through entrepreneurship of small companies and the cumulative knowledge and assets of larger companies. The policy position, then, cannot be for the promotion of any size of company but only for the appropriate and dynamic mixture of both large and small companies.

Marc Elliot

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Research Newsletter

U.S. COMPANIES TOP LIST FOR STRATEGIC ALLIANCES

INTRODUCTION

Strategic alliances among companies have become commonplace in the semiconductor industry around the world. But the United States tops the list for the number of strategic semiconductor alliances with 63.3 percent of the 1,875 strategic alliances instituted worldwide since 1961 (see Table 1). This should not be a surprise because the majority of individual semiconductor companies are in the United States. What is significant are the types of agreements instituted in the different regions.

THE STRATEGIC ALLIANCE STUDY

Because alliances have a direct effect on the direction of the industry, Dataquest sponsored a study and analysis of the alliances by Whorton School of Business, University of Pennsylvania. Data on semiconductor company alliances, going back 29 years, were compiled and analyzed by Professor Bruce Kogut and Doctoral Candidate Dong-Jae Kim of the Department of Management at Whorton. The following seven types of alliances were identified:

- Acquisition (includes merger) (ACQ)
- Joint venture (JV)
- Equity investment (EQT)
- Licensing (LIC)
- Second sourcing (SCND)
- Cooperative agreement (COAG)
- Technology transfer (TECH)

The recorded agreements cover 20 countries and have been grouped into four regions: the United States, Japan, Europe, and Asia/Pacific-Rest of World (ROW). These data come from Dataquest and from unpublished studies conducted by the Electronic Industries Association of Japan (EIAJ, 1987) and New York University (NYU, 1986). The study covered the period from 1961 to 1989. In a few cases, the agreements include more than two companies.

TABLE 1
Total Number of Alliances (1961-1989)*

	United States	Japan	Europe	Asia/Pacific-ROW	Total*
United States	1,538	506	214	120	2,378
Japan	506	242	61	31	840
Europe	214	61	49	25	349
Asia/Pacific-ROW	120	31	25	13	189
Total	2,378	840	349	189	3,756

*Double counted: each participant in an alliance is counted as one.
Source: EIAJ, NYU, Dataquest (February 1991)

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Since the early 1980s, the most accepted form of alliance worldwide is the cooperative agreement (53.3 percent) followed by technology transfers at 10.9 percent (see Table 2). Licensing accounted for only 8.4 percent, second-sourcing for 8 percent, acquisition for 7.8 percent, and joint ventures for 6.3 percent. Equity investment was the least-used form of alliance. Although the acquisition form of alliance is considered "noncooperative," it is still popular, growing from 3 percent of the alliances in 1986 to 15.1 percent in 1989 (see Table 3).

Alliances increased dramatically in the 1980s, with an average annual growth rate of 33.3 percent, but reached the peak in 1987. It is likely that the decline since 1987 indicates the increasing density of relationships within the industry because of the limited number of companies in the industry.

United States

In the United States, 49.6 percent of the alliances are cooperative agreements (see Table 4). This is fairly close to the worldwide industry average of 53.3 percent. But the second-highest type of strategic alliances in the United States is acquisition at 13.1 percent of the total—nearly twice the

Table 2
Worldwide Alliance Type Trends

Year	ACQ	JV	EQT	LIC	SCND	COAG	TECH	Total
1980	10	1	4	2	0	3	1	21
1981	7	0	4	5	2	13	4	35
1982	8	1	4	6	4	17	12	52
1983	2	2	7	16	10	34	17	88
1984	4	12	6	11	24	67	29	153
1985	9	18	7	23	26	117	32	232
1986	10	18	11	18	35	169	39	300
1987	33	39	21	30	27	240	30	420
1988	33	15	13	16	9	220	19	325
1989	22	6	14	22	4	62	9	139
Total	138	112	91	149	141	942	192	1,765
Percentage	7.8	6.3	5.1	8.4	7.9	53.3	10.8	

Source: EIAJ, NYU, Dataquest (February 1991)

Table 3
Alliance Shares by Region
(Cumulative Percentages)

Year	United States	Japan	Europe	Asia/Pacific-ROW
1980	75.4	4.9	13.4	6.3
1981	76.3	4.7	12.2	6.8
1982	75.3	7.9	11.6	5.2
1983	73.1	10.2	10.7	6.0
1984	71.2	13.3	10.5	5.0
1985	66.1	18.2	10.2	5.5
1986	62.1	22.4	9.8	5.7
1987	62.0	23.4	9.4	5.2
1988	62.7	23.1	9.4	4.8
1989	63.3	22.4	9.3	5.0

Source: EIAJ, NYU, Dataquest (February 1991)

industry average. The other forms of alliances participated in by U.S. companies are technology transfer (9.8 percent), second-sourcing (8.3 percent), licensing (8.2 percent), equity investment (6.3 percent), and joint venture (4.3 percent).

Japan

Japan pursued strategic alliances more actively in the latter half of the 1980s, gathering 20 percent of the total number of agreements by 1989 (Table 5). The cooperative agreement appears to be the preferred form of alliance for Japanese companies (60 percent as opposed to 49.6 percent for the United States). Japanese companies use acquisition (2 percent) far less than do U.S. companies (13 percent). Joint venture is the second-most popular type of alliance in Japan (11.2 percent), followed by technology transfers (9.5 percent), licensing (6.9 percent), second-sourcing (6.3 percent), and equity investment (3.9 percent).

It is not coincidental that the Japanese have chosen U.S. partners most frequently (60 percent) for strategic alliances, because the majority of technology developments and innovations have occurred from U.S. research. Alliances between Japanese companies account for 29 percent of Japanese alliances, while these companies partner with European companies 11 percent of the time.

Asia/Pacific-ROW

One interesting phenomenon of industry dynamics is the emerging role of companies from the Asia/Pacific Rim, specifically those from South Korea and Taiwan (see Figure 1). Taiwanese companies have demonstrated a use of strategic

TABLE 4
U.S. Alliances by Type

Regional Partner	ACQ	JV	EQT	LIC	SCND	COAG	TECH	Total*
United States	258	39	106	132	130	740	126	1,538
Japan	11	49	23	36	32	293	60	506
Europe	25	3	16	8	28	101	31	214
Asia/Pacific-ROW	16	11	4	19	8	46	16	120
Total	310	102	149	195	198	1,180	233	2,378
Percentage	13.1	4.3	6.3	8.2	8.3	49.6	9.8	

*Double counted: each participant in the alliance is counted as one. Totals include 11 unidentified nationalities.
Source: EIAJ, NYU, Dataquest (February 1991)

TABLE 5
Japanese Alliances by Type

Regional Partner	ACQ	JV	EQT	LIC	SCND	COAG	TECH	Total*
Japan	2	32	8	10	10	170	10	242
United States	11	49	23	36	32	293	60	506
Europe	2	9	0	6	10	27	7	61
Asia/Pacific-ROW	1	4	2	6	1	14	3	31
Total	16	94	33	58	53	504	80	840
Percentage	1.9	11.2	3.9	6.9	6.3	60.0	9.5	

*Double counted: each participant in the alliance is counted as one. Totals include two unidentified nationalities.
Source: EIAJ, NYU, Dataquest (February 1991)

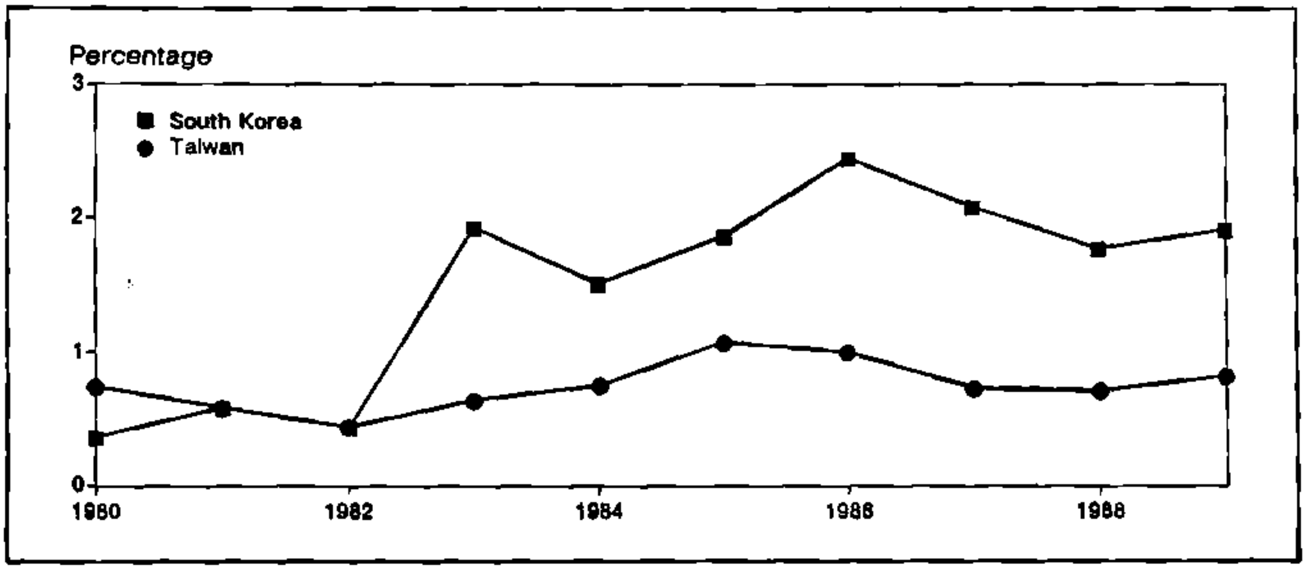
alliances since the first two licensing agreements in 1979. South Korean companies have actively participated in strategic alliances since 1980. South Korean companies reached their peak in alliances in 1986, with 2.5 percent of total worldwide alliances. Taiwan companies peaked in 1985 with about 1.1 percent of total alliances.

South Korea

More than 41 percent of South Korea's 36 alliances are cooperative agreements (see Table 6). Technology transfer (20.8 percent) and licensing (18 percent) were the second and third most frequently used types of alliances. Second sourcing (9.7 percent) has also been actively pursued. Their heavy reliance on technology transfers, licensing, and second sourcing indicates that South Korean companies have, so far, been technology innovation followers. However, this may be gradually changing as they sink more money into R&D.

More than 76 percent of South Korean companies' alliances are with U.S. companies. But it is interesting to note that few (only seven) of the alliances have been with Japanese companies. This small portion of Japanese partners might indicate the basis of an old argument against Japanese companies' policies toward developing countries: they are unwilling to share or transfer technological know-how.

Figure 1
Alliance Shares—South Korea and Taiwan



Source: EIAS, NYU, Dataquest (February 1991)

Table 6
South Korean Alliances by Type

Regional Partner	ACQ	JV	EQT	LIC	SCND	COAG	TECH	Total*
South Korea	0	0	0	0	0	6	0	6
United States	1	2	3	11	7	20	11	55
Japan	0	0	0	1	0	4	2	7
Europe	1	0	0	0	0	0	2	3
Asia/Pacific-ROW	0	0	0	1	0	0	0	1
Total	2	2	3	13	7	30	15	72
Percentage	2.8	2.8	4.2	18.0	9.7	41.7	20.8	

*Double counted: each participant in the agreement is counted as one.
Source: EIAJ, NYU, Dataquest (February 1991)

TABLE 7
Taiwanese Alliances by Type

Regional Partner	ACQ	JV	EQT	LIC	SCND	COAG	TECH	Total*
Taiwan	0	0	0	4	0	0	0	4
United States	1	1	0	4	1	10	2	19
Japan	0	0	0	0	1	2	0	3
Europe	0	0	2	0	0	1	0	3
Asia/Pacific-ROW	0	0	1	1	0	0	0	2
Total	1	1	3	9	2	13	2	31
Percentage	3.2	3.2	9.7	29.0	6.5	41.9	6.5	100.0

*Double counted: each participant in an alliance is counted as one.
Source: EIAJ, NYU, Dataquest (February 1991)

Taiwan

Licensing and technology transfers explain 35 percent of the 15 Taiwanese strategic alliances (see Table 7). The Taiwanese companies are technology followers, similar to South Korean companies. However, unlike the South Korean companies, the Taiwanese are more diversified in partner nationality. About 13 percent of the agreements are with domestic companies. The rest of the agreements are with offshore companies as follows: 61 percent, United States; 10 percent, Europe; 10 percent, Japan; 6 percent, other countries.

DATAQUEST PERSPECTIVE

A View of the Giants

A quick look at the tables shows that the United States and Japan dominate the number of strategic alliances. However, differences exist in the type of agreements used. Japanese companies generally use cooperative forms of alliances, and U.S. companies typically take a more aggressive posture. More than 60 percent of the alliances in Japan are cooperative agreements, compared with 49.6 percent in the United States. However, acquisition is used 13 percent of the time in U.S. agreements, compared with 1.9 percent in Japan.

Actually, U.S. companies use mergers and acquisitions more frequently than do companies from all the other countries in the world combined. This is a fundamental difference between U.S. business practices and those of companies in other countries.

A second basic difference is that Japanese companies have formed alliances with foreign partners more frequently than have U.S. companies. U.S. companies tend to rely on domestic partners for alliances. Japanese companies select domestic partners 29 percent of the time, whereas U.S. companies select domestic partners 65 percent of the time. This trend might be explained by a higher proportion of technology leadership in the United States; however, the leadership in several technologies has shifted to Japan.

Emerging Influences

Although South Korean and Taiwanese companies lagged behind their counterparts in technology, they do exhibit strong competitive qualities. They have been acquiring technology through their strategic alliances. With growing domestic economies and increasing domestic and worldwide semiconductor demand, Dataquest believes that the companies of these two countries will place an increasingly stronger emphasis on technology development. As a result, we expect to see more important roles played by these two emerging countries in the future.

Marc Elliot

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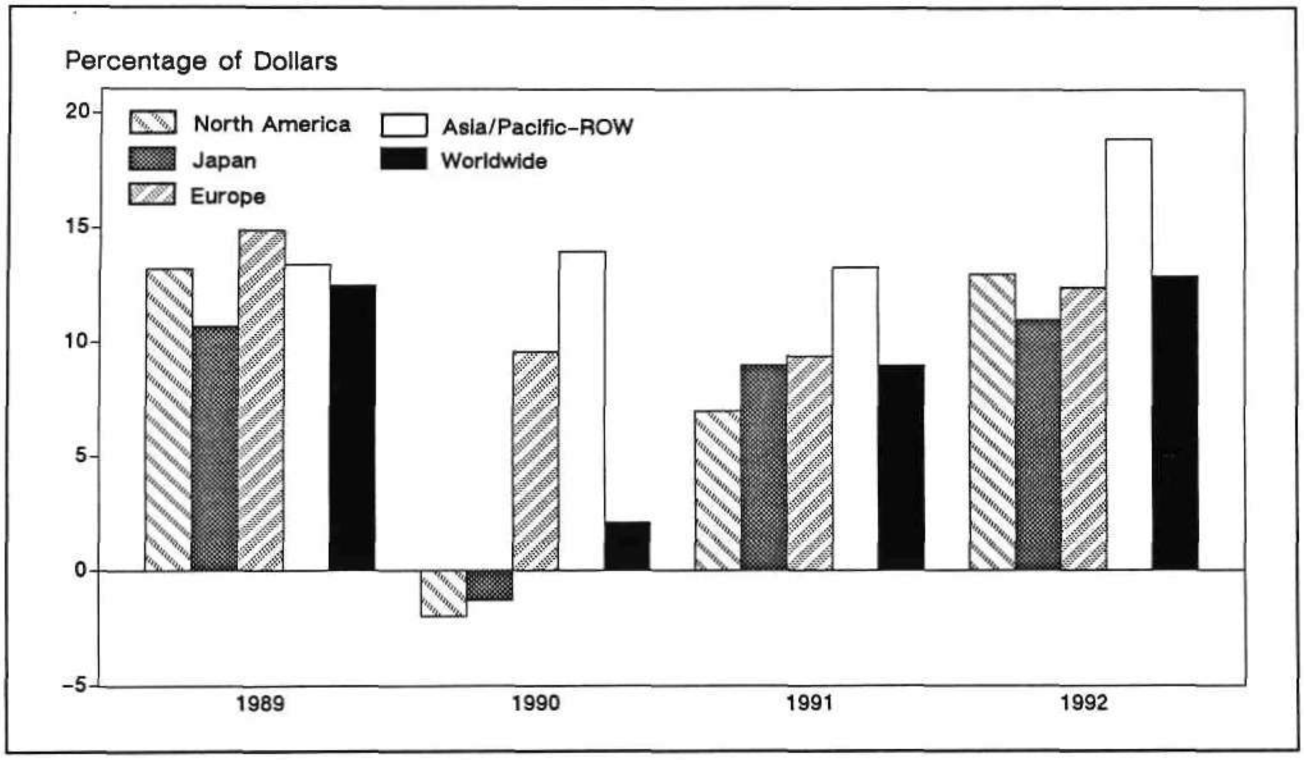
Research Newsletter

FIRST QUARTER 1991 WORLDWIDE SEMICONDUCTOR INDUSTRY OUTLOOK: EMBATTLED, BUT NOT BOMBED OUT

INTRODUCTION

In spite of a U.S. recession and the threat of war, the worldwide semiconductor industry grew in the fourth quarter of 1990 in both bookings and billings. The Persian Gulf war, which began on January 16, 1991, when the allied forces started bombing Baghdad, might be expected to cast a pall over the entire world economy to the detriment of the semiconductor industry. However, Dataquest believes that the industry will continue to grow, albeit modestly, through 1991. We expect quarterly growth to be stronger in 1992. Our annual growth forecast by region is shown in Figure 1. Overall, we expect 9 percent growth in 1991 and 13 percent growth in 1992.

FIGURE 1
Annual Semiconductor Industry Growth Rates by Regional Market (Percentage of Dollars)



Source: Dataquest (January 1991)

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The reasons for our relative optimism are as follows:

- Our monthly survey of major OEM semiconductor procurement managers continues to support improvement in the systems market outlook.
- Semiconductor inventories at OEMs are less than 20 days and within 8 days of target.
- Many semiconductor manufacturers are reporting strong bookings for the month of January.
- WSTS statistics show both bookings and billings on an upward trend through November, the last worldwide actuals available.
- Increasing pervasiveness of semiconductors in electronics and consumer goods and increasing functionality per chip will continue to raise chip average selling prices and allow the semiconductor industry to grow faster than the electronic equipment industries.
- Telecommunications equipment production continues to do well, due in part to demand from eastern Europe. This will continue to drive semiconductor consumption in Europe.
- There is evidence—in the huge approval rating of U.S. President George Bush, the large U.S. stock market rallies, and signs of improvement in the index of leading indicators—that U.S. consumer confidence has increased dramatically since the bombing of Baghdad began.
- U.S. allies have pledged $45 billion toward the cost of the war thus far, thereby alleviating a potentially onerous financial burden on one nation.

To be sure, there are also possible hazards on the horizon:

- Protraction and/or major expansion of the war in the Persian Gulf could sabotage world economies.
- Increased political and economic instability in the Soviet Union could become a very explosive situation with worldwide repercussions.
- Lack of soundness of the U.S. financial system could damage the U.S. economy if massive bank failures were to occur. This possibility can be averted by effective action on the part of the Federal Reserve Board, Congress, and the Bush administration.
- A trade war, brought on by patriotic fervor in the United States, could disrupt world economies enough to adversely affect the semiconductor industry. This possibility is avoidable if the U.S. government and its allies actively control events that might result in protectionist U.S. policies.

OUTLOOK FOR 1991 AND 1992

We have looked at several different scenarios for semiconductor industry growth this year and next. They range from highly optimistic to highly pessimistic. We believe that the most likely scenario is somewhere in between, with worldwide growth of 9 percent in 1991 and 13 percent in 1992.

In the final months of 1990, both bookings and billings were well ahead of the same period in 1989, at 13 and 14 percent, respectively. The same trend holds when looking at the three months ended November 1990 versus the three months ended November 1989. Because of this trend and because of renewed confidence levels since fighting began in the Gulf, we believe that the first and second quarters of 1991 are going to show growth, with most of it in the second quarter. We are forecasting modest growth in the third and fourth quarters of 1991. We think quarterly growth will be considerably higher in 1992 for the following reasons:

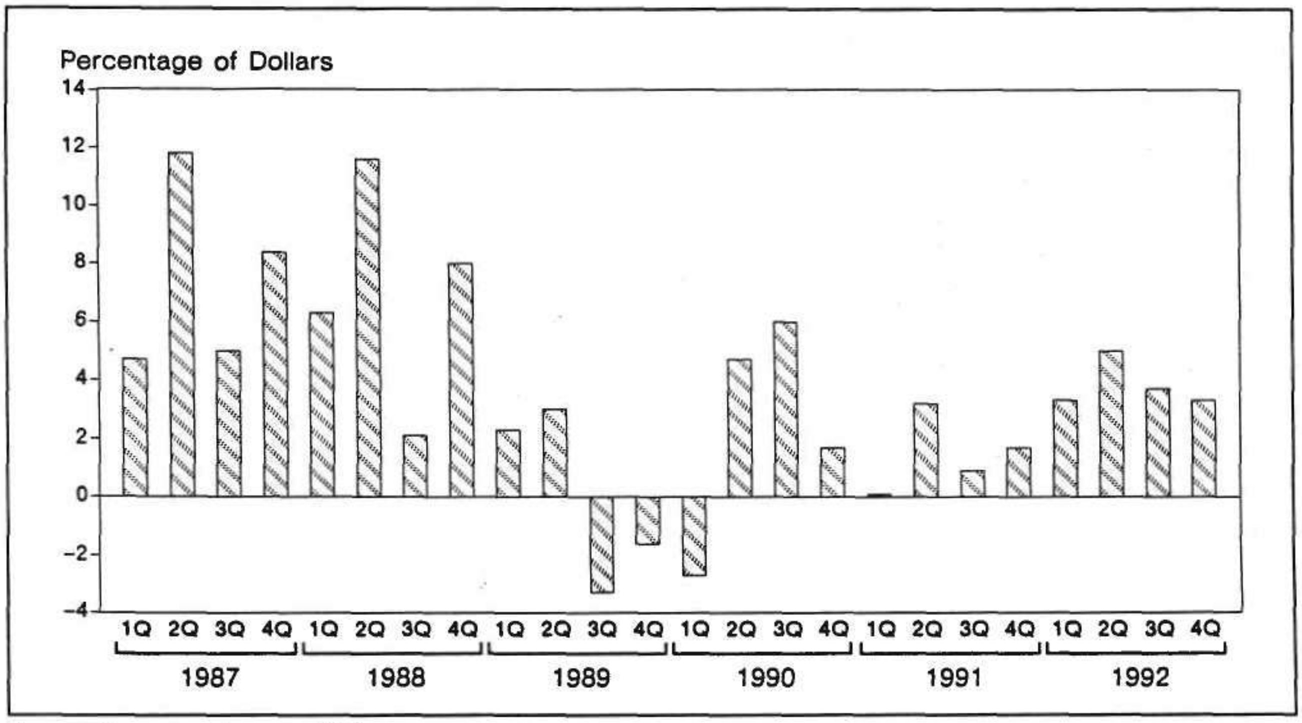
- We believe that the war will have been resolved.
- We believe that the U.S. savings and loan and banking crisis will be in the solution phase.
- We believe that psychology will play a strong role: Just as low consumer confidence contributed strongly to the U.S. recession in the fourth quarter of 1990, a positive mind frame in the electronics industry can buoy up the semiconductor industry.

Figure 2 shows our sequential quarterly growth history and forecast worldwide. Figure 3 shows worldwide growth by quarter versus the same quarter a year ago.

Regionally, we expect to see the following trends in 1991:

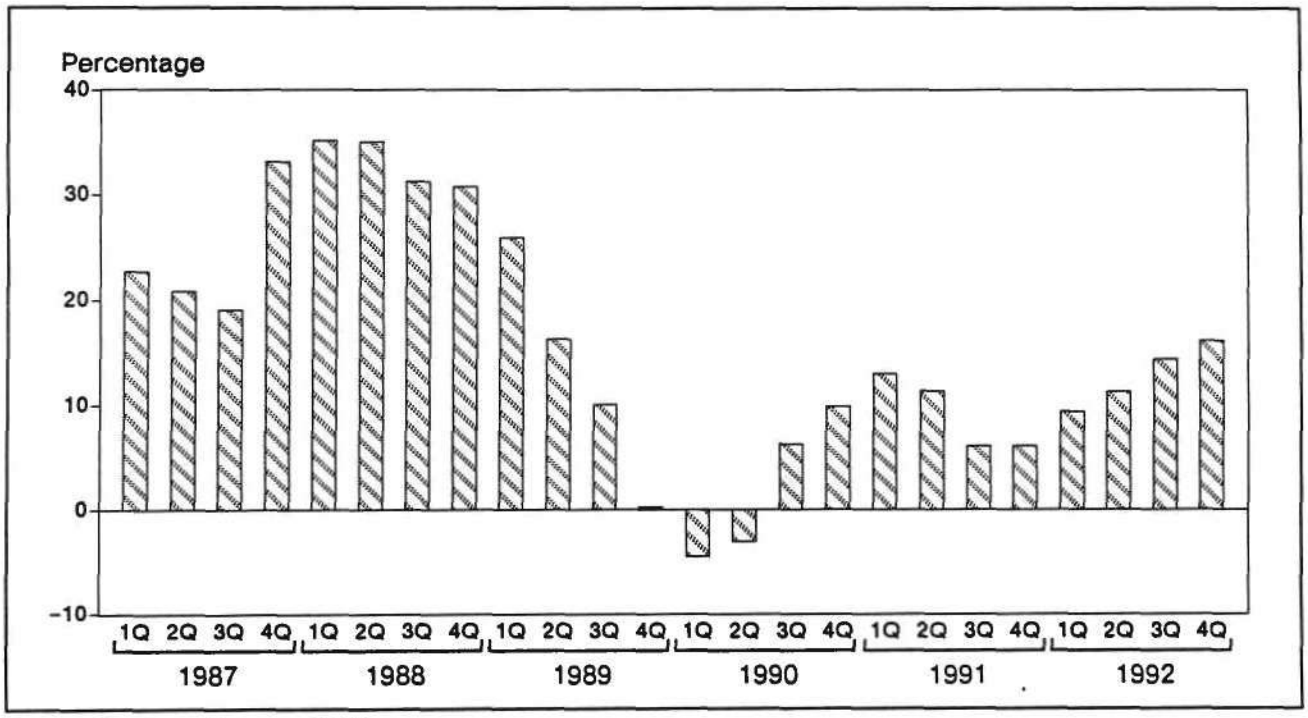
- North American market growth will be strongest in the second quarter.
- European market growth will be strongest in the first quarter. European semiconductor consumption benefited in 1990 from a boom in TV and VCR production, which we do not believe will be repeated this year.

FIGURE 2
Worldwide Semiconductor Industry Growth by Sequential Quarters



Source: Dataquest (January 1991)

FIGURE 3
Worldwide Semiconductor Industry Growth versus the Same Quarter One Year Ago



Source: Dataquest (January 1991)

- Japan will show the weakest quarterly growth of any region this year, largely due to the unprecedented economic challenges it is facing in its stock market and real estate market and the slowdown in consumer spending in the United States, upon which a large part of Japan's semiconductor consumption depends.
- The Asia/Pacific-Rest of World (ROW) market, which slowed in the fourth quarter of 1990 due to a falloff in clone demand, will resume growth in the second quarter of 1991.

In general, the outlook for the Asia/Pacific markets continues to be brighter than that for other regions for the following reasons:

- The Asia/Pacific countries' GDPs in general continue to grow at high single-digit rates.
- Much of the Asia/Pacific semiconductor demand will come from products to be sold within the country of manufacture. In fact, Japanese companies are now producing goods in Asian countries for sale there rather than for export to other regions.
- This market is still the smallest, least mature regional market; therefore, it can support a higher percentage growth than can other regions.

Our 1992 outlook calls for Asia/Pacific-ROW to remain the fastest-growing regional market, followed, in order of growth, by North America, Europe, and Japan.

DATAQUEST ANALYSIS

Never before has Dataquest forecast semiconductor industry growth during a global conflict that could affect worldwide economic powers. We believe that enough positive factors exist to result in modest industry growth both this year and next. The war could have either a significantly positive effect or, conversely, a significantly depressing effect on the semiconductor industry. We have chosen a scenario in which most volatile effects are counterbalanced by other influences, and life continues on, though perhaps not at the frenetic pace of the 1980s.

Patricia S. Cox

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Research *Newsletter*

DRAM PRODUCT LIFE CYCLES—A VIEW FROM THE INDUSTRY

INTRODUCTION

At the Dataquest Semiconductor Industry Conference held in October in Monterey, California, a half-day session was dedicated to the subject of DRAMs. Six speakers discussed DRAM topics that included DRAM product life cycles, manufacturing costs, average selling prices (ASPs), capacity, packaging trends, technical characteristics, and applications. This newsletter focuses on DRAM product life cycles, one of the DRAM topics presented at the conference.

The DRAM product life cycle for each new generation of DRAMs is a subject of great interest to Semiconductor Equipment Manufacturing and Materials Service (SEMMS) clients. A secure knowledge of DRAM product cycles helps participants at all levels of the electronics industry--including equipment and materials suppliers, device manufacturers, and device end users--better plan their future company activities.

Three of the invited speakers presented their views of DRAM product life cycles, which, in the interest of our clients, we present in this newsletter. David Sear, vice president, Standard Products Operations, Integrated Circuits Division, Fujitsu Microelectronics, gave Fujitsu's view; Dr. Tsugio Makimoto, director and general manager, Semiconductor Design and Development Center, Hitachi, presented Hitachi's view; and Robert J. Brown, senior vice president and group executive, Semiconductor Operations Group, Toshiba America Electronic Components, presented Toshiba's view. We also augment the speakers' viewpoints with Dataquest's perspective.

DRAM PRODUCT LIFE CYCLES

Figures 1, 2, and 3 show Fujitsu's, Hitachi's, and Toshiba's views of DRAM product life cycles, respectively. The figures show the life cycles of each DRAM generation and the projected worldwide unit demand throughout the DRAM's life cycle. The three figures probably were meant to present general industry projections rather than official company forecasts, and Dataquest does not want to manipulate these data to arrive at decisions unwarranted by the accuracy of the data. Nevertheless, significant differences exist among the general viewpoints of these companies, such that the reader should examine the charts in more detail. (The charts also use different scales, so the reader should be careful with direct comparisons of the charts.)

For Fujitsu, worldwide peak unit production for each new generation of DRAMs surpassed that of the previous generation. Toshiba's view is similar to Fujitsu's, at least for the 256K, 1Mb, and 4Mb generations. Hitachi's view is somewhat different: It projects that peak production, at least for the 1Mb, 4Mb, and 16Mb DRAMs, essentially is the same for each new generation and lower than the peak production for 256K DRAMs. Table 1 shows some rough data that Dataquest extracted from Figures 1 through 3. Using the 16Mb DRAM as an example, Fujitsu forecasts peak unit production to be 1,500 million units, twice Hitachi's estimated peak production of 750 million units.

Fujitsu estimates that worldwide DRAM demand will exceed 500 million units for each DRAM generation from 1Mb through 64Mb for six to seven years, while Hitachi estimates that worldwide demand will exceed 500 million units for only three to four years for the 1Mb, 4Mb, and 16Mb DRAM generations.

When Fujitsu's higher peak unit production and longer time for the DRAM generation to be above 500 million units is compared with Hitachi's lower peak production and shorter time above 500 million units, it is clear that Fujitsu forecasts a much larger number of units for each DRAM generation than does Hitachi.

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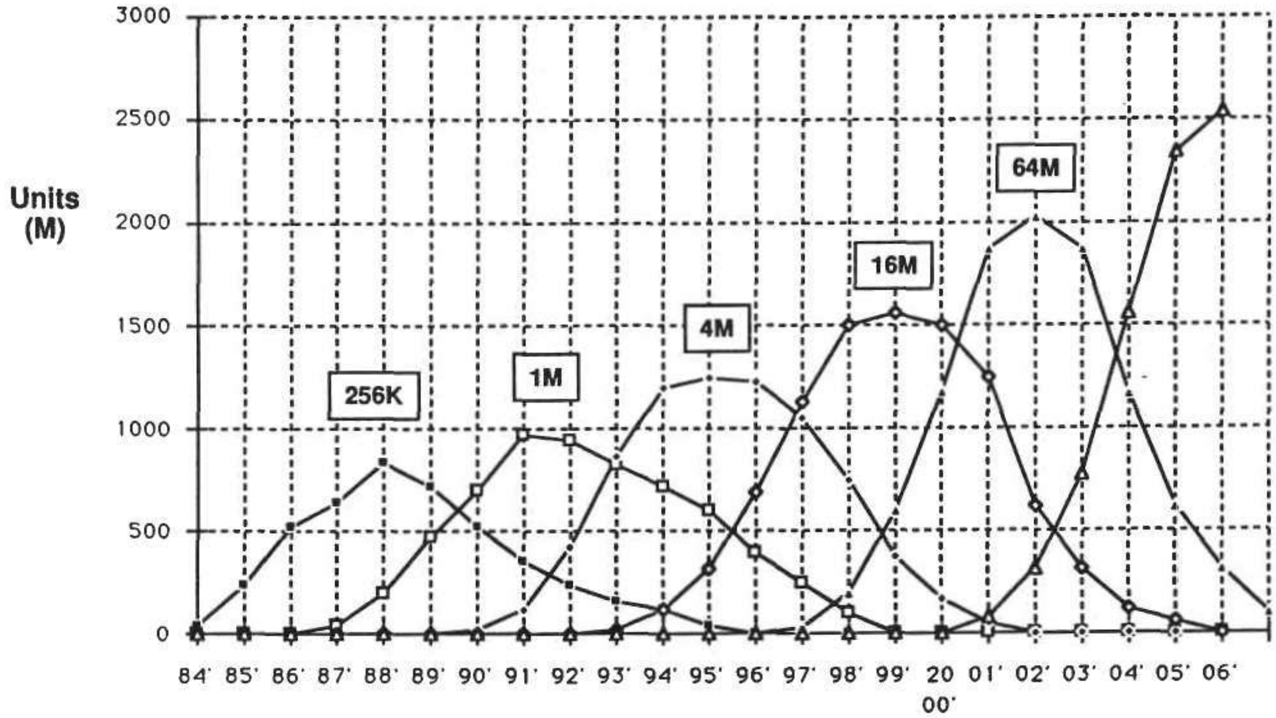
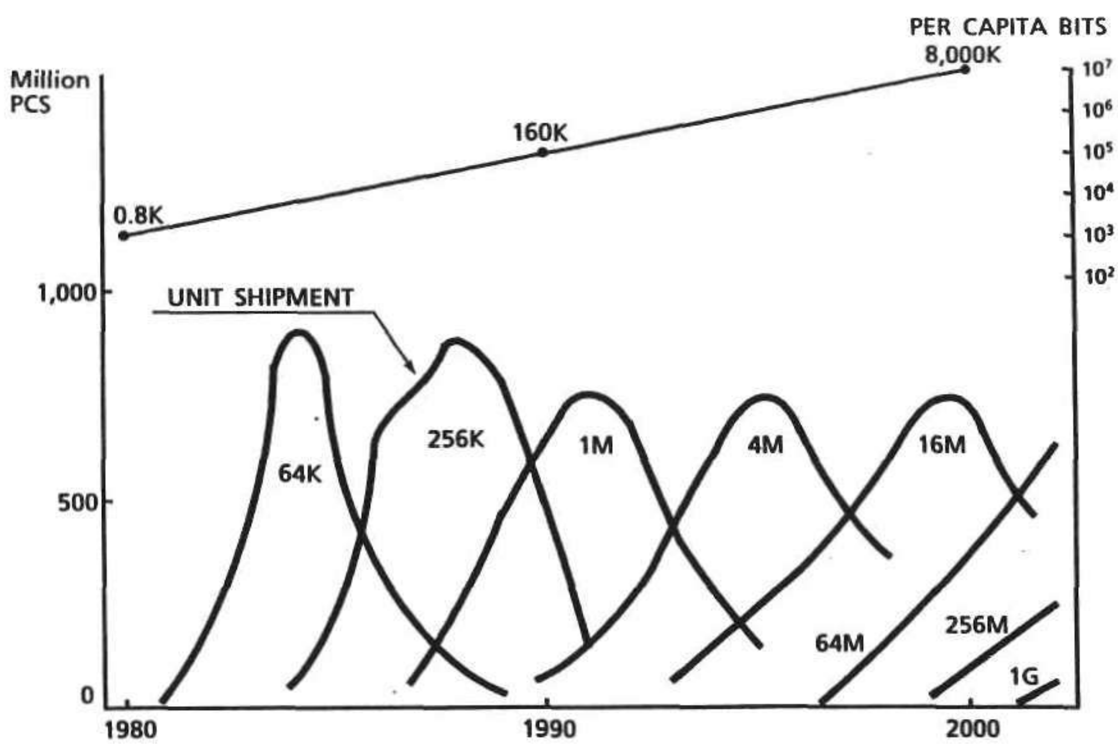
FIGURE 1
Fujitsu's Projected DRAM Life Cycle



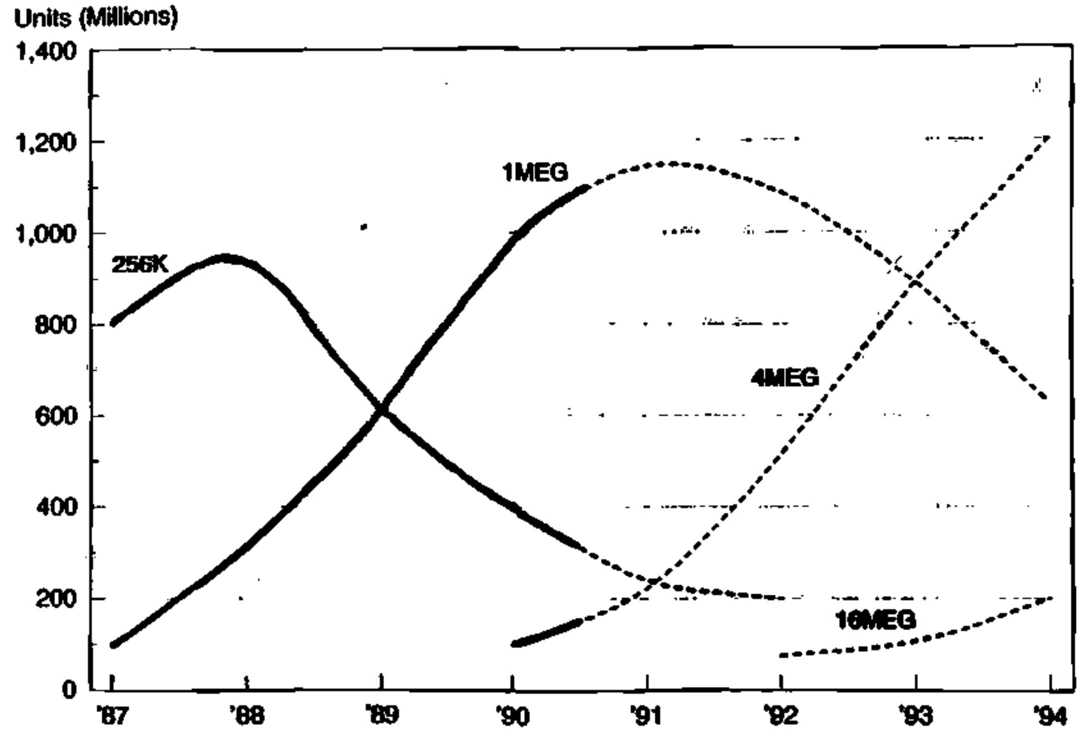
Source: Fujitsu

FIGURE 2
Hitachi's DRAM Trend



Source: Hitachi

FIGURE 3
Toshiba's DRAM Market Forecast



Source: Toshiba

Although these are only a few companies' views of the future, the fact that they are disparate leads to caution. The semiconductor industry in general needs to have a fairly consistent view of the future in order to avoid the cyclicality that has characterized the industry. For instance, if the consensus forecast is for high worldwide demand, then capital expansions are more likely to be made to meet the projections, and the companies making expansions will be able to share in the rising market. On the other hand, if actual demand turns out to be lower than was originally forecast, the industry will have an overcapacity situation with all the concomitant problems that such a situation brings to the semiconductor manufacturers and the equipment and material suppliers.

Similarly, if the forecast is for a lower worldwide demand, then fewer capital expansions will be made, and the companies moderating their expansions will not find themselves in an overcapacity situation. However, if the actual demand proves to be much higher than originally forecast, then the industry will find itself in an undersupply situation with all of the problems that entails for the end users of the devices.

Table 1 shows that the three companies agree on the year of peak unit production for each DRAM generation--1991 for the 1Mb, 1995 for the 4Mb, and 1999 for the 16Mb. Fujitsu estimates that the 64Mb DRAM will reach peak production between the years 2002 and 2003. The figures also show that DRAM generation life cycles for the 1Mb, 4Mb, and 16Mb devices are approximately nine to ten years or more.

DATAQUEST PERSPECTIVE

Dataquest's projections for peak unit production of the 64K through 4Mb devices also are shown in Table 1.

Dataquest estimates that the 1Mb DRAM will reach a peak unit production of 1,075 million units during 1991, which is similar to Fujitsu's and Toshiba's projections, but considerably higher than Hitachi's forecast of 750 million units. We believe that 1Mb suppliers currently are in an oversupply and overcapacity situation, which continues to drive down prices for 1Mb DRAMs. We also believe that major European and Japanese DRAM suppliers are cutting back production volumes of 1Mb devices. The number of cutbacks and the timeliness of these cutbacks may not be adequate to reduce the estimated oversupply for the

Table 1
DRAM Market Trends—Different Views
(Millions of Units)

	64K		256K		1Mb		4Mb		16Mb		64Mb	
	Peak Year	Units at Peak	Peak Year	Units at Peak	Peak Year	Units at Peak	Peak Year	Units at Peak	Peak Year	Units at Peak	Peak Year	Units at Peak
Fujitsu	NA	NA	1988	800	1991	1,000	1995	1,200	1999	1,500	2002-2003	2,000
Hitachi	1984-1985	900	1988	875	1991	750	1995-1996	750	1999-2000	750	NA	NA
Toshiba	NA	NA	1987-1988	950	1991	1,150	NA	NA	NA	NA	NA	NA
Dataquest	1984	852	1988	963	1991	1,075	1995	1,200	NA	NA	NA	NA

NA = Not available
Source: Fujitsu, Hitachi, Toshiba, Dataquest (December 1990)

remainder of this year and 1991. With the increasing availability of and demand for 4Mb DRAMs, many end users may consider purchasing more 1Mb devices to protect their investments in products that require the 1Mb device.

Considering the 4Mb DRAMs, we estimate that peak unit production will occur in 1995 and will be more than 1,200 million units.

A number of semiconductor manufacturers have announced availability of 16Mb DRAM engineering samples starting in either the fourth quarter of 1990 or the first quarter of 1991. The manufacturers include Fujitsu, Hitachi, Matsushita, NEC, Samsung, Siemens, Texas Instruments, and Toshiba. Engineering complications still exist for the 16Mb DRAM, including the trench or stacked capacitor cells and standardized packaging dimensions. We believe that volume shipments of the 16Mb DRAM will not occur until 1992 and that peak production occurring in the years 1999 to 2000 is realistic.

Hitachi announced late last summer that it has a prototype of a 64Mb DRAM and is rapidly working toward a fully functional sample. It is unlikely that this sample will be available until after 1992.

DATAQUEST CONCLUSIONS

For equipment and materials suppliers, DRAM product life cycles indicate when each new generation of equipment and materials is required. Dr. Graydon Larrabee of Texas Instruments has estimated that development of manufacturing processes and production equipment for each new generation of semiconductor devices must begin about eight to ten years before the year in which volume shipments of the device first occur. For instance, the projections shown in Figures 1 and 2 indicate that volume shipments of the 64Mb DRAM will commence around 1997. This start date means that 64Mb DRAM processes and equipment must already be under substantial development, and, indeed, this is the case indicated by Hitachi's 64Mb DRAM announcement.

The eight- to ten-year development cycle also means that equipment and material suppliers need a long-term approach to R&D that includes both near-term and long-term projects. The challenge is how can the smaller equipment and materials suppliers generate sufficient R&D funds to accomplish such a strategy? The challenge extends to the smaller semiconductor manufacturers as well—are they making sufficient R&D investments in long-term projects to ensure their future survival? U.S. wafer fab equipment manufacturers and semiconductor manufacturers already are sustaining an R&D investment rate of about 14 percent of sales, which is among the highest of any industry.

Joe Grenier
Ione Ishii

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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Research Newsletter

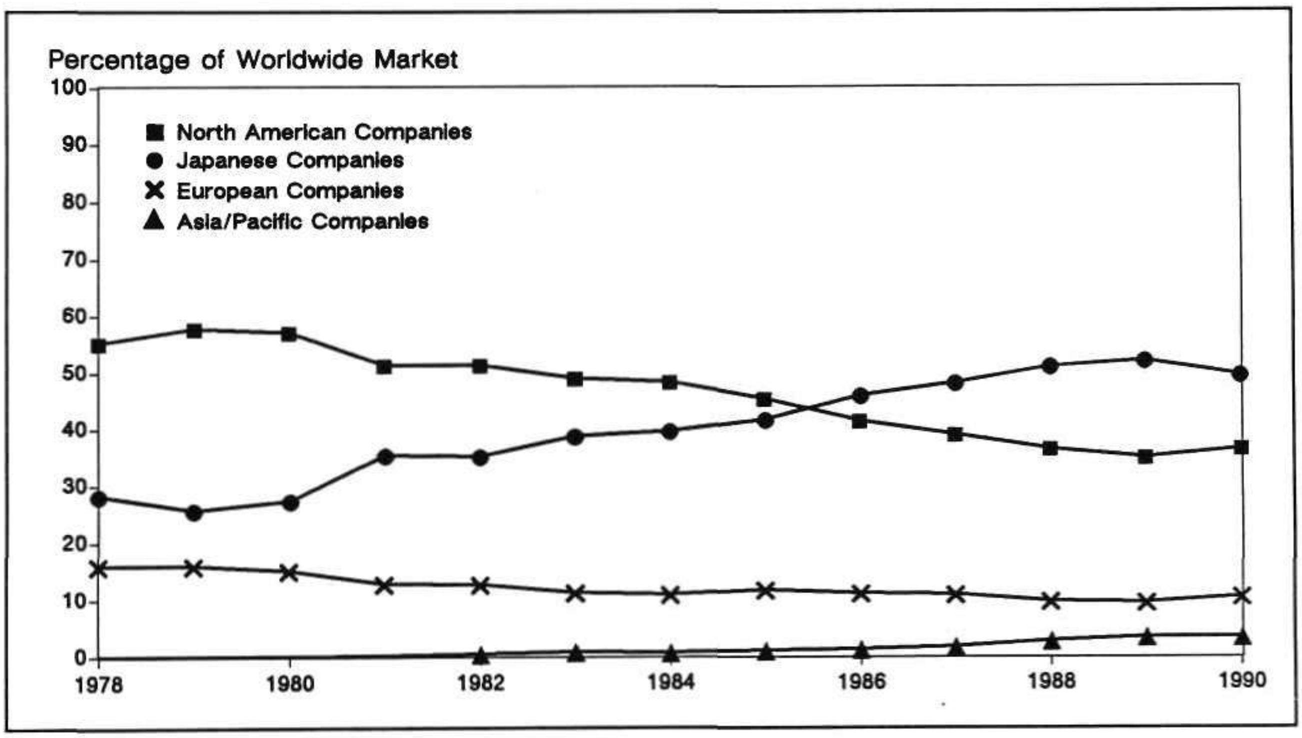
PRELIMINARY 1990 WORLDWIDE SEMICONDUCTOR MARKET SHARE ESTIMATES: THE MICROPROCESSOR REIGNS

INTRODUCTION

Dataquest has completed its preliminary analysis of 1990 semiconductor market shares for more than 150 semiconductor vendors worldwide. We have reached the following conclusions based on surveys of these vendors and our analysis of the market:

- In a worldwide semiconductor market that grew only 2 percent, MOS microcomponents grew a whopping 23 percent, paying off in a big way for Intel, Motorola, Texas Instruments, National Semiconductor, and Philips.
- MOS memory revenue dropped by 17 percent worldwide, resulting in market share losses for the companies that participate in this market.
- For the first time since 1982, Japanese companies lost share of the worldwide market, dropping from a 52.1 percent market share in 1989 to 49.5 percent in 1990.

FIGURE 1
Regional Shares of Worldwide Semiconductor Market (Percentage of Dollars)



Source: Dataquest (January 1991)

SG Market Share Newsletters 1991-1

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- For the first time since 1979, North American companies gained market share, growing from 34.9 percent of the worldwide market in 1989 to 36.5 percent in 1990.
- While Asian companies held steady at 3.5 percent market share, European companies reversed a downward slide and gained a percentage point of worldwide market share at 10.5 percent. We expect this upward trend to continue in the future.
- Japanese companies now control 22 percent of the North American semiconductor market, down from 24 percent in 1990; at the same time, North American companies have increased their Japanese market share to 10.4 percent, up from less than 10 percent in 1989.

Figure 1 shows the worldwide market share held by each regional company base.

Rankings

Table 1 lists the top 20 semiconductor suppliers worldwide. Although the semiconductor market grew only 2 percent in 1990 (in line with our forecast of a flat year), the growth rates of individual players varied widely, depending on product portfolio. Among the top 20, Intel's 29 percent growth because of its strength in microcomponents was by far the highest, catapulting Intel to the number five position worldwide, up from number eight in 1989.

By the same token, although the top four players remained the same as in 1989 (NEC, Toshiba, Hitachi, and Motorola), the first three each experienced revenue declines of 1 percent because of the heavy proportion of MOS memory in their product portfolios. Motorola, on the other hand, was able to grow 11 percent because of its strong microcomponent growth.

The bipolar digital IC market is still shrinking; it declined 1 percent in 1990. Although most players in this market are suffering because of a shift to CMOS, Fujitsu was able to buck this trend with its super ECL gate arrays, which are used in its new mainframe computer (among other products), which had very strong growth this year. This high-ASP product enabled Fujitsu to surpass Texas Instruments to become the top-ranked bipolar digital supplier in 1990.

MOS memory, the largest semiconductor product category, suffered from free-falling DRAM prices and a slowdown in nonvolatile memory demand, with revenue declining 17 percent from 1989. The Japanese companies clearly were the most severely hit because of their dominance in this market. Samsung's DRAM revenue actually grew in 1990, however, because of its shift to 1Mb production. In 1989, most of its production had been 256K. Sharp was able to grow its MOS memory revenue on the strength of its swift entry into the SRAM market and strong demand from the game market for its 8Mb ROMs.

As mentioned previously, MOS microcomponents was the fastest-growing product category, increasing 23 percent from 1989. Intel retained its position as the number one supplier, growing 41 percent; in fact, it strengthened its lead over the number two supplier, NEC, quite significantly. North American and European companies succeeded in taking market share in microcomponents from Japanese companies.

MOS logic grew by 5 percent in 1990. The top 5 players remained the same—NEC, Toshiba, Motorola, Fujitsu, and LSI Logic. Among the top 20, VLSI Technology showed strong growth at 25 percent and moved from number 18 in 1989 to number 14 in 1990. Siemens also showed strong growth at 24 percent and moved from number 20 to number 17.

In the analog market, European companies showed extremely strong growth over 1989, because of the strength of the telecommunications market in Europe. European telecom companies did very well in 1990, winning projects not only in Europe but in third-world countries as well as Eastern Europe. Philips, the analog revenue of which grew by 17 percent and which jumped to the number one spot in the rankings, also profited from its own very strong consumer electronics business. The analog growth rate in 1990 also is influenced by a change in our definition of mixed-signal IC revenue, some of which was reported previously in the MOS logic category.

The discrete and optoelectronic markets both showed growth in 1990. Particularly strong growth was shown by International Rectifier, which grew 30 percent in discrete and went from the number 14 position to number 12.

Tables 2 through 9 list the top 20 suppliers in the product segments of total integrated circuit,

TABLE 1
Preliminary Estimated Worldwide Market Share Ranking
Total Semiconductor
(Millions of Dollars)

1990 Rank	1989 Rank		1989 Revenue	1990 Revenue	Percent Change	1990 Market Share (%)
1	1	NEC	5,015	4,952	(1)	8.5
2	2	Toshiba	4,930	4,905	(1)	8.4
3	3	Hitachi	3,974	3,927	(1)	6.7
4	4	Motorola	3,319	3,692	11	6.3
5	8	Intel	2,430	3,135	29	5.4
6	5	Fujitsu	2,963	3,019	2	5.2
7	6	Texas Instruments	2,787	2,574	(8)	4.4
8	7	Mitsubishi	2,579	2,476	(4)	4.2
9	9	Matsushita	1,882	1,945	3	3.3
10	10	Philips	1,716	1,932	13	3.3
11	11	National Semiconductor	1,618	1,718	6	2.9
12	13	SGS-Thomson	1,301	1,463	12	2.5
13	12	Sanyo	1,365	1,381	1	2.4
14	15	Sharp	1,230	1,360	11	2.3
15	14	Samsung	1,260	1,315	4	2.3
16	16	Siemens	1,194	1,221	2	2.1
17	19	Sony	1,077	1,172	9	2.0
18	17	Oki	1,154	1,074	(7)	1.8
19	18	Advanced Micro Devices	1,100	1,067	(3)	1.8
20	20	AT&T	873	830	(5)	1.4
Total Market			57,213	58,414	2	100.0

Source: Dataquest (January 1991)

bipolar digital, MOS memory, MOS microcomponent, MOS logic, analog, discrete, and opto.

The following notes apply to the tables in this newsletter:

- Our company base has grown from approximately 125 in 1989 to 155 in 1990.
- Some revenue reported in 1989 as MOS logic was reported in 1990 as analog (mixed signal), because of a change in our definitions.
- NM = Not meaningful
- NA = Not available

TABLE 2
Preliminary Estimated Worldwide Market Share Ranking
Total Integrated Circuit
(Millions of Dollars)

1990 Rank	1989 Rank		1989 Revenue	1990 Revenue	Percent Change	1990 Market Share (%)
1	1	NEC	4,321	4,263	(1)	9.0
2	2	Toshiba	3,774	3,684	(2)	7.8
3	3	Hitachi	3,218	3,195	(1)	6.7
4	7	Intel	2,430	3,135	29	6.6
5	6	Motorola	2,519	2,851	13	6.0
6	4	Fujitsu	2,738	2,777	1	5.9
7	5	Texas Instruments	2,691	2,488	(8)	5.2
8	8	Mitsubishi	2,185	2,092	(4)	4.4
9	9	National Semiconductor	1,548	1,645	6	3.5
10	10	Philips	1,250	1,416	13	3.0
11	11	Matsushita	1,244	1,285	3	2.7
12	12	Samsung	1,182	1,238	5	2.6
13	15	SGS-Thomson	1,019	1,148	13	2.4
14	14	Advanced Micro Devices	1,100	1,067	(3)	2.2
15	13	Oki	1,111	1,031	(7)	2.2
16	17	Sharp	902	1,021	13	2.2
17	16	Sanyo	975	979	0	2.1
18	18	Siemens	847	833	(2)	1.8
19	19	Sony	732	817	12	1.7
20	20	AT&T	716	681	(5)	1.4
Total Market			46,924	47,426	1	100.0

Source: Dataquest (January 1991)

Table 3
Preliminary Estimated Worldwide Market Share Ranking
Bipolar Digital
(Millions of Dollars)

1990 Rank	1989 Rank		1989 Revenue	1990 Revenue	Percent Change	1990 Market Share (%)
1	2	Fujitsu	617	710	15	15.9
2	1	Texas Instruments	671	663	(1)	14.8
3	3	Hitachi	479	510	6	11.4
4	5	National Semiconductor	458	440	(4)	9.8
5	6	Motorola	369	408	11	9.1
6	4	Advanced Micro Devices	474	380	(20)	8.5
7	7	Philips	306	299	(2)	6.7
8	8	NEC	302	292	(3)	6.5
9	9	Mitsubishi	125	121	(3)	2.7
10	11	Toshiba	102	113	11	2.5
11	12	Sanyo	67	67	0	1.5
12	16	Harris	50	60	20	1.3
13	13	AT&T	56	59	5	1.3
14	14	Raytheon	55	54	(2)	1.2
15	15	Siemens	54	53	(2)	1.2
16	17	Oki	48	47	(2)	1.1
17	NM	GEC Plessey	0	40	NM	0.9
18	18	Goldstar	32	32	0	0.7
19	19	Chips & Technologies	24	25	4	0.6
20	20	Applied Micro Circuits Corp.	20	24	20	0.5
Total Market			4,510	4,472	(1)	100.0

Source: Dataquest (January 1991)

TABLE 4
Preliminary Estimated Worldwide Market Share Ranking
MOS Memory
(Millions of Dollars)

1990 Rank	1989 Rank		1989 Revenue	1990 Revenue	Percent Change	1990 Market Share (%)
1	1	Toshiba	1,918	1,681	(12)	12.3
2	2	NEC	1,739	1,453	(16)	10.7
3	3	Hitachi	1,534	1,346	(12)	9.9
4	4	Fujitsu	1,265	1,114	(12)	8.2
5	5	Mitsubishi	1,161	997	(14)	7.3
6	7	Samsung	935	971	4	7.1
7	6	Texas Instruments	1,095	741	(32)	5.4
8	8	Sharp	476	547	15	4.0
9	12	Motorola	407	409	0	3.0
10	9	Oki	473	392	(17)	2.9
11	10	Intel	433	344	(21)	2.5
12	11	Siemens	416	344	(17)	2.5
13	14	Matsushita	370	319	(14)	2.3
14	15	SGS-Thomson	269	299	11	2.2
15	13	Micron Technology	395	286	(28)	2.1
16	16	Advanced Micro Devices	258	280	9	2.1
17	18	Sony	228	252	11	1.9
18	17	NMB Semiconductor	247	201	(19)	1.5
19	21	Cypress Semiconductor	149	159	7	1.2
20	23	National Semiconductor	138	147	7	1.1
Total Market			16,361	13,612	(17)	100.0

Source: Dataquest (January 1991)

TABLE 5
Preliminary Estimated Worldwide Market Share Ranking
MOS Microcomponent
(Millions of Dollars)

1990 Rank	1989 Rank		1989 Revenue	1990 Revenue	Percent Change	1990 Market Share (%)
1	1	Intel	1,929	2,718	41	27.0
2	2	NEC	937	1,083	16	10.7
3	3	Motorola	803	1,002	25	9.9
4	4	Hitachi	554	648	17	6.4
5	5	Mitsubishi	435	462	6	4.6
6	6	Toshiba	407	449	10	4.5
7	7	Texas Instruments	252	320	27	3.2
8	8	Matsushita	217	240	11	2.4
9	10	Fujitsu	211	239	13	2.4
10	11	National Semiconductor	172	237	38	2.4
11	9	Chips & Technologies	216	230	6	2.3
12	12	Advanced Micro Devices	172	200	16	2.0
13	17	Philips	131	189	44	1.9
14	13	SGS-Thomson	161	175	9	1.7
15	16	Western Digital	135	148	10	1.5
16	14	Oki	149	147	(1)	1.5
17	15	AT&T	141	145	3	1.4
18	19	Sharp	112	134	20	1.3
19	31	Cirrus Logic	29	129	345	1.3
20	18	Harris	115	110	(4)	1.1
Total Market			8,202	10,076	23	100.0

Source: Dataquest (January 1991)

TABLE 6
Preliminary Estimated Worldwide Market Share Ranking
MOS Logic
(Millions of Dollars)

1990 Rank	1989 Rank		1989 Revenue	1990 Revenue	Percent Change	1990 Market Share (%)
1	1	NEC	928	1,036	12	11.7
2	2	Toshiba	775	832	7	9.4
3	3	Motorola	495	553	12	6.2
4	4	Fujitsu	482	550	14	6.2
5	5	LSI Logic	445	504	13	5.7
6	6	Oki	406	410	1	4.6
7	7	Hitachi	319	354	11	4.0
8	8	Matsushita	267	309	16	3.5
9	10	Texas Instruments	256	306	20	3.4
10	11	Sharp	249	271	9	3.1
11	9	AT&T	257	267	4	3.0
12	12	Philips	231	235	2	2.6
13	13	National Semiconductor	222	219	(1)	2.5
14	18	VLSI Technology	169	211	25	2.4
15	14	Harris	210	201	(4)	2.3
16	17	Sanyo	178	194	9	2.2
17	20	Siemens	133	154	16	1.7
18	22	Samsung	123	153	24	1.7
19	21	Yamaha	130	145	12	1.6
20	15	Seiko Epson	201	128	(36)	1.4
Total Market			8,461	8,884	5	100.0

Source: Dataquest (January 1991)

TABLE 7
Preliminary Estimated Worldwide Market Share Ranking
Analog
(Millions of Dollars)

1990 Rank	1989 Rank		1989 Revenue	1990 Revenue	Percent Change	1990 Market Share (%)
1	4	Philips	522	613	17	5.9
2	1	Toshiba	572	609	6	5.9
3	2	National Semiconductor	558	602	8	5.8
4	8	SGS-Thomson	393	554	41	5.3
5	3	Sanyo	530	541	2	5.2
6	5	Motorola	445	479	8	4.6
7	6	Texas Instruments	417	458	10	4.4
8	9	Mitsubishi	384	434	13	4.2
9	10	Matsushita	376	403	7	3.9
10	11	Sony	361	401	11	3.9
11	7	NEC	415	399	(4)	3.8
12	12	Analog Devices	337	360	7	3.5
13	13	Hitachi	332	337	2	3.2
14	15	Rohm	277	282	2	2.7
15	14	Harris	280	260	(7)	2.5
16	16	AT&T	249	197	(21)	1.9
17	151	GEC Plessey	0	195	NA	1.9
18	24	Silicon Systems	112	180	61	1.7
19	19	Siemens	152	175	15	1.7
20	17	Fujitsu	163	164	1	1.6
Total Market			9,390	10,382	11	100.0

Source: Dataquest (January 1991)

TABLE 8
Preliminary Estimated Worldwide Market Share Ranking
Total Discrete
(Millions of Dollars)

1990 Rank	1989 Rank		1989 Revenue	1990 Revenue	Percent Change	1990 Market Share (%)
1	1	Toshiba	848	910	7	11.0
2	2	Motorola	775	814	5	9.9
3	3	Hitachi	690	662	(4)	8.0
4	4	NEC	574	565	(2)	6.8
5	5	Philips	442	494	12	6.0
6	6	Mitsubishi	364	352	(3)	4.3
7	7	Matsushita	332	351	6	4.2
8	8	Rohm	301	320	6	3.9
9	10	SGS-Thomson	282	315	12	3.8
10	9	Fuji Electric	287	312	9	3.8
11	11	Siemens	232	260	12	3.1
12	14	International Rectifier	187	243	30	2.9
13	12	Sanyo	230	232	1	2.8
14	13	Sanken	213	224	5	2.7
15	NA	Shindengen Electric	NA	177	NA	2.1
16	15	General Instrument	170	173	2	2.1
17	16	ITT	155	161	4	1.9
18	17	AT&T	147	135	(8)	1.6
19	18	Harris	120	130	8	1.6
20	19	Fujitsu	109	117	7	1.4
Total Market			7,662	8,262	8	100.0

Source: Dataquest (January 1991)

TABLE 9
Preliminary Estimated Worldwide Market Share Ranking
Total Optoelectronic
(Millions of Dollars)

1990 Rank	1989 Rank		1989 Revenue	1990 Revenue	Percent Change	1990 Market Share (%)
1	1	Sharp	328	339	3	12.7
2	2	Toshiba	308	311	1	11.6
3	3	Matsushita	306	309	1	11.5
4	4	Sony	249	270	8	10.1
5	5	Hewlett-Packard	213	223	5	8.3
6	6	Sanyo	160	170	6	6.4
7	9	Siemens	115	128	11	4.8
8	8	Fujitsu	116	125	8	4.7
9	7	NEC	120	124	3	4.6
10	10	Rohm	96	105	9	3.9
11	11	Telefunken Electronic	78	90	15	3.4
12	13	Hitachi	66	70	6	2.6
13	12	Optek	77	66	(14)	2.5
14	14	Quality Technologies	38	35	(8)	1.3
15	15	Texas Instruments	36	33	(8)	1.2
16	16	Oki	33	33	0	1.2
17	18	Mitsubishi	30	32	7	1.2
18	19	Motorola	25	27	8	1.0
19	17	Honeywell	31	25	(19)	0.9
20	20	Philips	24	22	(8)	0.8
Total Market			2,627	2,676	2	100.0

Source: Dataquest (January 1991)

DATAQUEST ANALYSIS

The year 1990 was a flat one for the worldwide semiconductor industry. Although the first half of the year showed some surprising strength in end markets, particularly personal computers, this demand slacked off as the year progressed. This slackening, combined with severe downward pricing pressure on memories (in spite of unit demand growth), an uncertain economy, industry layoffs, and the unrest in the Middle East, caused a depressed state of mind in the semiconductor industry.

The bright spots in 1990 were high microcomponent demand and the moderately positive growth in the stable analog, discrete, opto, and MOS logic markets.

The Asia/Pacific companies, while unable to increase market share, were at least able to hold steady. North American and European companies should be happy with their gained market share. Japanese companies' revenue declined, but they still control more of the semiconductor market than any other company base. The uncharted waters of 1991 may demonstrate if the strategy of relying heavily on DRAMs is still the way to maintenance or growth of market share in the semiconductor market of the 1990s.

Patricia S. Cox

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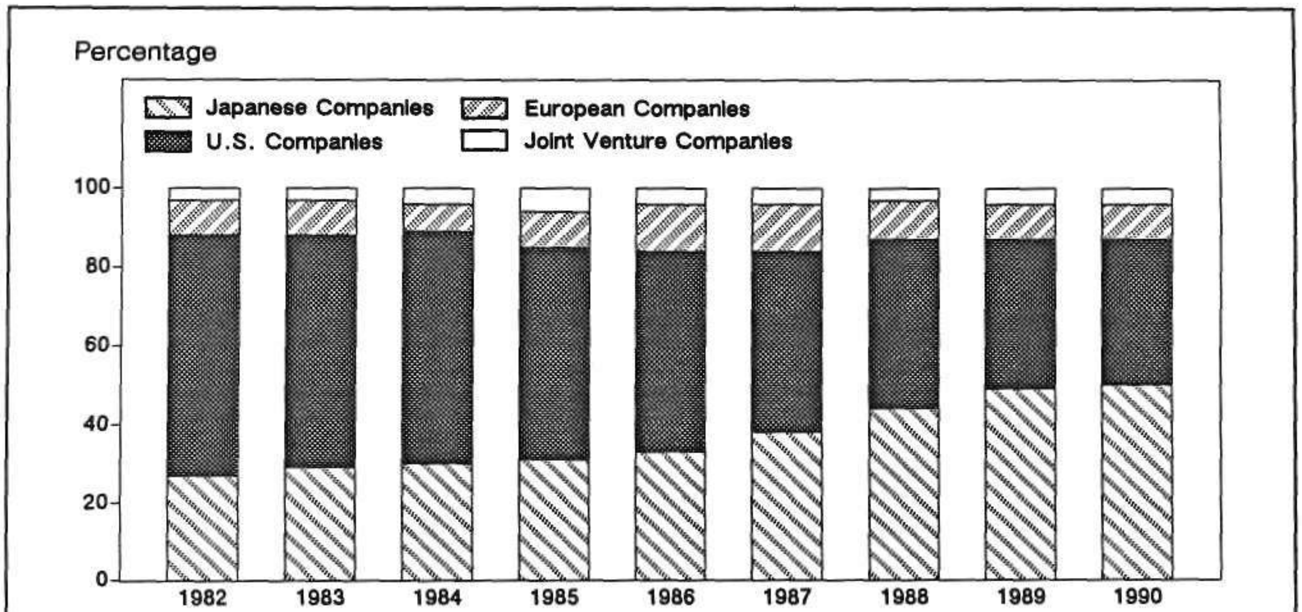
Research Newsletter

EQUIPMENT COMPANY OWNERSHIP—AT THE TURNING POINT

In the 1960s and 1970s, the wafer fab equipment industry was dominated by U.S. companies. However, as the industry matured in the 1980s, one of the major trends that emerged was the steady gain in worldwide market share for Japanese equipment companies. This steady gain has been due to the growth of a vigorous domestic semiconductor device manufacturing industry in Japan, which in 1990 accounted for $2,943 million of the $5,813 million worldwide wafer fab equipment market. A dominant position in their home market, coupled with a growing export business, have contributed to establishing Japanese equipment companies as market share leaders in the worldwide wafer fab equipment industry.

Figure 1 shows the persistent advance in market share by Japanese wafer fab equipment companies and the concomitant loss of share by U.S. equipment companies for key segments of wafer processing equipment. It is clear from Figure 1 that Japanese equipment companies have become dominant in the overall wafer fab equipment market, but what is happening in the individual key equipment segments? This newsletter examines the shift in regional company market shares for the key segments of the wafer fab equipment industry. It identifies the turning points and discusses the reasons behind the transfer of dominant share from one group of regional companies to another.

FIGURE 1
Worldwide Market Share of Regional Companies for Key Equipment Segments*, 1982-1990
(Percentage of Dollars)



Source: Dataquest (April 1991)

SEMMS Newsletters 1991 Equipment—Wafer Fab Equipment/Industry Trends

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Dataquest Incorporated, 1290 Ridder Park Drive, San Jose, CA 95131-2398 / (408) 437-8000 / Telex 171973 / Fax (408) 437-0292

Maintaining or Gaining Share

Table 1 identifies the dominant share held by U.S., Japanese, and European suppliers for several key segments of wafer fab equipment in 1990. The 1984 percentages are include as a point of comparison. Dominant share is measured on the basis of unit shipments rather than revenue because doing so removes the effect of currency appreciation during this time period. Dominant share represents the largest value of market share held by a group of regionally owned companies. For example, U.S. companies held dominant share of medium- and high-current implanters in 1990 with 47 percent of worldwide shipments, while Japanese and joint-venture companies accounted for 29 and 24 percent share, respectively. In this analysis, specific segments of wafer fab equipment were chosen with two criteria in mind: technological importance in advanced wafer processing and clearly definable trends in dominant share held by regional companies.

Two clear trends are evident in Table 1. When the percent share in 1990 is compared with the 1984 level, U.S., Japanese, and European companies have all maintained dominant share in certain segments of wafer fab equipment, but only Japanese companies have gained dominant share in any given segment of equipment.

Strengths Maintained

U.S. Companies

Nontube (dedicated) CVD reactor technology (APCVD, LPCVD, PECVD) continues to be one of the major strengths of U.S. wafer fab equipment

Table 1
Dominant Share of 1990 Unit Shipments by Company Regional Ownership for Selected Segments of Wafer Fab Equipment
(Percentage of Worldwide Unit Shipments)

	1984	1990
Maintained Dominant Share		
U.S. Companies		
APCVD	61	62
Nontube LPCVD	100	76
Nontube PECVD	50	77
High- and medium-current implanters	66	47
Rapid thermal processing	82	72
Optical CD	56	54
Japanese Companies		
Vertical tube diffusion	71	78
CD SEM	*	84
European Companies		
Horizontal tube PECVD	78	94
Molecular beam epitaxy	63	53
Gained Dominant Market Share		
Japanese Companies		
Steppers	39	80
Dry strip	27	51
Dry etch	29	55
Horizontal and vertical tube LPCVD	24	49
Sputtering	24	54

*This market emerged after 1984.
Source: Dataquest (April 1991)

companies. They maintain their number one position in this area because of their significant installed base of knowledge in reactor design and process technology. Dataquest believes that to capture dominant share away from U.S. companies in this area would require far more effort than in any other segment of wafer fab equipment because of the process-intensive nature of CVD.

U.S. companies continue to maintain their dominant share position in the medium- and high-current implanter equipment segments. Two longtime 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 U.S. companies. Dataquest believes that the U.S. companies have continued to maintain dominant share in this segment 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).

Japanese Companies

As shown in Table 1, Japanese companies have been the driving force behind the development and implementation of vertical diffusion furnace technology and critical dimension (CD) SEMs in semiconductor manufacturing. These two relatively new categories of wafer fab equipment emerged in the mid-1980s as next-generation replacement technologies for the more traditional segments of horizontal diffusion furnaces and optical CD measurement. Japanese equipment companies have successfully maintained a dominant position in vertical diffusion and CD SEM systems since their introduction of this equipment to the market.

European Companies

Table 1 identifies two segments of the wafer fab equipment industry in which European companies have established and maintained market strength throughout much of the 1980s. In the case of horizontal tube PECVD systems, a single European vendor, ASM International, dominates this market application. European companies have maintained a strong position in the molecular beam epitaxy (MBE) market because of an historically strong base in high-vacuum technology.

At the Turning Point—Dominant Share Gains

As shown in Table 1, Japanese equipment companies have gained the position of dominant share in five key areas of wafer fab equipment in which U.S. companies had previously dominated the market. Table 2 identifies the turning point, or specific year, when the shift in dominant share occurred. In this analysis, a difference of five or fewer percentage points in share of unit shipments is considered a tie in determining dominant share. Thus, for steppers, the turning point was during the 1985/1986 time frame when U.S. and Japanese equipment companies held essentially equal share. From 1987 to the present, however, Japanese companies have continued to increase their share of worldwide stepper unit shipments. The turning point in dominant share for dry strip and tube LPCVD systems was in 1988, the turning point in dry etch was in 1989, and the turning point in sputter systems appears to have occurred in 1990.

It should be noted that in our analysis, dominant share in unit shipments was matched by dominant share as measured on a revenue basis,

TABLE 2
Turning Point in Gaining Dominant Share
(Percentage of Worldwide Unit Shipments)

	1982	1983	1984	1985	1986	1987	1988	1989	1990
Steppers	X	X	X	X/O	X/O	O	O	O	O
Dry Strip	X	X	X	X	X	X	X/O	O	O
Tube LPCVD	X	X	X	X	X	X	X/O	O	O
Dry Etch	X	X	X	X	X	X	X	X/O	O
Sputter	X	X	X	X	X	X	X	X	O

X = U.S. companies held dominant share, O = Japanese companies held dominant share.
Source: Dataquest (April 1991)

with the exception of one category. In the area of dry etch, Japanese equipment companies held dominant share in unit shipments in 1990; however, on a revenue basis, U.S. and Japanese companies had approximately equal share of the $683 million market. Japanese etch companies offer a broad base of equipment encompassing leading-edge tools as well as older technology, while U.S. companies are focused primarily on leading-edge systems. This translates to an overall average selling price for Japanese etch units that is lower than that for U.S. etch systems.

Japanese companies established dominant share in these equipment categories through a combination of domestic technology development and acquisition of overseas companies and their technology. Powerhouse optics companies Nikon and Canon chose to manufacture full stepper systems rather than just supply sophisticated lens optics to other stepper vendors. The Japanese stepper companies have attained a dominant share of the world market today because of their emphasis on equipment reliability in combination with leading-edge lens design and manufacturing. Tokyo Electron's buyout of the TEL/Lam and TEL/Thermco joint ventures added dry etch and tube LPCVD technology, originally developed at U.S. companies, to an already flourishing technology base in Japan. In 1990, dominant share in the sputter market shifted from U.S. companies to the Japanese, in large part because of the acquisition of Materials Research Corporation by Sony.

Table 2 shows that Japanese equipment companies have assumed dominant share of key segments of the wafer fab equipment market at the rate of approximately one segment per year for the past five years. Clearly, the question is whether this trend will continue, and if so, what will be the next segments of the wafer fab equipment industry where dominant share will transfer from one group of regional companies to another.

DATAQUEST PERSPECTIVE

The establishment of dominant share in key segments of wafer fab equipment has propelled the Japanese equipment industry into its number one position. Dataquest believes that it is unlikely the loss of dominant share by U.S. companies in key segments of equipment can be regained without tremendous capital investment, particularly in those segments with a turning point more than two years old. One important aspect that our analysis suggests is a reevaluation of the role that SEMATECH should play in revitalizing semiconductor manufacturing in the United States. With limited resources partly dependent on the whims of the congressional budget cycle, Dataquest believes that SEMATECH should consider keeping its efforts tightly focused on supporting only a few key areas. These areas should be leading-edge equipment technology and process development programs in which U.S. companies still have an opportunity to either successfully establish or capture a dominant share position in the worldwide market. The time for "catch up" in some segments of the wafer fab equipment business is over; the turning point is past.

Peggy Marie Wood

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Research Newsletter

THE BRANSON/IPC AND GASONICS MERGER: A GROWTH OPTION FOR SMALL COMPANIES WITHIN THE WAFER FAB EQUIPMENT INDUSTRY?

SUMMARY

Gasonics' acquisition of Branson/IPC from Emerson Electric (St. Louis, Missouri) may result in the emergence of a global equipment industry player with a well-balanced portfolio of products and the critical mass necessary for sustained growth within the wafer fabrication equipment industry. The combined entity, with revenue of approximately $40 million in 1990, is better positioned to become a key player in the dry etch, dry strip, and diffusion segments of the wafer fab equipment market.

Dataquest believes that this merger illustrates the trend toward rapid consolidation in the highly fragmented North American equipment industry as it struggles to cope with the escalating costs of new product development and market penetration in an increasingly globalized industry. Emerson Electric's divestiture of Branson/IPC may also indicate that many diversified North American industrial conglomerates do not wish to handle the volatile, technology-driven nature of the fragmented semiconductor equipment industry.

PRODUCTS AND MARKETS SERVED BY GASONICS AND BRANSON/IPC

Table 1 displays Dataquest's estimates for the 1990 wafer fabrication equipment market revenue of Gasonics and Branson/IPC in the dry strip, dry etch, and diffusion market segments. The combined entity has good synergy in its dry etch, dry strip, and diffusion equipment market presence. Branson/IPC specializes in RF-based plasma technology, while Gasonics specializes in microwave-based plasma technologies. Dataquest believes that semiconductor manufacturers will use a combination of single-wafer and batch dry strip processes utilizing RF-plasma or microwave plasma technologies for various device mask levels. The combined expertise of Gasonics and Branson/IPC in RF/microwave strip technologies will enable the companies to offer a one-stop worldwide solution to dry strip market needs. The merged entity will have a significant presence in all key wafer fabrication regional equipment markets.

In addition, Branson/IPC's growing line of industrial RF-plasma cleaning systems will provide

TABLE 1
Branson/IPC and Gasonics Products and 1990 Market Shares
(Millions of Dollars)

Company	Products	Market Segment	1990 Revenue
Branson/IPC	L3200, L3300	RF plasma/single-wafer dry strip	10.0
	Series 9000	RF plasma/batch-barrel dry strip	4.5
	L2200	RF plasma/single-wafer isotropic etch	3.5
Gasonics	Aura Series	Microwave/single-wafer dry strip	8.2
	AE2001	Microwave/single-wafer isotropic etch	1.5
	HIPOx Series	High-pressure oxidation/diffusion	8.0

Source: Dataquest (April 1991)

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a stable revenue stream that will complement the more volatile revenue streams from the semiconductor equipment operation. Branson/IPC's industrial cleaning systems are being explored for a wide range of applications in diverse areas such as the aircraft, automotive, medical, and electrical machinery industries.

COMPETITION IN THE MARKETS SERVED BY BRANSON/IPC AND GASONICS

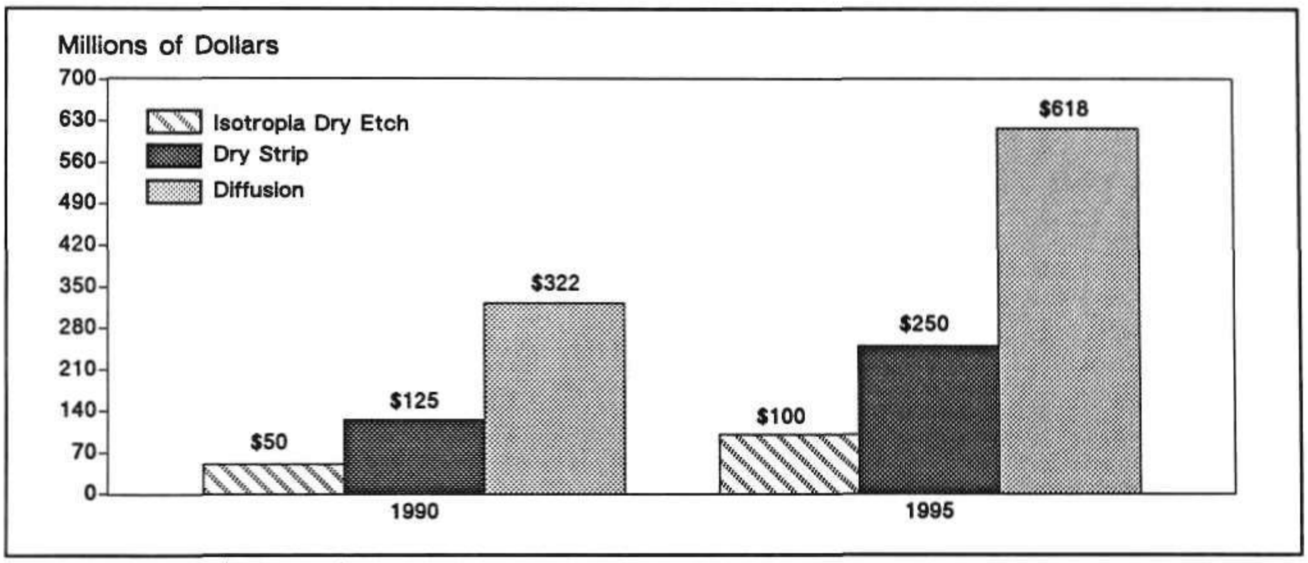
Figure 1 shows Dataquest's forecast for the growth of the dry strip, isotropic dry etch, and diffusion equipment markets between 1990 and 1995. The combined markets, which Branson/Gasonics plan to address, will have a compound annual growth rate of 14.3 percent, growing from $497 million in 1990 to $968 million in 1995. The dry strip market has assumed more importance with the move to submicron processes. Issues such as ionization damage due to dry strip plasma exposure, resist removal difficulties due to ion implant and reactive ion etch (RIE) high-energy damage, and thin oxide charge buildup have increased the size and importance of the dry strip market.

Table 2 shows the worldwide 1990 dry strip equipment company rankings. The Branson/Gasonics merger will catapult the new company close to the top of the worldwide dry strip company rankings among such Japanese competitors as Alcan Tech, Plasma Systems, Ramco, and Tokyo Ohka Kogyo.

The isotropic dry etch market is a relatively small niche within the much larger total dry etch market. Gasonics and Branson/IPC hope to address the standalone isotropic dry etch market as well as the cluster tool module market, which will incorporate dry etch, dry strip, chemical vapor deposition (CVD), and physical vapor deposition (PVD) processes. Competition, however, is heating up in the isotropic dry etch market as leading dry etch equipment companies develop their own versions of isotropic etch modules for integration with their cluster tools.

Gasonics' high-pressure HIPOx diffusion/oxidation system occupies a unique niche within the diffusion/oxidation equipment market. All other diffusion equipment companies offer atmospheric process solutions. Gasonics, with its high-pressure system, owns a very small fraction of the overall diffusion/oxidation equipment market. However, Dataquest believes that high-pressure, low-temperature diffusion/oxidation systems will find increasing applications in submicron processes, which attempt to minimize device exposure to high temperatures for long periods of time. The combined company will have greater resources to develop new applications and market the HIPOx product family more aggressively worldwide.

FIGURE 1
Worldwide Dry Strip, Isotropic Dry Etch, and Diffusion Equipment Market Forecast (Million of Dollars)



Source: Dataquest (April 1991)

TABLE 2
Worldwide 1990 Dry Strip Equipment Company Rankings
(Millions of Dollars)

Company	Revenue	Percent 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
Worldwide Market Total 125.3 100.0		

Note: Rankings are calendar year system revenue only; no spares or service are included.
Source: Dataquest (April 1991)

IMPLICATIONS OF THE MERGER FOR THE FAB EQUIPMENT INDUSTRY

Dataquest believes that the Branson/Gasonics merger illustrates the $25 million to $30 million annual revenue barrier that equipment companies have to surmount in order to generate a sufficient income stream to fund future product development. This becomes especially important in an industry characterized by ever-shortening design-in market windows for future device generations, high R&D costs, and high costs due to the need for complete global customer support. The North American wafer fab equipment industry abounds in small, entrepreneural companies with creative products, single-market focus, and limited R&D and global expansion resources. Such small companies are also constrained by their inability to raise cheap, long-term capital in the short-term-oriented North American equity and debt markets.

The options for the survival of these small, entrepreneurial North American companies are limited—seek a buyout or a cash infusion from a larger partner and risk losing the flexible entrepreneural edge and control over the technology or seek a marriage of equals with another small entrepreneural company and attain critical mass that way. Dataquest believes that the marriage-among-equals option pursued by Branson/IPC and Gasonics may have a good chance for success within the wafer fab equipment industry. The semiconductor equipment industry will closely watch the combined Branson/Gasonics entity's future market activities in order to gauge the long-term success of this growth strategy.

Krishna Shankar

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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Research Newsletter

1990 WAFER FAB EQUIPMENT MARKET: JAPAN ACCOUNTS FOR MORE THAN HALF OF WORLD'S SUPPLY AND DEMAND

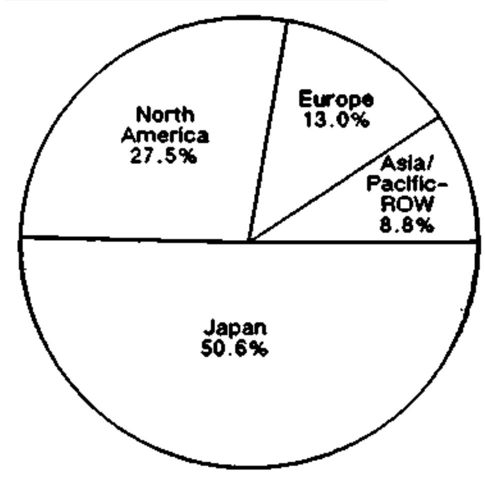
The Japanese market for semiconductor wafer fab equipment accounted for more than 50 percent of the worldwide market in 1990. At the same time, Japanese equipment companies supplied more than half of the world's wafer fab equipment needs. These are just a few of the results from the annual survey of the wafer fab equipment industry recently completed by Dataquest's Semiconductor Equipment, Manufacturing, and Materials Service (SEMMS).

1990 IN REVIEW

In 1990, the world market for wafer fab equipment was $5.8 billion, down 3.1 percent from its 1989 level of $6.0 billion. While Japan and Europe both enjoyed modest growth of 5.2 and 5.3 percent, respectively, North America was down 3.8 percent. The Asia/Pacific market for wafer fab equipment was hit especially hard in 1990 by the reduced spending levels of the major Korean manufacturers, and it was further exacerbated by the woes of the Taiwanese financial market. These factors contributed to a heady decline of 37.3 percent in spending for wafer fab equipment in Asia/Pacific in 1990.

Modest growth in Japan coupled with contracting markets in North America and Asia/Pacific contributed to a 3.9 percent increase in 1990 regional market share for Japan. As shown in Figure 1, Japan accounted for more than half of the world's demand for wafer fab equipment with 50.6 percent of the $5.8 million world market.

FIGURE 1
1990 Wafer Fab Equipment Market by Region (Percentage of Dollars)



Note: Parts do not add to 100% because of rounding.

Source: Dataquest (April 1991)

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SEMMS Newsletters 1991 Equipment—Wafer Fab Equipment/Industry Trends

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Europe, also propelled by modest growth, exhibited a 1 percentage point increase in 1990 in its regional share of the world equipment market. North America maintained the same regional percentage share in 1990 as in 1989, while Asia/Pacific declined almost 5 percentage points.

Throughout the 1980s, Japanese equipment companies have steadily gained market share in the wafer fab equipment industry; 1990 was no exception. Japanese equipment company share of the worldwide wafer fab equipment market was 51.1 percent in 1990, an increase of 2.8 percentage points from its 1989 level. Japanese equipment companies increased share in all regions of the world except Asia/Pacific. In particular, Japanese equipment vendors garnered a significant increase of market share in Europe in 1990 and now account for almost one-fourth of all wafer fab equipment spending in that region. The increase of Japanese equipment company share in Europe is a direct result of the European fab expansion plans of Japanese semiconductor manufacturers that tend to rely on Japanese equipment and materials companies to supply their new overseas fabs.

FUTURE ANALYSIS

Detailed analysis of the wafer fab equipment market by equipment category, regional emphasis, and company ownership will be discussed in a series of newsletters by SEMMS analysts during the next several months. In the meantime, the SEMMS wafer fab equipment database, including detailed company market share estimates by region, by vendor, and by equipment category, is available immediately to SEMMS clients via electronic delivery of Dataquest's *On-Line Service*.

Peggy Marie Wood

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Research Newsletter

STEPPER EQUIPMENT MARKET—1990 MARKET IN REVIEW

SUMMARY

Worldwide stepper shipments totaled 775 units in 1990, down almost 19 percent from the 1989 level of 954 steppers. The 1990 stepper market, measured on a revenue basis, was $1,067 million, down only 10 percent from its 1989 level. The difference in percentage change between units and revenue clearly reflects the pervasive trend of increasing average selling prices (ASPs) for advanced wafer processing equipment. Higher ASPs for steppers are being driven by new lenses with high numerical apertures and wide fields, as well as a continuing shift in the stepper product mix toward i-line stepper systems. Dataquest expects worldwide stepper shipments in 1991 to be 800 units, up a modest 3 percent from 1990, while stepper revenue is expected to be up 13 percent to $1,210 million.

REGIONAL MARKETS

All regions of the world had reduced stepper shipments in 1990 compared with 1989, with the exception of Europe, which experienced modest growth from 86 units in 1989 to 94 in 1990. Asia/Pacific-Rest of World (ROW), in particular, experienced a severe decline in stepper shipments from 157 units in 1989 to only 73 in 1990. This drastic decline in stepper shipments was of a magnitude similar to the decline observed in other equipment segments as semiconductor manufacturers in South Korea and Taiwan reevaluated their capital spending plans in light of softening DRAM prices, the specter of overcapacity, and faltering financial markets.

Japan represents the largest regional market for wafer steppers and, with 410 steppers, accounted for 53 percent of worldwide stepper shipments in 1990 (see Figure 1). Activity in i-line stepper lithography has escalated dramatically in Japan in the past several years as DRAM manufacturers have settled on their 16Mb and 64Mb lithographic strategies. I-line units accounted for only 6 percent of the product mix in Japan in 1988, yet by 1990, i-line systems represented 37 percent of all steppers sold in this region of the world. Phase shift masks, now in development, offer the prospect of extending existing i-line lens technology to smaller line geometries without any significant loss in depth of focus. Dataquest anticipates that if phase shift mask technology proves both successful and cost-effective, i-line steppers will be used for DRAM processing well into the 256Mb generation.

North American stepper shipments in 1990 totaled 198 units, or about one-fourth of the world market. North America traditionally has been the strongest market for i-line steppers supported by a well-established vendor base for both steppers and photoresist. I-line systems represented 42 percent of the North American stepper mix in 1990; however, on an absolute basis, i-line shipment levels in North America ranked second behind Japan. I-line lithography in Europe and Asia/Pacific-ROW has yet to be embraced with the same level of activity as in Japan and North America. I-line shipments in Europe and Asia/Pacific-ROW were 28 and 25 percent, respectively, of total shipments. In 1990 overall, i-line units represented 36 percent of worldwide stepper shipments, up from only 12 percent of the stepper product mix two years earlier.

REGIONAL OWNERSHIP

The stepper equipment market continues to be dominated by Japanese suppliers (see Figure 1). Together, Nikon, Canon, and Hitachi controlled close to 80 percent of 1990 worldwide stepper shipments and over 98 percent of stepper shipments in their home market of Japan. Historically, all of

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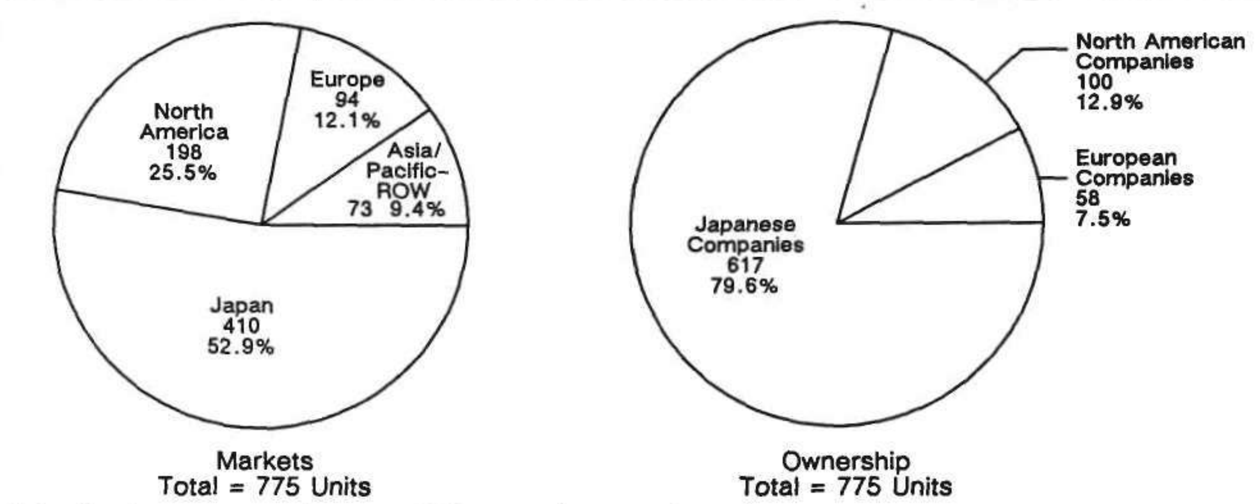
FIGURE 1
1990 Stepper Regional Markets and Ownership (Units)



Note: Pie chart segments do not total 100 percent because of rounding.

Source: Dataquest (April 1991)

Hitachi's stepper shipments have been in Japan; however, 1990 marked the first year for Hitachi stepper exports: a handful of systems were shipped to Hitachi's semiconductor operations in the United States. In contrast to Hitachi, Nikon and Canon have been aggressive in establishing a strong presence outside of Japan. Together, these two companies in 1990 represented 43 percent of stepper shipments in North America, 74 percent of stepper shipments in Europe, and 73 percent of stepper shipments in Asia/Pacific-ROW.

COMPANY RANKING

As shown in Table 1, Nikon maintained its number one ranking in the stepper equipment market in 1990, accounting for one-half of the world market with 384 steppers. Dataquest estimates that approximately 30 percent of Nikon's stepper mix were i-line systems in 1990, a significant change in product mix compared with 1988 when all of Nikon's stepper shipments were g-line systems. Canon ranked second in the stepper market in 1990, a strong position for a vendor that was not yet shipping i-line systems. In mid-1990, the company announced its entry into the i-line market with its model FPA-2000i1, the first announcement of an i-line stepper with a wide-field lens (20mm x 20mm). Shipments of Canon's new i-line system are expected to begin in 1991.

Hitachi ranked third in stepper shipments in 1990 with an estimated 83 units, essentially all of which were i-line systems. Dataquest estimates that approximately 30 percent of Hitachi's stepper shipments are for internal use at Hitachi semiconductor facilities. One of the advantages that Hitachi enjoys in process equipment development is the close ties it has to its semiconductor manufacturing parent corporation. At the same time, this can be viewed as a disadvantage in the marketplace because some semiconductor manufacturers are reluctant to buy Hitachi equipment and thus expose their clean room and processing activities to Hitachi engineers.

ASM Lithography, the only European vendor of optical steppers, continues to be a shining star in

TABLE 1
1990 Worldwide Stepper Company Rankings

Company	Units	Market Share (%)
Nikon	384	49.5
Canon	150	19.4
Hitachi	83	10.7
ASM Lithography	58	7.5
GCA	52	6.7
Ultratech	39	5.0
SVG Lithography	9	*
Total	775	

Source: Dataquest (April 1991)

the European wafer fab equipment industry. Over the past several years, the company has successfully positioned itself as a leading vendor of advanced i-line systems. At the SPIE Symposium on Microlithography in March 1991, ASM Lithography introduced a new wide-field i-line stepper with sub-0.5-micron capability. Dataquest believes that this new system places ASM in a strong competitive position in this highly technical segment of the wafer fab equipment industry. ASM Lithography ranked fourth in stepper shipments in 1990 with an estimated 58 units.

GCA ranked fifth in 1990 stepper shipments with an estimated 52 systems, the majority of which were i-line systems. GCA was the first vendor to start i-line stepper shipments back in 1985. At SPIE in March 1991, GCA described its most advanced systems for i-line and excimer laser lithography. Its new family of XLS steppers was developed in conjunction with Sematech and its member companies. The relationship with Sematech and its member companies has been important to GCA because more than three-fourths of its unit shipments the last several years have been in its home market of the United States.

Clearly, 1990 was a year of uncertainty for Ultratech. In May 1990, General Signal, the parent corporation of GCA and Ultratech, announced that it would consolidate the operations of its regionally dispersed stepper businesses. (GCA is in Massachusetts; Ultratech is in California.) However, before this decision was put into motion, a management buyout of Ultratech was announced. By the end of summer 1990, however, the plans for the buyout had fallen apart over disagreements regarding financing. At the end of 1990, General Signal was back where it began the year, the parent corporation of two stepper companies located in different parts of the United States and pursuing different stepper technologies. Dataquest believes that the uncertainty regarding Ultratech's future, coupled with the widespread acceptance of reduction lithography as the de facto standard in the industry, was responsible for the erosion of the company's position in the market.

SVG Lithography (SVGL) was a new name in the stepper market in 1990. SVGL was established as a subsidiary of Silicon Valley Group (SVG) after it acquired the former optical lithography group of Perkin-Elmer in May 1990. With the acquisition, SVGL acquired the complex, advanced lithography technology known as "step-and-scan" because of its combined capability of both projection and step-and-repeat lithography. Dataquest estimates that in calendar year 1990, Perkin-Elmer and SVGL had combined shipments of nine Micrascan systems, of which all but one system went to IBM for its advanced DRAM production.

DATAQUEST PERSPECTIVE

The stepper market is the largest single segment of the wafer fab equipment industry, accounting for $1,067 million, or 18 percent of the 1990 world market of $5,813 million. Stepper technology is a fundamental component of advanced device processing that allows for the continuing reduction of line geometries. This means that stepper vendors regularly face huge R&D investments to stay on the cutting edge of new lens and stepper system development. With the departure of American Semiconductor Equipment Technologies (ASET) in 1989, only seven companies remain in this market segment, and the barriers to entry are sufficiently high that it is unlikely that new companies will enter the market. The question remains of whether the smaller stepper companies have sufficient critical mass to manage the long-term pressures of global sales, service, and support and invest a sufficient level of capital in new product development.

Clearly, Silicon Valley Group is learning firsthand the rigors of supporting an advanced lithography equipment group. In the quarter ending December 31, 1990, SVG reported net income of $81,000 on sales of $60.9 million, in sharp contrast to the average quarterly net income of $1.1 million reported to its stockholders over the last nine years. SVG recently held public offerings for its stock as one means to generate additional capital for its activities. Dataquest believes that future growth for GCA and Ultratech will depend on General Signal's attitude concerning its continuing participation in the semiconductor wafer fab equipment industry. General Signal has spun out several of its wafer fab equipment groups over the last several years and entertained the concept of a management buyout of Ultratech last summer. Today, Ultratech is still part of the General Signal family, meaning that the two stepper business units compete against each other for both corporate R&D dollars and orders in the marketplace.

Although only a handful of companies participate in the stepper market, it will continue to capture the interest and imagination of the industry because it represents the leading edge of technology. Successful performance in this segment brings with it significant financial rewards.

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

Etch/Clean

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Research Newsletter

WET PROCESSING EQUIPMENT: 1990 MARKET IN REVIEW

SUMMARY

The worldwide wet processing equipment market totaled $350.3 million in 1990, a decrease of 1.2 percent over 1989 sales levels. Wet processing equipment comprises five categories: integrated wet systems, manual benches, rinsers/dryers, acid/solvent processors, and megasonic cleaners. The year-to-year decline in wet process revenue is attributable to manual benches, rinser/dryers, and acid/solvent processors. Integrated wet processing systems and megasonic sales both grew in 1990 in spite of a weak semiconductor capital equipment market.

REGIONAL MARKETS

Geographically, Japan is the world's largest wet processing equipment market. Sales in Japan totaled $222.8 million in 1990 (see Figure 1). The size of the Japanese market can be explained by the sheer size of the device production capacity of Japanese fab lines and by the device manufacturers' determination to push wet processing technology to the limit.

North American sales, $71.8 million in 1990, are much smaller than Japanese sales for two reasons. First, U.S. manufacturers on average spend considerably less for wet processing equipment per fab line than do Japanese manufacturers because they have been slow to automate the wet processing area. Second, U.S. semiconductor manufacturers have focused their efforts on dry processing rather than wet processing.

Sales in European and Asia/Pacific-Rest of World (ROW) are smaller, reflecting the semiconductor production capacity in these regions. In 1990, sales of wet processing equipment totaled $30.5 million in Europe and $26.2 million in Asia/Pacific-ROW. Dataquest is forecasting the Asia/Pacific-ROW region to have the fastest-growing demand for wet processing equipment during the next five years. Japanese equipment vendors are expected to benefit the most from this growth, given their strength in this equipment segment and their proximity to the market.

COMPANY RANKINGS

Japanese companies Dainippon Screen, Kaijo Denki, Sankyo Engineering, and Sugai lead the worldwide ranking in sales of wet processing equipment (see Table 1). Japan's dominance in wet processing equipment (see Figure 1) is attributable to sales of integrated wet bench systems, which make up 68 percent of the total wet processing market. This leadership position is unlikely to be relinquished any time soon.

A few U.S. companies have strong positions in the wet processing equipment market. FSI International is the sixth-largest worldwide vendor of wet processing equipment, holding a particularly strong position in the acid/solvent processor market. Submicron Systems, a three-year-old U.S.-based company, has become the largest supplier of integrated wet benches in the North American market. Athens Corporation and Alameda Instruments have pioneering acid reprocessing technology, which has the potential to grow rapidly during the next 10 years.

DATAQUEST PERSPECTIVE

The wet processing equipment market has grown at a 21.5 percent compound annual growth rate (CAGR) from 1986 to 1990. This growth mirrors the overall semiconductor capital equipment industry, which grew 21 percent in the same five-year period.

SEMMS Newsletters 1991 Equipment—Etch/Clean

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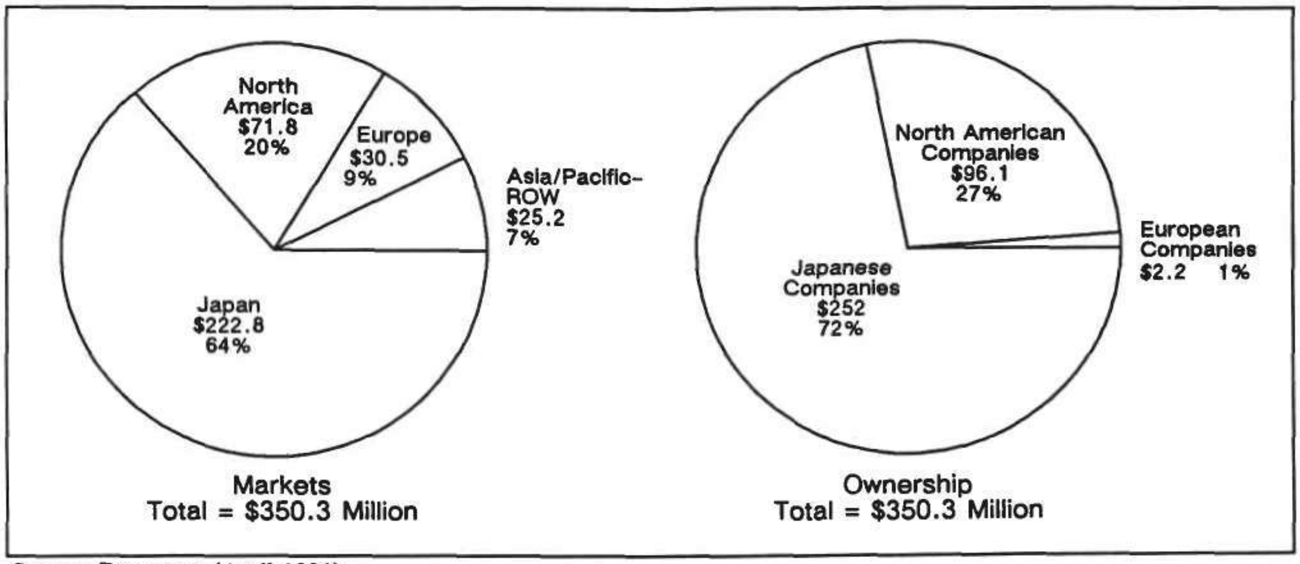
FIGURE 1
1990 Wet Processing Equipment Regional Markets and Ownership (Revenue in Millions of Dollars)



Source: Dataquest (April 1991)

TABLE 1
1990 Worldwide Wet Processing Company Rankings (Millions of Dollars)

	Revenue	Market Share (%)
Dainippon Screen	53.9	15.4
Sankyo Engineering	38.7	11.0
Kaijo Denki	37.1	10.6
Sugai	35.7	10.2
Shimada	16.4	4.7
FSI International	16.2	4.6
Verteq	12.9	3.7
Maruwa	12.3	3.5
Semitool	11.5	3.3
Enya	10.8	3.1
Other	104.8	29.9
Worldwide Market Total	350.3	100.0

Note: The table shows calendar year 1990 system revenue; spares and service not included.
Source: Dataquest (April 1991)

TABLE 2
1990 Worldwide Wet Processing Equipment Segments (Millions of Dollars)

	Sales	CAGR (%) 1986-1990
Integrated Wet Systems	238.2	32.0
Manual Wet Systems	39.6	7.5
Rinser/Dryers	38.1	8.1
Acid/Solvent Processors	25.6	4.5
Megasonic Cleaners	8.8	29.8
Total	350.3	21.5

Source: Dataquest (April 1991)

However, two segments within the wet processing equipment market stand out in terms of growth (see Table 2). The integrated wet processing equipment grew at a blistering pace with a 32 percent CAGR from 1986 to 1990, and megasonic cleaners closely followed with a 29.8 CAGR since 1986. The other segments, manual wet benches, rinser/dryers, and acid/solvent processors, fell behind both the wet processing equipment and the overall semiconductor equipment growth rate.

The five-year CAGR for these three segments was 7.5 percent, 8.1 percent, and 4.5 percent, respectively.

Although wet processing technology is well defined, Dataquest expects this equipment to evolve as the level of automation increases in semiconductor fabs. Moreover, the size of the market, $350.3 million in 1990, is expected to attract some of the larger semiconductor equipment vendors that currently do not participate in this area.

Mark FitzGerald (San Jose)
Kunio Achiwa (Tokyo)

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Research Newsletter

DRY ETCH EQUIPMENT: 1990 MARKET IN REVIEW

SUMMARY

Dataquest believes that the worldwide 1990 dry etch equipment market essentially remained flat between 1989 and 1990. The worldwide 1990 dry etch market was $683 million. Although the worldwide market was flat, Japan's dry etch market, the world's largest, increased 9 percent to $360 million in 1990. Japanese device manufacturers continued to invest strategically in leading-edge 200mm submicron fabs in spite of a sluggish chip demand environment. The North American dry etch market remained flat in 1990, while the European market grew strongly because of the influx of North American and Japanese capital investment into European fabs. The Asia/Pacific-Rest of World (ROW) market contracted severely in 1990 because of political and economic uncertainities in that region.

North American dry etch companies, with 49 percent of the worldwide dry etch market, clung to a slim 3 percent lead over Japanese dry etch companies, which advanced to owning 46 percent of the market. Japanese dry etch companies gained market share for two main reasons: their home-field advantage of operating in the largest, most technologically demanding market and their early transition to single-wafer plasma-enhanced reactive ion etch (RIE) and microwave/electron cyclotron resonance (ECR) etch technologies. North American companies are responding aggressively by speedy globalization and rapidly bringing innovative plasma source technology to market.

REGIONAL MARKETS

Figure 1 shows the relative proportions of the 1990 worldwide dry etch market segmented by region and company ownership. The North American market made up 27 percent of the 1990 worldwide dry etch market. U.S. semiconductor companies have focused on high-value-added, high-margin products such as microprocessors, VLSI logic chip sets, and programmable logic devices. They have largely retreated from high-volume, low-margin products such as DRAMs and low-end gate arrays. Hence, key high-volume segments of the North American wafer fab equipment market such as steppers and dry etch equipment have not grown as rapidly as have the corresponding Japanese wafer fab market segments. It should also be noted that offshore Japanese fabs represent an increasing portion of the North American dry etch market. Leading North American device companies hope to increase their production of leading-edge high-volume microprocessors, high-end ASICs, and chip sets in order to stay on the technology and volume learning curve. Thus, the North American dry etch market may expand more rapidly in the future.

The Japanese dry etch equipment market grew from 49 percent of the $669 million 1989 dry etch market to 53 percent of the $683 million 1990 market. The number of mask levels in DRAM processes continues to increase dramatically with each new generation. For example, the 16Mb DRAM process may use 24 to 28 mask levels. Japan, as the leading producer of advanced DRAMs, is a natural technology driver for the development of high-volume dry etch equipment. Dry etch equipment average selling prices have also increased dramatically because of increasingly complex submicron etch requirements. Japan has also increased its market presence in other high-volume device markets such as gate arrays and other ASICs, PC chip sets, and foundry products for fabless semiconductor companies. Dataquest believes that the combination of high-volume production and leading edge technology is a major catalyst in accelerating the growth of core Japanese wafer fab equipment markets such as the stepper and dry etch markets.

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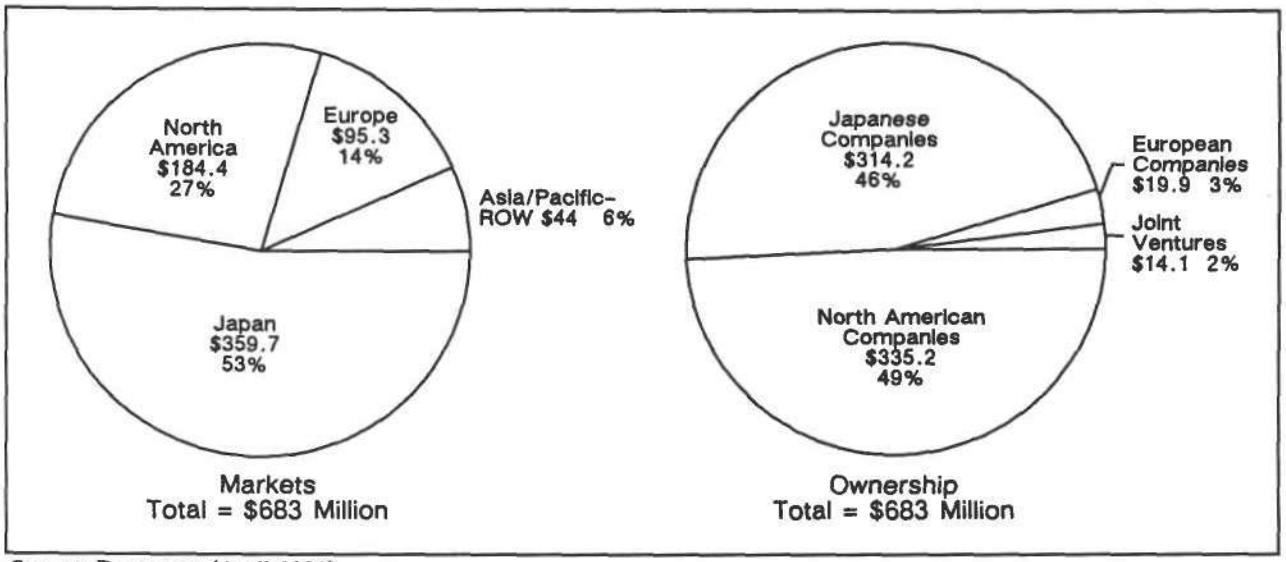
FIGURE 1
1990 Regional Dry Etch Markets and Ownership (Millions of Dollars)



Source: Dataquest (April 1991)

The European dry etch market increased from 13 percent of the 1989 market to 14 percent of the 1990 market. A major portion of European market growth was due to the influx of offshore European fabs built by North American and Japanese companies such as Fujitsu, Hitachi, Mitsubishi, and TI. Typically, these offshore European fabs were clones of existing North American and Japanese fabs. Thus, a major portion of the European dry etch market was open only to global dry etch vendors that had a significant presence in all three major semiconductor manufacturing regions of the world.

Asia/Pacific-ROW dry etch market share contracted from 12 percent of the 1989 market to 6 percent of the 1990 market. Factors such as severely depressed DRAM prices, excessive PC chip set competition, stock market crashes, and political/economic instability led to severe constraints on capital spending by Asia/Pacific-ROW device companies. Dataquest believes that the Asia/Pacific-ROW dry etch market may improve in 1991 as capital spending is resumed for future key production technologies such as the 16Mb DRAM and submicron foundries.

REGIONAL OWNERSHIP

Figure 1 shows the regional ownership of the 1990 worldwide dry etch markets. North American companies continued to lead the worldwide dry etch market, albeit by a small margin. North American dry etch companies saw their market share erode from 58 percent of the 1989 market to 49 percent of the 1990 market. Factors that caused this market share erosion included a major transition in product generation by Applied Materials, the leading North America-based dry etch company; severe global competition from Japanese dry etch companies; and a relatively flat 1990 North American dry etch equipment market.

Japanese dry etch companies' market share increased from 39 percent of the 1989 market to 46 percent of the 1990 market. Factors that caused Japanese companies to gain market share included participation in the large domestic Japanese market, close strategic partnerships with leading Japanese device manufacturers, crucial technology leadership in single-wafer microwave/ECR dry etch, and heavy emphasis on customer support and service.

Japanese dry etch companies have also successfully globalized operations to serve their customers through joint ventures and regional subsidiaries.

Joint-venture companies such as Varian/TEL had strong dry etch revenue growth in 1990. Dataquest believes that joint ventures represent a new, viable globalization business strategy for quick market penetration using the local joint venture partner's installed base of customer support and service capabilities.

COMPANY RANKINGS

Table 1 shows the rankings of the major players by their worldwide revenue in the 1990 dry etch equipment market. Six North American companies, eight Japanese companies, one European company, and one joint-venture company made up the top dry etch 1990 company rankings.

Applied Materials, with 25.6 percent of the 1990 dry etch market, retained its market leadership position. Applied's batch hexode 8000 Series systems and the PE5000 multichamber system enabled the company to lead the dry etch market. However, Applied's lead over the competition in this market has narrowed in the last few years. Applied's dry etch revenue shrank 15 percent from $208 million in 1989 to $175 million in 1990 in an essentially flat market environment. Applied lost market share in 1990 because of its late transition from the batch hexode 8000 family to the single-wafer PE5000 magnetically enhanced RIE technology. Companies that compete with Applied in the

TABLE 1
1990 Worldwide Dry Etch Equipment Company Rankings
(Revenue in Millions of Dollars)

Company	Revenue	Market Share (%)	Market Segment
Applied Materials	175.0	25.6	RIE, MERIE
Tokyo Electron	99.2	14.5	Plasma, RIE
Hitachi	91.5	13.4	Microwave/ECR, RIE
Lam Research	85.7	12.5	Plasma, RIE
Sumitomo Metals	33.0	4.8	Microwave/ECR, RIE
Tegal	31.0	4.5	Plasma, RIE, triode
Anelva	29.4	4.3	Microwave/ECR, RIE
Tokuda	24.1	3.5	RIE
Drytek	22.0	3.2	RIE, triode
Tokyo Ohka Kogyo	18.9	2.8	Microwave/ECR, plasma
Plasma-Therm	18.0	2.6	Plasma, RIE
Electrotech	17.5	2.6	RIE, triode
Varian/TEL	11.6	1.7	Plasma, RIE
Ulvac	6.6	1.0	RIE
MRC/Sony	4.7	0.7	MERIE
Branson/IPC	3.5	0.5	Plasma
Others	11.7	1.7	
Worldwide Market Total	683.4	100.0	

Note: The table shows calendar year 1990 systems revenue; spares and service are not included.
Source: Dataquest (April 1991)

dry etch market forged ahead earlier into the single-wafer plasma-assisted RIE and microwave/ECR dry etch technology.

The phenomenal success of the Precision 8000 technology prompted Applied to use a strategy of incremental improvement in its proven batch hexode technology rather than a strategy of revolutionary single-wafer dry etch technology using innovative plasma sources. In the domestic North American market, Applied encountered vigorous competition from Lam Research Corporation's (LRC's) highly successful Rainbow Series etch systems. Applied also encountered intense competition in Japan from companies such as Hitachi and TEL, which have invested heavily in R&D, joint product development with customers, and strategic customer support capability.

Dataquest believes that Applied is refocusing its efforts in the dry etch market by emphasizing its competitive strengths in specific segments such as the metal etch, polycide etch, and silicon trench etch markets. Applied's strengths in dielectric and metal CVD and PVD will also probably result in synergistic integration products based on the PE5000/Endura 5500 mainframe cluster tools.

TEL, ranked number two, captured 14.5 percent of the market with $99 million in 1990 revenue. TEL has successfully penetrated the large Japanese market through its single-wafer plasma-assisted RIE technology. TEL has built up an impressive reputation for customer support and product reliability and is aggressively globalizing its business through the Varian/TEL joint venture.

TEL has done well in absorbing LRC's AutoEtch plasma etch technology from the prior TEL/Lam joint venture and enhancing the product line to meet the Japanese dry etch market's requirements. Subsequently, TEL has developed its own proprietary plasma-enhanced RIE product line to meet the needs of the 4Mb DRAM generation. TEL recently introduced a new series of 200mm MERIE systems to serve the needs of the 16Mb/64Mb generation. TEL's systems are widely used in poly/polycide gate, nitride, and oxide dry etch applications. Dataquest believes that TEL's independent corporate position regarding the major Japanese business groups, together with its close strategic partnerships with key global device manufacturers, will help maintain its leadership position within the market.

Hitachi appears to have done phenomenally well in 1990. Its 1990 dry etch revenue of $91.5 million catapulted it to third place with 13.4 percent of the market. Hitachi's microwave/ECR single-wafer systems continued to successfully penetrate the metal and poly/polycide dry etch market. Hitachi's metal etch system, with its post-etch treatment involving dry strip and in-situ wet clean, was particularly successful in the fast-growing metal etch market. Hitachi is at the forefront of the Japanese market movement toward exploiting the high ionization efficiencies, high etch rates, high selectivity, and low ion bombardment of microwave/ECR-type single-wafer dry etch technologies. Hitachi recently began emphasizing its global equipment marketing capabilities by expanding aggressively in the international market.

LRC captured 12.5 percent of the 1990 dry etch market. LRC would be the second-ranked 1990 dry etch company with revenue of approximately $110 million if Sumitomo Metals' resale of Rainbow systems were included in the Japan market. Dataquest believes that LRC-originated single-wafer plasma-assisted RIE technology accounted for a substantial portion of the 1990 dry etch market. LRC has been very successful in the evolutionary extension of the original AutoEtch technology to the Rainbow family.

The Rainbow system, with its patented split-power/reverse-phase RF source, has been very successful in gaining market share in the oxide etch market. LRC is well positioned to exploit the fast-growing metal etch market by virtue of its joint-development projects with SEMATECH and Du Pont. LRC's prominent position in the Asia/Pacific-ROW and European markets, together with its successful Japanese partnership with Sumitomo Metals, will enable it to continue its key global dry etch market leadership. The LRC/Sumitomo Metals partnership appears to be a win-win position for the two companies because of their combined regional presence and relative strengths in RF-based plasma etch, microwave/ECR etch, thermal CVD, and ECR CVD.

Sumitomo Metals, by virtue of its ECR etch technology and successful Rainbow partnership with LRC, ranked fifth with 4.8 percent of the market. Dataquest believes that Sumitomo Metals will become an increasingly important player in the large Japanese market because of its parent company's (Sumitomo Group's) deep pockets and its growing investment in customer support facilities throughout Japan.

Tegal ranked sixth with 4.5 percent of the 1990 market. Tegal is still in the midst of its transition from being a Motorola Enterprises captive subsidiary to becoming a free-standing, global, multiproduct equipment company. In 1990, the company introduced its mainframe Series 6000 cluster tool, which will accommodate all of its dry etch module technologies in the plasma, RIE, and triode market segments.

Anelva, with 4.3 percent of the 1990 market, ranked seventh. In addition to its batch and single-wafer RIE market presence, Anelva recently entered the microwave/ECR dry etch market. Dataquest believes that Anelva will be a key player in future cluster tool integration markets because of its strengths in related thin-film technologies such as dry etch, PVD, and CVD.

DATAQUEST PERSPECTIVE

Dataquest believes that competition has intensified in the crucial global $683 million dry etch equipment market. European, Japanese, and North American companies are aggressively pursuing a range of technologies such as enhanced RF plasma sources, MERIE sources, and microwave/ECR sources in attempt to meet the complex requirements of cost-effective sub-0.5-micron device geometries. Japanese companies have almost caught up with North American companies in the quest for global market share. North American companies are actively pursuing the large international market through joint ventures, trading partnerships, and regional subsidiaries. Japanese companies are leveraging off their strengths in the large Japanese market in order to follow their increasingly globalized customers offshore.

Krishna Shankar (San Jose)
Kunio Achiwa (Tokyo)

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Research Newsletter

WET PROCESSING APPEARS TO HAVE NINE LIVES

Despite the widely held opinion that wet process technology will eventually be replaced by dry process technology, the demand for wet station equipment continues to grow in submicron applications. For instance, the number of cleaning steps is increasing with each new generation of DRAM (see Table 1). In addition, wet stations are widely used throughout front-end processes (see the following list), and it is unlikely that these steps will be replaced by dry processes in the near future. The prevalence of cleaning steps is evident in reviewing process flows (see Figure 1).

Wet process applications include the following:

- Before and after CVD process
- After etching process
- After implantation process
- Photoresist stripping process
- Silicon nitride etching process
- After cleaning of poly/PSG

In particular, silicon nitride (Si_3N_4) etching is almost exclusively a wet process because dry etching shows poor selectivity. Also, wet cleaning has a major advantage in that it does not leave a spot on the wafer.

SURFACE CONTROL

With submicron pattern development, the role of wet stations has shifted from conventional particle control to surface control, an example being the cleaning of native oxide film prior to a chemical vapor deposition (CVD) process. As a result, oxygen dissolved in deionized (DI) water needs to be reduced below a 10-parts-per-billion (ppb) level. Also, in the area of particle control, inspection specifications of 10 particles >0.1 micron per 200mm wafer are required for 16Mb DRAMs compared with 10 to 20 particles >0.2 micron per 150mm wafer for 4Mb DRAM. In practice, however, because detection of 0.1-micron particles is not possible, inspection is conducted at the 0.16-micron level, and acceptance criteria seem to be established at about 30 particles.

HIGHLY INTEGRATED SYSTEM WITH SHUTTLE

The increasing level of clean room automation is clearly reflected in wet station equipment. The use of automatic wafer transportation systems, which is a key element of clean room automation, is driving the development of wet stations capable of accommodating automated guided vehicle (AGV) systems. Of wet stations shipped in 1989 by the largest Japanese vendor, Dainippon

TABLE 1
DRAM Process Trends

	1Mb DRAM	4Mb DRAM
Number of mask layers	16	20
Total number of process steps	300	350
Number of cleaning process steps	35	48

Source: Dataquest (February 1991)

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Figure 1
Process Flow

1. Prediffusion Rinsing

NH_4OH/ H_2O_2	QDR	HF	QDR	Hcl/ H_2O_2	QDR	FR	SD

2. Si_3N_4 Stripping

H_3PO_4	H_3PO_4	QDR	FR	SD

3. Photoresist Stripping

H_2SO_4 / H_2O_2	H_2SO_4 / H_2O_2	QDR	FR	SD

4. Buffer Oxide Etching

HF	QDR	FR	SD

5. HF Cleaning

HF	QDR	FR	SD

Note: QDR = Quick Damper Rinse, FR = Final Rinse, SD = Spin Dryer or IPA vapor dryer

Source: Dataquest (February 1991)

Screen, 80 percent were systems equipped with a shuttle.

The typical system consists of an I/O port, clean stocker, wafer transfer section, shuttle, and integrated wet station (see Figure 2). Carriers are transported to the wet station I/O port by the AGV. The carriers move into the clean stocker, which is a buffer zone for carriers at the start and finish of the wet process step. Carriers then move to a wafer transfer section, where the carrier is changed over to a second carrier. The second carrier is used only within the wet station in order to prevent carriers saturated with chemicals from moving to the next process along the AGV and contaminating the process.

The internal carrier is transported to a loading position of the wet station via the shuttle. The carrier is moved through the wet process step by a robot. On completion of the wet process, the wafers are transferred to the original carrier and kept in the clean stocker until it is picked up by the AGV.

Throughput

The average throughput for 150mm wafers is 12 carriers per hour, including chemical exchange time and required maintenance time. To minimize the process time, a weighing tank is heated up in advance.

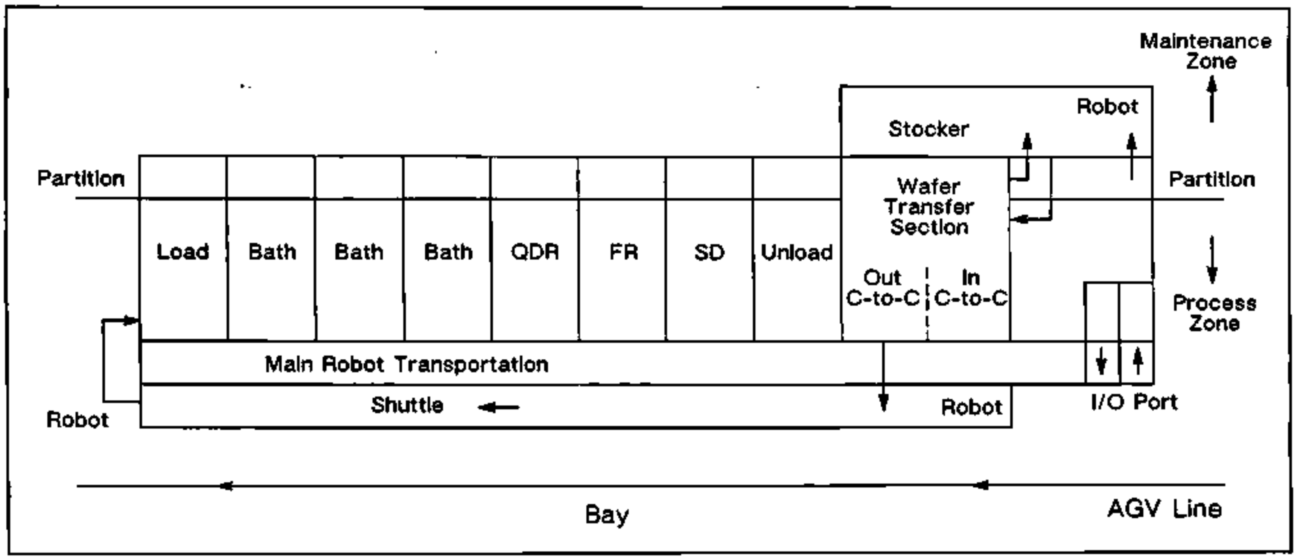
Equipment uptime varies greatly, depending on the vendor. Leading Japanese vendors typically target an uptime specification of greater than 95 percent of production time (excluding ordinary maintenance time). This trend suggests that reliability is a key factor to market acceptance.

Hidden Know-How

Although the wet stations do not use leading-edge technology, equipment vendors are upgrading systems with detailed design changes in order to improve equipment performance and reliability. Japanese vendors in particular have paid close attention to many of the small design features that hold the key to wet station reliability.

For instance, liquid-level sensors are used to detect wafer head positions in addition to the sensing of chemical mixture. Also, some of the equipment is designed to transfer a wafer carrier in water from the quick damper to the final rinsing process to prevent oxidation from exposure to the air.

FIGURE 2
Highly Integrated Wet Station Structure



Source: Dataquest (February 1991)

Finally, the upper edge of the bath is designed with sharp, angular edges. Suppliers have learned that this design ensures smooth liquid overflow, thereby preventing bacteria from growing in a standing liquid. It also permits the bath to be quickly drained during quick damper rinse.

FUTURE TRENDS

Wet station manufacturers are expected to develop a carrierless handling system. This design will eliminate the carrier, which is a major obstacle in preventing cross-contamination. This design will have the added cost advantage of eliminating carrier wear and tear.

Ongoing trends in process equipment integration suggest that the cleaning process will eventually be incorporated into a system that can interface with in-situ cluster tools. However, various problems need to be solved, including the removal of inorganic contaminants and particles or the prevention of spots on the wafer. SiO_2 etching using HF vapor is the first step to clustering. This cleaning process uses HF in a vapor rather than wet state. Vapor cleaning is effective in preventing organic and inorganic contaminants and particles from depositing on an activated silicon surface. Applications for HF vapor clean are listed as follows:

- Cleaning before silicide formation
- Removing native oxide in trench
- Cleaning before epitaxial deposition
- Cleaning after CVD oxide deposition
- Cleaning before metal deposition

As a transition to clustering for native oxide prevention, a system is designed to carry out the rinsing-drying process under an atmosphere of N_2 gas.

Finally, Dataquest expects wet station footprints to shrink in the future. The trend has been toward a larger footprint for each new generation. The average fab now uses about 15 wet stations, which occupy 30 to 40 percent of expensive clean room floor space. The percentage will increase for 200mm wafer fab clean rooms because of the forecast increase in the number of cleaning steps. In order to counterbalance this trend, wet station manufacturers need to design systems with smaller footprints. The single-wafer systems have smaller footprints, but their low throughput is not suitable for volume production.

DATAQUEST CONCLUSIONS

Wet process equipment has historically been a niche technology. The vendor base has been populated by a large number of small companies. However, wet station sales are fast becoming a significant segment of total semiconductor capital equipment sales. As the level of integration and the average selling price of equipment increase, Dataquest expects only the larger players that offer highly automated stations to survive. The size of the market may also attract the participation of large diversified semiconductor equipment makers that want to broaden their product line.

Although wet process technology is relatively old in terms of semiconductor technology, Japanese vendors are excelling at pushing the use of this equipment into the submicron era. U.S. equipment makers that have been the most vocal in sounding the death knell of wet process technology should take notice.

Kunio Achiwa (Tokyo)
Mark FitzGerald (San Jose)

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Deposition

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Research Newsletter

PVD EQUIPMENT: 1990 MARKET IN REVIEW

SUMMARY

The worldwide physical vapor deposition (PVD) equipment market grew 11 percent from $368 million in 1989 to $408 million in 1990. All 1990 PVD market growth occurred in the sputtering equipment market segment, which accounted for 88 percent ($359 million) of the 1990 market. The worldwide evaporation equipment market, which accounted for the remaining 12 percent ($49 million) of the PVD market, remained flat in 1990. The PVD market grew in spite of an overall 1990 wafer fabrication equipment market environment that was slightly down. The emergence of 200mm double-metal 4Mb DRAM shrink production and 16Mb DRAM pilot lines, together with the migration of microprocessors, gate arrays, and VLSI logic devices to triple-metal processes, were responsible for the PVD market's growth.

Japan, with 48 percent of the world's PVD market, retained its position as the largest regional market. The North American market, with 31 percent of the 1990 total, remained the second-largest regional market. Japanese companies increased their ownership to 58 percent of the 1990 worldwide PVD market, while North American companies captured 30 percent of the total. Japanese PVD equipment companies took advantage of their home-field position within the leading-edge Japanese market to introduce evolutionary improved versions of their PVD tools. North American companies, in contrast, focused on revolutionary cluster tools that incorporated modular PVD chamber architecture and offered future integration paths with related chemical vapor deposition (CVD) and dry etch processes.

REGIONAL MARKETS

Figure 1 shows the 1990 regional PVD markets and ownerships. Japan, the world's largest PVD market, accounted for 48 percent of the total. Japan's emphasis on high-volume, leading-edge DRAM production, together with its increasing presence in gate arrays, ASICs, chip sets, and foundry products, led to its evolution as the largest PVD market. The Japanese PVD market grew rapidly in 1990 because of the move from single-metal 1Mb/4Mb DRAM processes to double-metal 4Mb shrinks and 16Mb processes. The move to 200mm fabs in Japan has also resulted in dramatic increases in sputtering equipment average selling prices (ASPs). Japanese device manufacturers focused heavily on double-metal DRAM processes and triple-metal gate array processes in their attempts to stay ahead of commodity DRAM and gate-array competition from Asia/Pacific-Rest of World (ROW) device manufacturers. Small, fast DRAM and ASIC chips implemented in multilevel interconnect technologies and small outline packages will offer Japanese device manufacturers a cost/performance edge in the highly competitive DRAM and gate array markets.

The North American PVD market, with 31 percent of the world's total, remained the second-largest market. North America has traditionally been the leading producer of high-performance microprocessors and other advanced VLSI logic chips. Such random logic chips rely heavily on double-metal interconnect technology. In the mid-1980s, the North American production region led the world in the migration to multilevel interconnect processes. However, microprocessor and advanced VLSI logic unit volumes are much smaller compared with DRAM and gate array unit volumes. North American device manufacturers such as Intel and Motorola have achieved higher revenue streams per dollar of wafer fab capital investment due to the higher ASPs of their proprietary microprocessor devices. Typically, North American device manufacturers have bought less core wafer fab equipment such as PVD, CVD, lithography, dry etch, ion implantion, and diffusion

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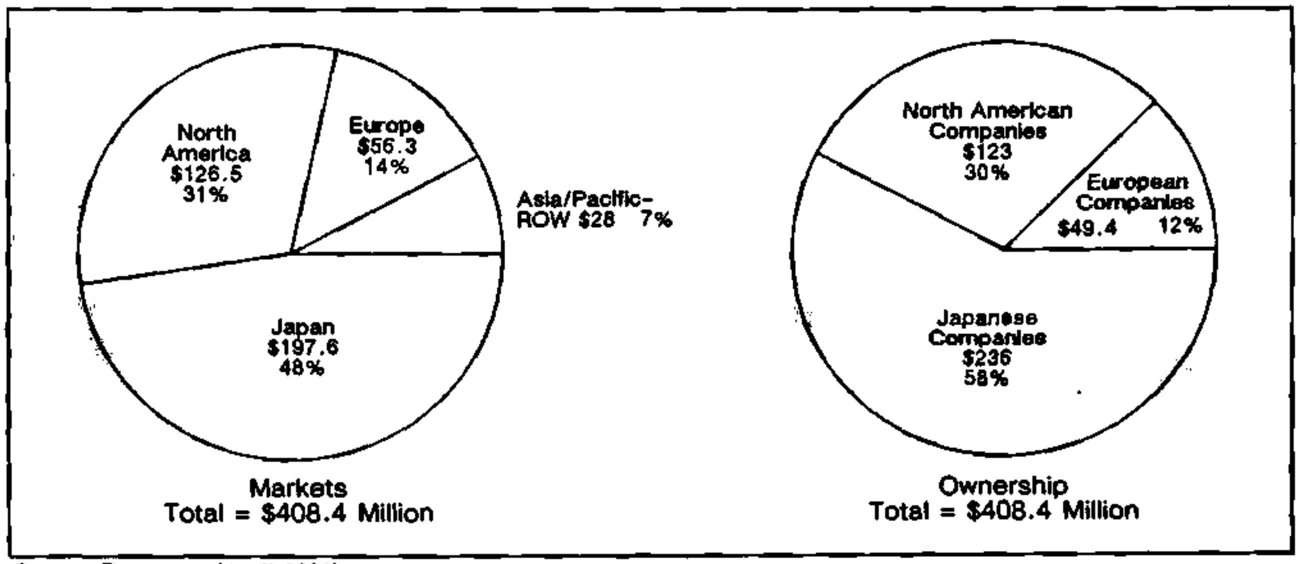
FIGURE 1
1990 PVD Equipment Regional Markets and Ownership
(Revenue in Millions of Dollars)



Source: Dataquest (April 1991)

equipment in order to ramp up to a given revenue level than have their DRAM-focused Japanese counterparts. Dataquest believes, however, that the North American PVD market will exhibit increased growth during the next few years because of the rapid migration of microprocessors, gate arrays, and VLSI logic devices to three- and even four-level metal processes. The increasing number of offshore Japanese fabs in North America will also contribute to the growth of the North American PVD market.

The European market grew a healthy 25 percent to occupy 14 percent of the 1990 PVD market. A substantial portion of Europe's market growth was due to the ramp-up of offshore Japanese and North American semiconductor operations in Europe. Dataquest expects continued PVD market growth in Europe, fueled mainly by the globalization of the semiconductor industry. However, the offshore European fabs tend to be clones of domestic Japanese and North American fabs. Hence, PVD equipment companies have to be global in customer support and service in order to get a slice of the market in all major worldwide semiconductor manufacturing regions.

The Asia/Pacific-ROW market shrank from 10 percent of the 1989 PVD market to 7 percent of the 1990 PVD market. Factors such as excess DRAM capacity and low DRAM prices, excessive PC chip set competition, inability to raise capital due to depressed stock market valuations, and political instability were responsible for the weak 1990 Asia/Pacific-ROW market. Dataquest expects growth to pick up in the Asia/Pacific-ROW market in 1991 and beyond because of a new round of capital investment in 200mm 16Mb DRAM fabs in South Korea, new submicron ASIC and foundry fabs in Taiwan, and new fabs in developing countries such as Malaysia, Indonesia, Thailand, and India.

REGIONAL OWNERSHIP

Figure 1 shows regional ownership of the worldwide 1990 PVD equipment market. Japanese PVD companies dramatically increased their ownership from 44 percent of the $368 million 1989 market to 58 percent of the $408 million 1990 market. Sony's acquisition of Materials Research Corporation (MRC) of Orangeburg, New York, toward the end of 1989 was a significant factor in the rapid PVD market share gain by Japanese equipment companies. Japanese companies have also been successful in jointly developing high-volume sputtering systems with their large, advanced DRAM-focused domestic Japanese semiconductor manufacturers. Japanese PVD companies such as Anelva and Ulvac are large, diversified companies that cater to a wide range of industrial vacuum coating applications. Diversified target markets and large size enable Japanese PVD companies to successfully weather the cylicality and capital-intensive nature of the wafer fabrication equipment industry.

The sheer size of the domestic Japanese market, together with the growing number of offshore Japanese fabs, has provided Japanese PVD companies with economies of scale in sputtering system production and ample R&D funds for new product development. Dataquest expects Japanese PVD companies to leverage off their domestic strengths and increase their international business activities as they follow their increasingly globalized Japanese semiconductor manufacturers offshore. Japanese PVD companies will face numerous challenges relating to global customer support and service capabilities, new business culture and customer/vendor relationships, and increased competition from North American and European PVD equipment companies that will attempt to protect their home base.

North American companies owned 30 percent of the 1990 PVD market. North American PVD companies are in the vanguard of the worldwide PVD market movement toward flexible, modular, cluster-tool sputtering systems that can integrate future related processes such as CVD, dry etch, dry strip, and rapid thermal processing. North American companies are confronted by a relatively slower-growing domestic market compared with the international market. Hence, they are rapidly redirecting their efforts toward penetration of the international PVD markets. North American companies also face the challenges of global customer support and service, new business cultures, and the high costs associated with penetrating international markets through regional subsidiaries and distributors.

European companies captured 12 percent of the 1990 PVD market. Companies such as Balzers and Electrotech were active in the cluster-tool-based sputtering equipment market. European companies expect to capture an increasing portion of the European PVD business provided by domestic and offshore fabs. Europe's stance on domestically manufactured chips, together with global semiconductor companies' attempts to stimulate the domestic infrastructure by procuring equipment locally, is expected to support the growth plans of European PVD companies. European PVD companies such as Balzers and Leybold-Heraeus will benefit from the deep pockets of their diversified industrial parents in a manner similar to Japanese PVD companies.

COMPANY RANKINGS

Table 1 shows the worldwide 1990 PVD company rankings and the revenue split between

TABLE 1
1990 Worldwide PVD Equipment Company Rankings
(Revenue in Millions of Dollars)

Company	Revenue	Market Share (%)	Revenue Split by Market Segment (%)
Anelva	94.9	23.2	Sputtering: 96, Evaporation: 4
Varian	84.0	20.6	Sputtering: 100
Ulvac	72.0	17.6	Sputtering: 81, Evaporation: 19
MRC	62.6	15.3	Sputtering: 100
Applied Materials	15.0	3.7	Sputtering: 100
E.T. Electrotech	13.5	3.3	Sputtering: 100
Balzers	13.5	3.3	Sputtering: 52, Evaporation: 48
Temescal	13.1	3.2	Evaporation: 100
Others	39.8	9.7	
Worldwide Market Total	408.4	100.0	Sputtering: 88, Evaporation: 12

Note: The table shows calendar year 1990 systems revenue; spares and services are not included. Some columns do not add to totals shown because of rounding.
Source: Dataquest (April 1991)

sputtering and evaporation. Three European companies, three Japanese companies, and two North American companies make up the top eight PVD rankings.

Anelva, with 23.2 percent of the 1990 market, was the top-ranked PVD company. Anelva's modular Series 1051 system continued to be successful in the Japanese market. Anelva is a key player in the integrated titanium-titanium nitride barrier-aluminum alloy sputtering market for submicron applications and is also beginning to ship a growing number of its sputtering systems to offshore Japanese fabs. Anelva introduced a 200mm version of its Series 1051 product family in 1990. The company is actively developing integrated-process cluster tools incorporating PVD, CVD, and dry etch/ECR etch modules. Anelva's Series 1551 is targeted at R&D and pilot-line 16Mb/64Mb integrated process applications. Processes developed on the Series 1551 can be transferred to the high-volume Series 1051 cluster tool systems. Anelva's market presence in the disk coatings, LCD flat panel coatings, and other industrial coatings segments synergistically complements its semiconductor PVD equipment market activities.

Varian, with 20.6 percent of the 1990 market, retained its position as the second-ranked PVD company. Varian successfully ramped up production of its flagship M2000 cluster-tool-based sputtering system in 1990. The company focused its efforts in production enhancements, new sputtering source technology such as the Quantum source, and penetration of key global semiconductor fabs. Varian's M2000 Series is the company's platform for future integrated process applications involving dry etch, CVD, and PVD. In addition, Varian's older Series 3000 family of multichamber sputtering systems continues to be a successful cash cow product that targets capacity expansion fabs and more mature device fabs in the Asia/Pacific-ROW regions.

Varian's recent divestiture of all its noncore businesses leaves it with a highly focused semiconductor equipment market strategy in the core ion implant and sputtering systems business. Varian's partnership with Tokyo Electron Limited (TEL) has positioned the company well in achieving a global market presence. In addition, there is great synergy between Varian's PVD technology and TEL's dry etch technology. TEL has also retained the license to Varian's tungsten CVD technology in Japan. Dataquest believes that Varian and TEL may collaborate in the future to market an integrated tungsten CVD/etchback/aluminum PVD system based on the M2000 cluster tool platform.

Ulvac, the third-ranked PVD company, owns 17.6 percent of the 1990 market. Ulvac's sputtering systems accounted for $58 million (81 percent) of its 1990 PVD revenue; evaporation equipment made up the remaining 19 percent. Ulvac, with its new MLX-3000 series flexible cluster tool, is actively involved in the modular sputtering systems market. The MLX-3000 system is capable of 200mm processes and integration with other related Ulvac thin films technology such as plasma clean, selective tungsten plugs, dry etch, dry strip, and RTP processes. Dataquest believes that Ulvac is in the forefront of the Japanese market movement toward integrated process capabilities. Ulvac's future C-2111 Stellar mega cluster tool is designed to link two MLX-3000 cluster tools together with a transfer module. Ulvac is aggressively expanding its presence in North America and Europe through wholly owned regional subsidiaries.

MRC, the fourth-ranked PVD company, owned 15.3 percent of the 1990 market. MRC's Eclipse sputtering system continues to successfully penetrate key worldwide fabs. MRC recently introduced the Eclipse-Star system, which features several significant enhancements in process, particle control, and reliability. The company has the unique advantage of offering one-stop capability in sputtering target materials development and sputtering systems development. As device geometries head into the submicron regime, the coupling of target design, source materials, and sputtering system design becomes more crucial. MRC is also a leading merchant supplier of targets to other PVD equipment vendors and semiconductor manufacturers. MRC appears to have successfully made the transition from being an independent publicly owned company to a wholly owned subsidiary of Sony USA, Inc. Dataquest believes that Sony's global business image, deep pockets, and leading market position in optical and magnetic thin film technology for consumer applications will influence MRC to broaden its semiconductor equipment focus to include related areas such as magneto-optical disks, compact disc coatings, and LCD flat panel coatings. Dataquest believes that MRC will continue aggressive development of advanced flexible cluster tools that combine its sputtering and dry etch capabilities.

Applied Materials, which entered the PVD market in 1990, captured 3.7 percent of the 1990 market. Applied has built up great momentum in penetrating the sputtering process at several major worldwide submicron fabs. The Endura 5500 PVD system's unique staged ultrahigh vacuum environment, advanced source design, and integration capabilities with related processes such as tungsten CVD and etchback puts Applied in a strong position to offer a global, one-stop ULSI interconnect solution. Motorola's recent acceptance of the Endura system for its advanced MOS 11 submicron 200mm fab in Austin, Texas, represents a significant design win for Applied Materials. Dataquest believes that Applied Materials will face vigorous competition from other leading PVD companies that are racing to introduce their own cluster tools with integrated PVD, tungsten CVD, and etchback capabilities to market.

Balzers and Electrotech, each with 3.3 percent of the 1990 PVD market, were the sixth- and seventh-ranked companies. Both companies are actively marketing PVD cluster tool applications for barrier metal and aluminum interconnect processes. Balzers' recent acquisition of Spectrum CVD from Motorola New Enterprises (the new entity is called BCT-Spectrum) is aimed at exploiting the synergy between Balzers' PVD technology and Spectrum CVD's tungsten plug technology. The acquisition also provides Balzers with an important manufacturing and customer support base in the important North American market. Electotech, with its Sigma Series PVD cluster tool, is engaged in developing comprehensive thin film deposition and dry etch capabilities. The Sigma PVD platform nicely complements Electrotech's Delta CVD platform and Omega dry etch platform. Dataquest believes that Electrotech has positioned itself as a key domestic European thin films company that will play an important role in the fast-growing European semiconductor manufacturing arena.

Temescal, the eight-ranked PVD company, is entirely focused on the niche evaporation equipment market. Evaporation processes continue to be used in lift-off metallization and GaAs compound device applications. Evaporation technology also plays an important role in backside gold deposition processes to improve chip conductivity and adhesion to packages. Temescal is integrating more closely with BOC, its British parent, in order to apply its expertise to BOC's industrial thin film market activities.

DATAQUEST PERSPECTIVE

Dataquest believes that the $408 million PVD market will continue its technology-driven growth through the 1990s. The sputtering equipment market is characterized by intense competition as several new entrants challenge the entrenched market leaders. Integration technology involving PVD, CVD, and dry etch will play an important role in the cluster tool market. The PVD equipment market is dividing into a standalone, high-throughput rigid multichamber sputtering market and a cluster tool market with modular products that combine dry/plasma clean, sputtering, CVD, and dry etch processes.

The migration of 4Mb/16Mb DRAM devices to double-level metal processes and the migration of microprocessors, ASICs, and VLSI logic to triple-metal processes promise a healthy future for the PVD equipment market. However, parallel developments in CVD copper, aluminum, tungsten, and titanium nitride technologies could put a damper on future growth of the PVD market. Dataquest predicts that an interesting tug-of-war between the CVD and PVD conductor film markets will occur in the next few years. Market application forces characterized by PVD and metal CVD convergence will lend an interesting twist to this conflict.

Krishna Shankar (San Jose)
Kunio Achiwa (Tokyo)

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Research Newsletter

CVD EQUIPMENT: 1990 MARKET IN REVIEW

SUMMARY

The worldwide chemical vapor deposition (CVD) equipment market grew 13 percent from $609 million in 1989 to $689 million in 1990. The CVD market exhibited growth in spite of an overall 1990 wafer fabrication equipment market environment that was slightly down. Technology drivers such as the emergence of 200mm double-metal 4Mb shrink production and 16Mb pilot DRAM processes and the migration of microprocessor/ ULSI logic devices toward triple-metal processes were responsible for the persistent CVD market growth. The vertical low-pressure CVD tube market segment and the LPCVD/PECVD-dedicated reactor market segment were the highest-growth segments of the 1990 worldwide CVD market.

North American companies captured a dominant 60 percent share of the 1990 worldwide CVD equipment market, even though their biggest market is in Japan, which now constitutes 46 percent of the worldwide CVD market. North American companies dominate the LPCVD/PECVD reactor market segment, while Japanese companies dominate the fast-growing vertical LPCVD tube market segment.

REGIONAL MARKETS

Figure 1 illustrates the 1990 regional CVD equipment markets. As previously stated, Japan, with 46 percent of the 1990 market, is the largest CVD equipment market. This share is in line with Japan's stature as the world's largest semiconductor production, consumption, and wafer fabrication equipment market. Many Japanese device manufacturers continued to modestly increase their capital spending over 1989 levels in spite of a relatively flat chip demand environment. Japan-based device manufacturers invested strategically in 200mm fabs geared toward double-metal 4Mb DRAM shrinks and 16Mb DRAM pilot lines.

The North American CVD market maintained its 32 percent share of the 1990 worldwide CVD market. North America has traditionally been the leading producer of high-performance microprocessors, microcontrollers, and VLSI logic devices. All of these random logic devices rely heavily on advanced CVD films for multilevel interconnect technology. Capacity expansion and new fab additions by offshore Japanese fabs in North America also contributed significantly to the North American CVD equipment market.

The European CVD market exhibited healthy growth in 1990, growing to represent 13 percent of the 1990 CVD market. A substantial portion of this growth was due to the expansion of North American and Japanese device manufacturers into Europe in order to meet the potential requirements for domestically diffused European semiconductors.

The Asia/Pacific-Rest of World (ROW) CVD equipment market declined 33 percent between 1989 and 1990. Falling DRAM prices, economic and political uncertainties, and the collapse of the Taiwanese stock market had a significant dampening effect on the Asia/Pacific-ROW market.

REGIONAL OWNERSHIP

Figure 1 shows the 1990 world CVD market by regional ownership of equipment companies. As stated, North American companies continued to dominate with 60 percent of the 1990 market. North American companies continued their market focus on dedicated LPCVD/PECVD reactors for applications such as low-temperature plasma oxide, plasma nitride, and tungsten/tungsten silicide films. North American CVD companies have a significant lead in the development of cluster-tool-based integrated process sequences involving LPCVD/ PECVD and dry etch applications.

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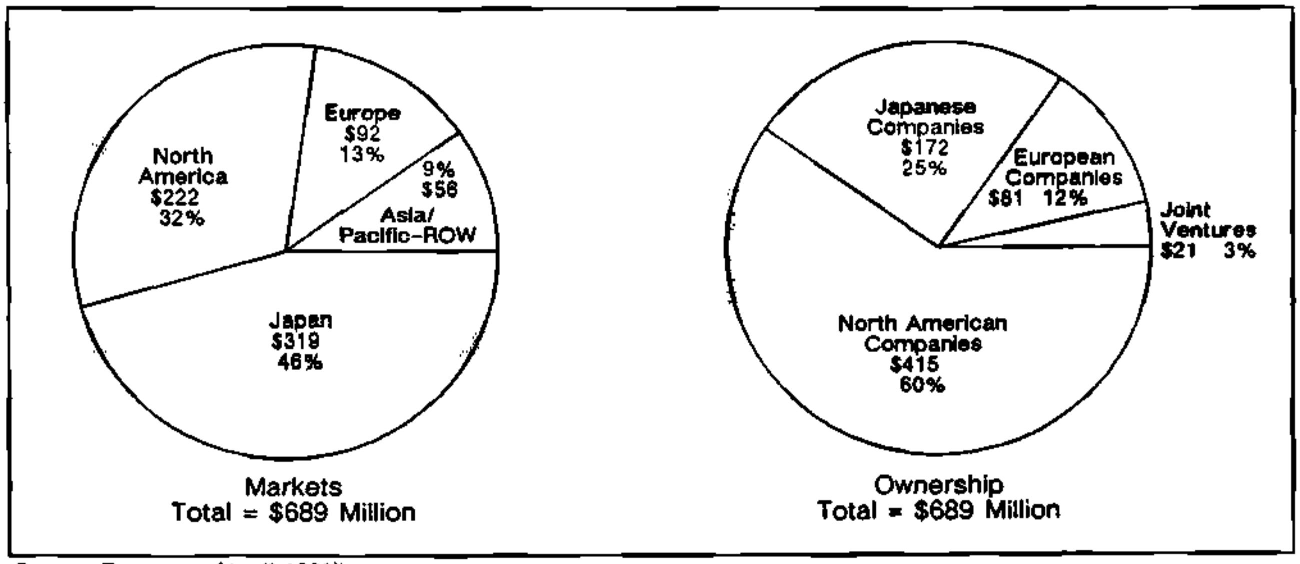
FIGURE 1
1990 CVD Equipment Regional Markets and Ownership
(Revenue in Millions of Dollars)



Source: Dataquest (April 1991)

Japanese CVD equipment companies, which captured 25 percent of the 1990 CVD market, focused on the vertical LPCVD tube segment for high-volume thermal nitride, polysilicon, and BPSG/thermal oxide applications. Dataquest believes that Japanese CVD equipment companies will address the low-temperature plasma oxide/plasma nitride film markets in the near term. Japanese equipment companies are developing ECR CVD and other low-temperature CVD processes for sub-0.5-micron device applications.

European companies owned 12 percent of the 1990 CVD market. Companies such as ASM International and Electrotech successfully addressed high-growth market segments such as vertical LPCVD tubes and dedicated PECVD reactors. European semiconductor R&D programs such as JESSI and ESPRIT are actively involved in developing advanced CVD capability for Europe-based 16Mb DRAMs and microprocessor/ULSI logic applications.

COMPANY RANKINGS

Table 1 ranks the major worldwide players by their 1990 revenue in the CVD marketplace. Five of the top ten spots are occupied by North American companies. Three Japanese companies and two European companies are included in the top ten CVD company rankings. It is apparent that U.S. companies have maintained their dominance of the CVD equipment market.

Applied Materials captured 29 percent of the 1990 CVD market, emerging with $201 million in revenue. The PE5000 dielectric CVD system continued to proliferate new applications for a range of low-temperature plasma oxide/plasma nitride processes. In addition, Applied also captured a significant portion of the 1990 tungsten LPCVD reactor market with its new PE5000 WCVD system. The PE5000 family's process versatility, together with Applied's global presence and customer support, has successfully maintained Applied's leadership in the CVD market.

Novellus climbed with meteoric success to the number two CVD spot in 1990. Novellus leveraged off its successful Concept One dielectric CVD architecture to make further inroads into the worldwide low-temperature plasma oxide/plasma nitride market. Novellus is poised for significant future growth as it enlarges its product portfolio in 1991 and 1992 to address the burgeoning metal CVD and cluster tool market.

Kokusai Electric and TEL exhibited spectacular growth in the vertical LPCVD tube market. They benefited from Japanese device manufacturers' rapid transition to vertical diffusion and

TABLE 1
1990 Worldwide CVD Equipment Company Rankings
(Revenue in Millions of Dollars)

Company	Revenue	Market Share (%)	Market Segment
Applied Materials	201.0	29.2	LPCVD/PECVD reactors
Novellus	63.0	9.2	PECVD reactors
Kokusai Electric	62.7	9.1	LPCVD reactors, LPCVD tubes
ASM International	56.0	8.1	LPCVD/PECVD reactors, LPCVD/PECVD tubes
Tokyo Electron Limited	45.8	6.7	LPCVD reactors, LPCVD tubes
Genus	44.0	6.4	LPCVD reactors
Watkins-Johnson	41.0	6.0	APCVD reactors
Silicon Valley Group	22.5	3.3	LPCVD reactors, LPCVD tubes
Electrotech	17.5	2.5	PECVD reactors
Amaya	16.0	2.3	APCVD reactors
BTU International	12.2	1.8	LPCVD tubes
Others	106.8	15.5	
Worldwide Market Total	688.5	100.0	

Note: The table shows calendar year 1990 systems revenue; spares and service are not included.
Source: Dataquest (April 1991)

LPCVD equipment for leading-edge 200mm 4Mb DRAM and ASIC fabs. Vertical LPCVD tube average selling prices soared dramatically because of increased automation, process control, and defect reduction features. Dataquest believes that Kokusai Electric and TEL will expand their vertical LPCVD process applications to include a variety of thermal nitride, polysilicon, and thermal BPSG/undoped oxide applications.

ASM International and Electrotech were the European entrants in the top 10 CVD company rankings. ASM International introduced a 200mm version of its successful PECVD tube product for intermetal dielectric and passivation applications. ASM International is also pursuing the LPCVD/PECVD reactor market with its Advance 600 platform for applications such as low-temperature oxides, nitrides, and aluminum-based metal CVD films. Electrotech continued to expand the range of CVD applications for its Delta Series cluster tool family.

Genus, with $44 million in 1990 CVD systems revenue, maintained its leadership in the metal CVD market. Genus introduced the 8720ST blanket tungsten system and the Series 6000 deposition/etchback cluster tool during 1990. The company also continued to rule the tungsten silicide market, unchallenged. Genus has enhanced its product performance by successfully leveraging off its SEMATECH Equipment Improvement Project and its close relationship with IBM. Dataquest expects Genus to broaden its product offerings as it responds to increased competition in the metal CVD marketplace.

Watkins-Johnson and Amaya continued to occupy significant positions within the top 10 CVD rankings because of their domination of the mature high-volume BPSG film market. Competition, however, is heating up in the BPSG film market as a variety of atmospheric-pressure cluster tools and vertical LPCVD tubes are expected to challenge the belt-furnace dominance of the BPSG film market.

BTU International and Silicon Valley Group carved out spots in the CVD company rankings because of their horizontal and vertical LPCVD tube products. Both companies significantly repositioned themselves in 1990 to address the fast-growing vertical LPCVD tube market. Dataquest expects BTU International and SVG to vigorously compete in the quest for worldwide dominance in the high-growth vertical LPCVD tube market.

DATAQUEST PERSPECTIVE

The CVD equipment market, which grew to $689 million in 1990, is expected to continue its healthy growth pattern during the next few years. The market continues to be technology driven because of the need for a variety of dielectric and conductor films in increasingly complex submicron interconnect processes. The CVD equipment market displayed growth in 1990 in spite of other key segments such as lithography and dry etch markets being flat or slightly down. This growth illustrates the technology-driven expansion of the CVD equipment market.

North American companies continued to dominate the CVD equipment market with 60 percent of the 1990 market even though their biggest market was Japan, which constituted 46 percent of the world CVD market. North American companies have maintained their CVD market leadership by sustained innovation in reactor architecture and new films coupled with successful globalization business strategies. Japanese CVD equipment companies have captured 25 percent of the 1990 CVD market by focusing on the large batch, automated LPCVD tube market for thermal oxide, nitride, and polysilicon applications. European CVD companies continue to pursue the global CVD market with the support of European R&D consortia such as JESSI and ESPRIT. Dataquest believes that competition will intensify in the high-stake, high-growth CVD market as global competitors square off in a global marketplace.

Krishna Shankar (San Jose)
Kunio Achiwa (Tokyo)

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Research Newsletter

SILICON EPITAXY EQUIPMENT MARKET—1990 MARKET IN REVIEW

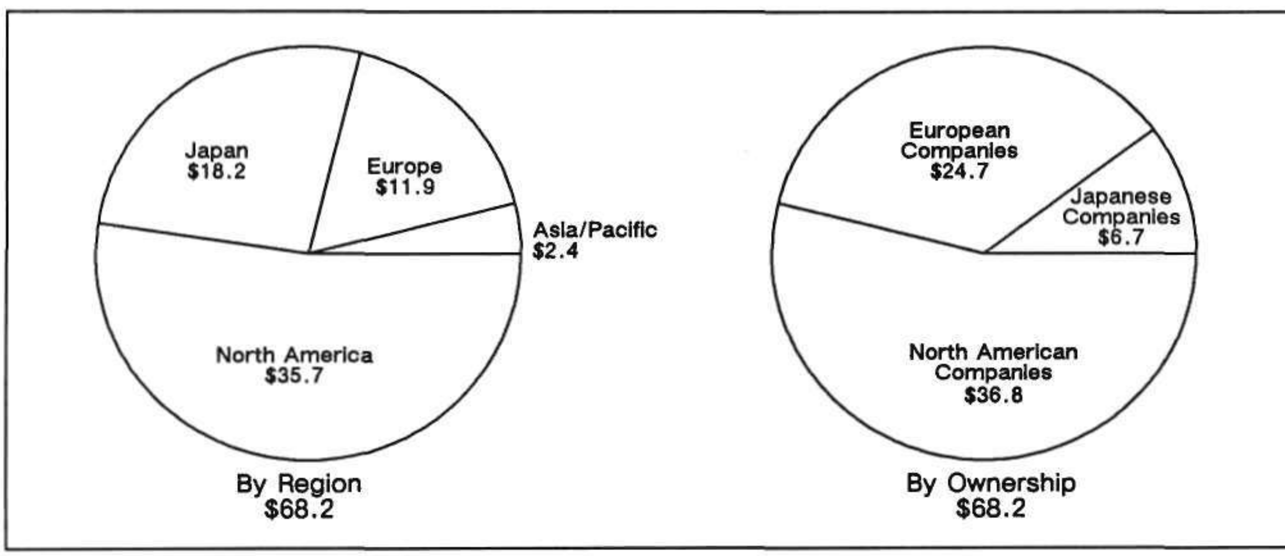
Worldwide silicon epi reactor sales totaled $68.2 million in 1990. Sales decreased 9.1 percent from 1989 levels, reflecting very weak European and Asia/Pacific markets. Dataquest forecasts 1991 sales to total $55 million, down 14.7 percent on a year-to-year basis. Sales in 1991 are expected to decrease further because of the recession in North America and flat demand for epi wafers outside North America.

REGIONAL MARKETS

North American epi reactor sales totaled $35.7 million, accounting for 52.3 percent of the worldwide market (see Figure 1). Sales increased 12.6 percent in 1990, fueled by explosive growth in CMOS epi wafer demand. Dataquest estimates that North American merchant epi wafer demand grew 20 to 25 percent in 1990. Microprocessor manufacturers Intel and Motorola and IBM's DRAM lines accounted for most of the growth in the North American epi wafer market.

The Japanese market was the second largest, with sales totaling $18.2 million or 26.7 percent of the worldwide market. Reactor sales were down 12.1 percent on a year-to-year basis. Bipolar and discrete applications account for 73 percent of the epi wafer demand in Japan, yet these markets are

FIGURE 1
1990 Silicon Epitaxy Reactor Market by Region and Ownership (Millions of Dollars)



Source: Dataquest (April 1991)

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growing slowly and require only incremental increases in reactor capacity.

The 1990 European and Asia/Pacific markets decreased 38.7 and 60.7 percent, respectively. European sales totaled $11.9 million, and Asia/Pacific sales totaled $2.4 million. Epi reactor sales in both markets suffered because of weak capital spending and flat growth in epi wafer demand.

COMPANY MARKET SHARE

The 1990 epi equipment market was dominated by one North American vendor, Applied Materials, and one European vendor, ASM Epitaxy (see Figure 1). Applied Materials' worldwide sales totaled $25 million; ASM Epitaxy's sales totaled $19.2 million (see Table 1). Both companies have a geographically diversified customer base in contrast to other players, whose sales were concentrated in a single region.

Applied Materials traditionally has been the market leader in the silicon epi market since the introduction of its radiant-heated barrel reactor in the late 1970s. Its reactor design virtually eliminated thermally induced slip. As a result, these reactors have been the system of choice for the production of CMOS epi wafers.

TABLE 1
1990 Worldwide Silicon Epitaxy Reactor Market by Company Share
(Millions of Dollars)

Company	Market Share	Percent
Applied Material	25.0	36.7
ASM Epitaxy	19.2	28.2
Lam Research	7.9	11.6
LPE	5.5	8.1
Toshiba Machine	4.5	6.6
Moore Technology	3.0	4.4
Kokusai Electric	2.2	3.2
Rapro	0.9	1.3
Total—Worldwide	68.2	100.0

Note: Columns may not add to totals shown because of rounding.
Source: Dataquest (April 1991)

However, in the past two years, single-wafer reactors pioneered by ASM Epitaxy have made significant inroads, especially in the larger-diameter CMOS applications. Sales have grown from $6 million in 1989 to $19.2 million in 1990.

The other vendors in the epi reactor market are marginal players. Little development work is going on in these companies, and their sales are tied more closely to the bipolar and discrete epi markets, which are growing very slowly.

DATAQUEST CONCLUSIONS

The silicon epi market is being pulled in two directions. Future applications, especially DRAM devices, will require tighter thickness, resistivity, particle, and oxygen specifications. These specifications cannot be met with current reactors but will require new reactor designs. Trends in semiconductor capital equipment prices suggests that new reactors will be very expensive. Yet, the price of epi films will have to decline dramatically before semiconductor manufacturers widely incorporate the films into their device designs.

The diverging trends are limiting the growth of the silicon epi equipment market. Dataquest does not anticipate that the epi equipment market will ever grow to be much more than $100 million per year worldwide without achieving a lower film cost.

Consequently, many equipment manufacturers are loath to spend their development dollars on a new reactor for such a small market. One company, Moore Technology, is successfully addressing the cost issue by redesigning existing systems to improve the throughput of the reactor, but Dataquest does not expect these systems to meet the epi film specifications required for the 64Mb DRAM. Future growth will depend on equipment vendors resolving both performance and cost issues.

Kunio Achiwa (Tokyo)
Mark FitzGerald (San Jose)

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Research Newsletter

DIFFUSION EQUIPMENT MARKET: 1990 IN REVIEW

SUMMARY

Dataquest estimates the 1990 worldwide diffusion equipment market to be $322 million, down 2 percent from $330 million in 1989. The vertical thermal reactor (VTR)-based diffusion tube segment grew explosively—67 percent from $96 million in 1989 to $160 million in 1990. However, the horizontal diffusion tube segment declined dramatically by 31 percent from $234 million in 1989 to $162 million in 1990. The fast-growing VTR diffusion tube segment now accounts for 50 percent of the worldwide diffusion market. Factors such as automation compatibility with 200mm fabs, better process control, and small equipment clean room footprint were responsible for the high growth in the VTR diffusion market segment.

Japan, the largest regional diffusion equipment market, accounted for 54 percent of the 1990 worldwide market. Japan's thrust into 200mm 0.5-micron 4Mb shrink/16Mb pilot line fabs continues to sustain high growth for the Japanese VTR diffusion equipment market. North America, as a region, accounted for 24 percent of the 1990 worldwide diffusion market. Relatively flat capital spending conditions in North America, together with the lack of activity in large-volume new fab construction, led to a weak 1990 North American market. The European diffusion equipment market represented 12 percent of the 1990 total, while the Asia/Pacific-Rest of World (ROW) region accounted for the remaining 10 percent of the market.

Japanese equipment companies dominated the diffusion market with 52 percent ownership of the 1990 world market. Japanese companies, with their early entry into the VTR diffusion and VTR low-pressure chemical vapor deposition (LPCVD) market, controlled a major portion of the crucial VTR market. North American diffusion companies, which are currently aggressively entering the VTR market, owned 31 percent of the 1990 worldwide diffusion market.

REGIONAL MARKETS

Figure 1 shows the 1990 diffusion equipment market by region and ownership. Dataquest includes diffusion, wet/dry oxidation, anneal, implant drive-in, and BPSG glass reflow processes within the diffusion equipment market. The low-pressure tube CVD and plasma-enhanced tube CVD processes are included within the overall CVD equipment market rather than the diffusion tube market (see SEMMS newsletter entitled "CVD Equipment: 1990 in Review").

Japan, the largest regional wafer fabrication equipment market, was also the largest diffusion equipment market with 54 percent of the $322 million 1990 market. 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.

Japan's early shift to VTR diffusion tube technology led to rapid increases in tube average selling prices (ASPs) because of increased automation and process-control requirements in 150 and 200mm submicron fabs. The Japanese diffusion equipment market size increased in 1990 because of an increase in unit shipments as well as tube ASPs. VTR tube ASPs are higher in Japan because

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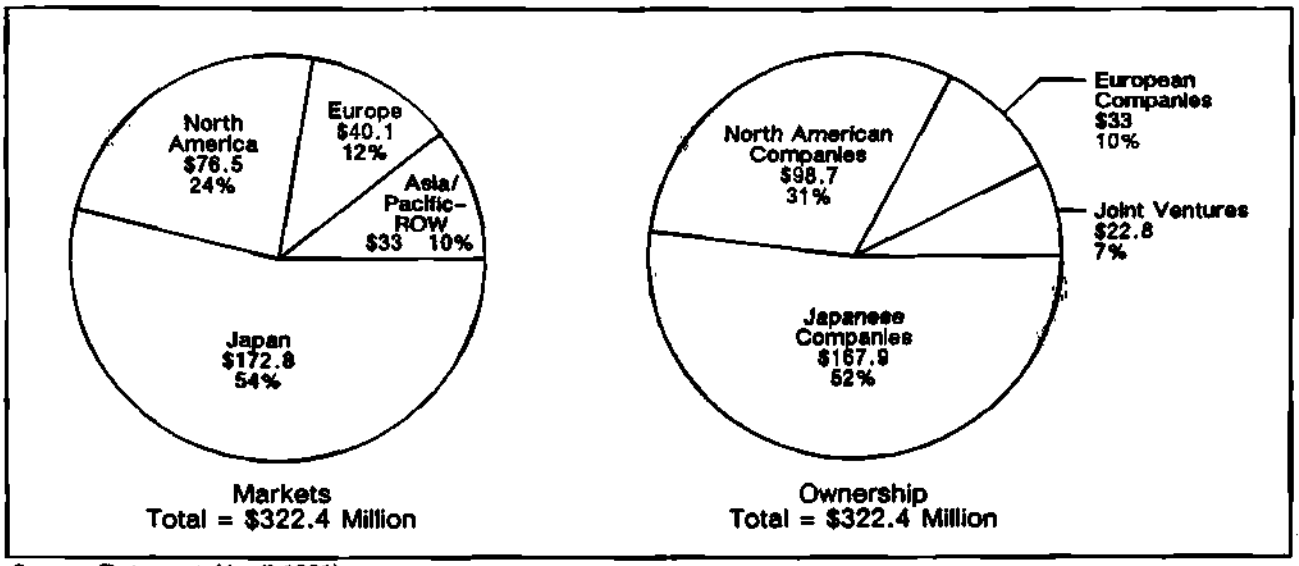
FIGURE 1
1990 Diffusion Equipment Regional Markets and Ownership (Revenue in Millions of Dollars)



Source: Dataquest (April 1991)

of extensive fab automation requirements. Many Japanese semiconductor manufacturers have adopted VTRs for almost all diffusion operations within the new 150 and 200mm fabs built in 1990. Spillover capital spending effects from 1989 into 1990, together with Japan's strategic manufacturing focus, sustained Japan's 1990 diffusion equipment market growth.

The North American diffusion equipment market accounted for 24 percent of the 1990 worldwide market. 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 1990 market. North America is also joining the move toward VTR diffusion and LPCVD systems, especially for new 200mm submicron applications. Captive semiconductor manufacturers such as Digital Equipment Corporation (DEC), Hewlett-Packard (HP), and IBM were more consistent in new fab addition and capacity expansion purchases than were their merchant counterparts.

North American semiconductor companies have largely retreated from memory, low-end gate arrays, and other high-volume, low-margin commodity devices. High device 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. Growth in the diffusion tube market depends on multiple orders from high-volume, leading-edge production fabs. The North American regional diffusion equipment has not provided such an environment for sustained growth in the last few years. However, the growing presence of offshore Japanese fabs may again stimulate growth in the North American diffusion equipment market.

The European diffusion equipment market accounted for 12 percent of the 1990 market. Most of the European market activities revolved around offshore Japanese and North American fabs in Europe. Companies such as DEC, Fujitsu, Hitachi, IBM, Mitsubishi, and Texas Instruments (TI) continued to expand their European operations in order to comply with possible future requirements for domestically diffused European semiconductors. These offshore European fabs typically were clones of parent North American and Japanese fabs. The choice of a global diffusion equipment vendor ensures a consistent process implementation and automation strategy for global semiconductor manufacturers with many regional fabs. Only global diffusion equipment companies with a presence in all major semiconductor manufacturing regions could hope to get a significant slice of the 1990 European diffusion market.

The Asia/Pacific-ROW diffusion market contracted from 21 percent of the $330 million 1989 market to 10 percent of the $322 million 1990 market. Factors such as depressed DRAM prices and excessive PC chip set competition together with political and economic uncertainities were responsible for the decline in the 1990 market. Dataquest believes that the 1991 Asia/Pacific-ROW diffusion market should stage a moderate recovery as new 16Mb pilot lines and submicron ASIC/foundry fabs are built.

Regional Ownership

Figure 1 shows the worldwide 1990 diffusion market by regional ownership. Japanese companies, with 52 percent of the market, dominated the 1990 diffusion market because of their lead in advanced VTR production technology. Japanese diffusion companies such as Tokyo Electron Limited (TEL) and Kokusai Electric virtually owned the large domestic Japanese VTR market. The wave of new 200mm Japanese DRAM fabs ensured a flow of large orders for technology-driven diffusion VTR products. Japanese diffusion equipment companies also are increasingly penetrating international markets as they hasten to set up global business organizations in order to serve their global customers.

North American company ownership of the worldwide diffusion market contracted from 35 percent in 1989 to 31 percent in 1990. North American diffusion equipment companies made a late transition from horizontal diffusion to vertical diffusion technology. They pursued a strategy of incremental improvements in their horizontal diffusion products in areas such as automation, particle reduction, and process enhancement. Meanwhile, they underestimated the market momentum toward vertical diffusion tubes, especially for submicron new 200mm fabs. North American diffusion companies such as BTU International and Silicon Valley Group (SVG) significantly repositioned their product development efforts in 1990 as they addressed the fast-growing vertical diffusion segment. Dataquest expects North American diffusion companies to vigorously challenge Japanese companies for dominance of the worldwide VTR market.

Company Rankings

Table 1 shows the worldwide 1990 diffusion equipment company rankings. The rankings do not include LPCVD or PECVD tube shipments. The 1990 diffusion market total was made up of approximately 50 percent horizontal tubes and 50 percent vertical tubes.

Table 1
Worldwide 1990 Diffusion Equipment Company Rankings
(Millions of Dollars)

Company	Revenue	Market Share (%)	Revenue Split by Market Segment (%)
Tokyo Electron Ltd.	92.2	28.6	52 vertical, 48 horizontal
Silicon Valley Group	54.2	16.8	30 vertical, 70 horizontal
Kokusai Electric	50.9	15.8	91 vertical, 9 horizontal
ASM International	24.4	7.6	36 vertical, 64 horizontal
BTU International	24.0	7.4	25 vertical, 75 horizontal
Ulvac/BTU	16.5	5.1	20 vertical, 80 horizontal
Koyo Lindberg	12.1	3.8	63 vertical, 37 horizontal
Centrotherm	8.4	2.6	0 vertical, 100 horizontal
General Signal ThinFilm	8.0	2.5	63 vertical, 37 horizontal
Gasonics	8.0	2.5	0 vertical, 100 horizontal
Others	23.7	7.4	
Worldwide Market Total	322.4	100.0	50 vertical, 50 horizontal

Note: The table shows calendar year 1990 system revenue; spares and service are not included.
Source: Dataquest (April 1991)

TEL, the top-ranked company, captured 28.6 percent of the 1990 market. TEL's diffusion unit shipments were balanced almost equally between horizontal and vertical units. Dataquest also separately accounts for TEL's North American and European diffusion tube shipments under the Varian/TEL joint venture, which had diffusion revenue of $6.3 million in 1990. TEL's success in the diffusion and LPCVD tube market prompted the company to construct another large-capacity VTR tube manufacturing facility in Japan in 1990.

Silicon Valley Group (SVG), the second-ranked company, owned 16.8 percent of the 1990 diffusion market. SVG continues to actively market its Thermco horizontal diffusion systems for capacity expansion, replacement, and noncritical applications in new fabs. SVG's recent design win at the Motorola MOS 11 200mm fab in Austin, Texas, is an indication of the company's growing strength in the North American diffusion market. SVG's future challenge is to penetrate the larger international market, especially in Japan and the Asia/Pacific-ROW region.

Kokusai Electric, with 15.8 percent of the 1990 market, is the third-ranked diffusion equipment company. The company was one of the early pioneers in VTR diffusion and LPCVD technology. Since then, the company has successfully launched several generations of VTRs into the marketplace. Kokusai Electric is aggressively addressing the international market by establishing regional customer support and applications facilities in the North American and European regional markets.

ASM International, with 7.6 percent of the 1990 market, was the fourth-ranked diffusion equipment company. The company, which dominates the horizontal PECVD tube market, has recently focused its efforts on the fast-growing diffusion and LPCVD VTR market. ASM Japan, a wholly owned subsidiary of ASM International, hopes to capture a slice of the competitive Japanese VTR market by designing and building its VTR systems through joint development with its Japanese customers.

BTU International, the fifth-ranked 1990 diffusion company, owned 7.4 percent of the market. The company is executing a major product transition from its older horizontal systems to vertical systems. The company recently ramped up shipments of its VTR products. Sematech has recently awarded equipment improvement contracts to BTU International and SVG for their VTR development projects.

DATAQUEST PERSPECTIVE

The $322 million 1990 worldwide diffusion equipment market remained essentially flat compared with its $330 million 1989 level. Although the overall diffusion market remained flat between 1989 and 1990, the horizontal tube segment of the market declined dramatically by 31 percent while the vertical tube segment grew explosively by 67 percent. The horizontal and vertical diffusion market segments were approximately equal in 1990.

Japan, which is the largest market, has almost completely switched over to vertical diffusion tubes for its new 200mm submicron fabs. Vertical tubes have the advantages of smaller footprint, modular automation, and better process control on 200mm submicron diffusion/oxidation processes. Applications for vertical diffusion tubes include thin gate oxidations, low-temperature anneals, and BPSG reflow.

The North American, European, and Asia/Pacific-ROW markets are also switching over to VTR diffusion processes for critical applications. Dataquest believes that horizontal diffusion processes will continue to be used in certain noncritical applications such as long, high-temperature drive-ins and wet field oxidation. A distinct cost/performance tradeoff exists between vertical and horizontal diffusion tubes. Semiconductor manufacturers appear to be leaning more toward the higher-performance characteristics of vertical diffusion tubes for critical 200mm submicron fabs in spite of significantly higher tube ASPs.

Krishna Shankar (San Jose)
Kunio Achiwa (Tokyo)

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Research Newsletter

CD SEM EQUIPMENT—SMALLER GEOMETRIES LEAD TO LARGER MARKET

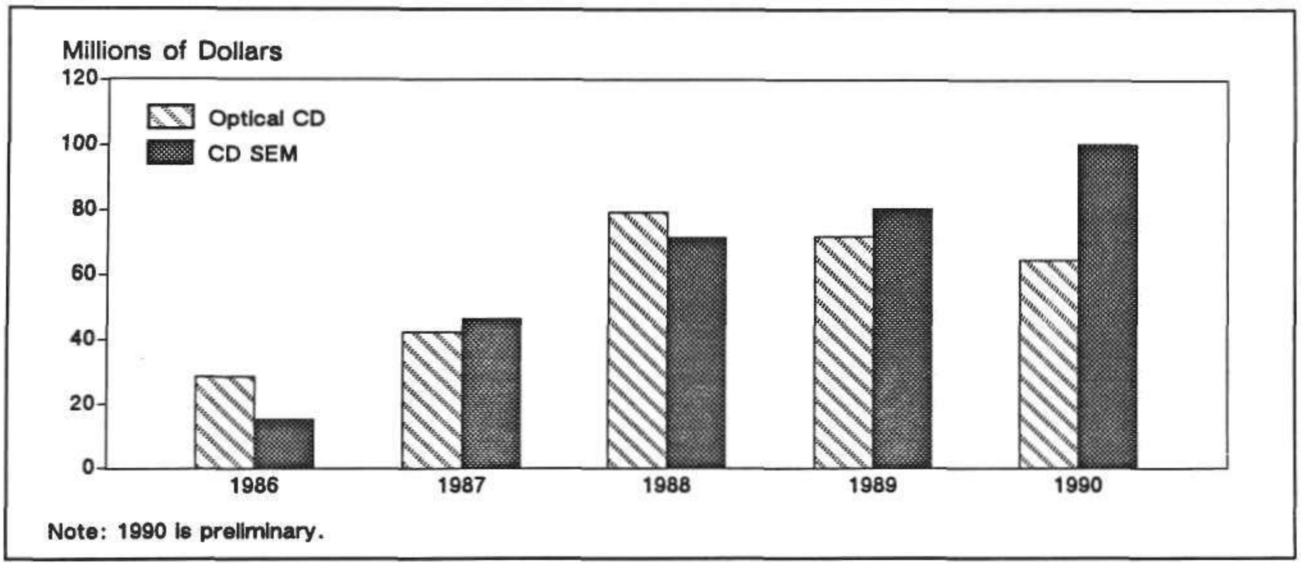
SUMMARY

The critical dimension scanning electron microscope (CD SEM) equipment market has experienced robust growth during the past five years, and, as shown in Figure 1, 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 total wafer fabrication equipment market in 1990 that is expected to be down a few percentage points from its 1989 level. This newsletter examines several of the factors that are 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 the white-light microscopy systems have been enhanced with sophisticated image processing capabilities to extend their 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

FIGURE 1
Optical CD and CD SEM Equipment Markets



Source: Dataquest (December 1990)

SEMMS Newsletters Process Control

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characterize the equipment for the 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 the 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 being pumped down in the load lock. An internal exchange unit allows the first wafer to move aside upon completion of its CD measurements so that the second wafer can be moved from the load lock to the measurement chamber. Opal claims a throughput of approximately 20 wafers per hour and expects it to be even higher in the future. Nanoquest (the former 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.

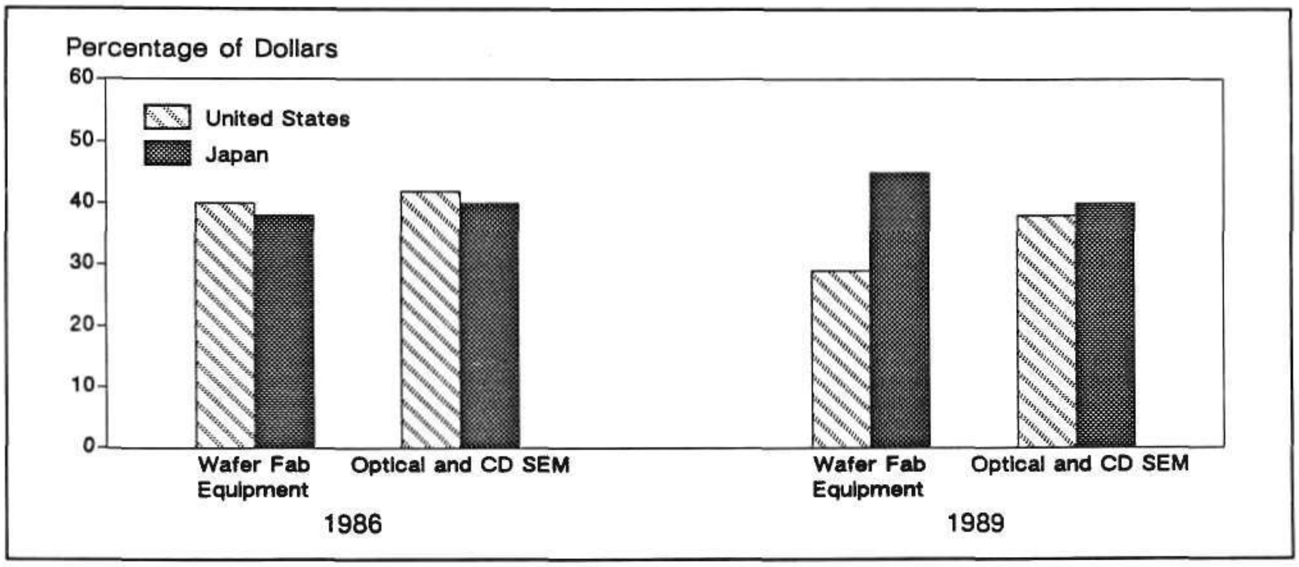
REGIONAL MANUFACTURING PRACTICES

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 the device into high-volume production. Once the 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 the practice of 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.

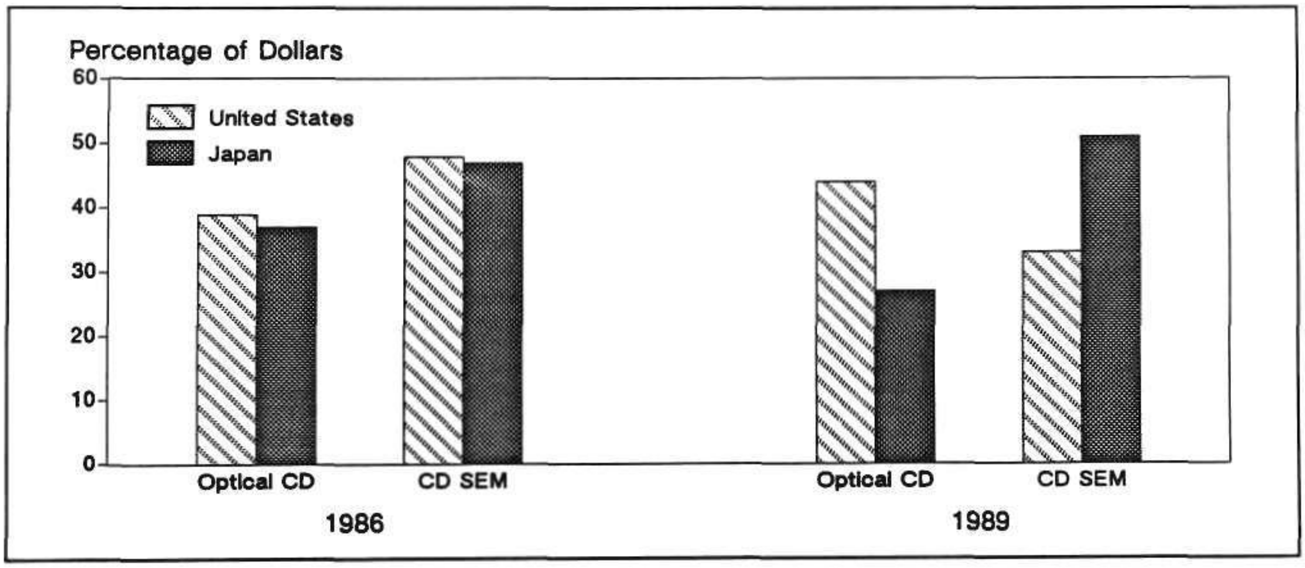
Even further regional manufacturing distinctions exist within the category of CD measurement equipment. Manufacturers in Japan use significantly more CD SEM systems than do their counterparts in the United States. Figure 3 shows that in 1986, semiconductor manufacturers in Japan and the United States 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,

FIGURE 2
Regional Equipment Market Trends
United States and Japan, 1986 and 1989



Source: Dataquest (December 1990)

FIGURE 3
Regional Trends—CD Equipment Market
United States and Japan, 1986 and 1989



Source: Dataquest (December 1990)

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.

This move by Japanese manufacturers 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 the 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 the 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. As shown in Table 1, Dataquest estimates that Hitachi commanded 75 percent of world market share in 1990. In 1986, when the world market for CD SEM equipment was only $15.4 million, Hitachi still accounted for more than one-half of the market with 56 percent share. Dataquest believes that Hitachi's success is due, in part, to the company's extensive experience in e-beam technology for 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.

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 (December 1990)

NEW OPPORTUNITIES—CLUSTER TOOL PROCESSING

As linewidth geometries continue to shrink, the overall market opportunities for CD SEMs are growing. One of the interesting opportunities in the CD SEM equipment market comes from the developing market for cluster tools. CD SEM measurement equipment is particularly well suited for a cluster tool vacuum environment designed for etch, strip, and deposition processes. Linewidth measurement would be performed on the wafer after etch/strip processing. The wafer then would be moved 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 such a strategy because of its association with Tegal. Tegal, another company funded by Nazem, is a well-established player in the plasma etch and strip equipment markets.

DATAQUEST FORECAST

Dataquest anticipates CD SEM tools will continue to experience healthy growth in the years to come 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 the other manufacturing regions of the world as well. Dataquest expects the CD SEM equipment market to be approximately $245 million by 1995, reflecting a 19.5 percent compound annual growth rate (CAGR) between 1990 and 1995.

Dataquest notes, however, that optical CD measurement tools are not likely 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. Conventional optical CD tools still provide a cost-effective, high-throughput option for the 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 a transparent film to the 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 the 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. Dataquest forecasts the optical CD equipment market to be $105 million in 1995, reflecting a five-year CAGR of 10.1 percent.

DATAQUEST CONCLUSIONS

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. These companies 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 the 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.

Kunio Achiwa
Peggy Marie Wood

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.

MANUFACTURING

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Research Newsletter

MERCHANT DRAM SUPPLIERS: ANOTHER SHAKEOUT COMING?

The prices of 1Mb and 4Mb DRAMs have been falling steadily. In the fourth quarter of 1989, the worldwide average selling price (ASP) of a 1Mb DRAM was $9.45. Today, the price of a 1Mb DRAM ranges from $4.30 to $5.00. In the fourth quarter of 1989, the ASP of a 4Mb DRAM was $87.78. Today, the price of a 4Mb DRAM ranges from $18.00 to $23.00.

Part of this decline is normal. Learning-curve price declines are a part of each generation of DRAMs. These declines stimulate demand and allow buyers to economically cross over to the next generation of DRAMs. However, in the fourth quarter of 1990, 1Mb DRAM price declines seemed much sharper than would be expected from learning-curve experience only. Prices were squeezing profits. Japanese DRAM manufacturers responded with production cutbacks of 1Mb DRAMs.

These recent and larger-than-expected 1Mb DRAM price declines are due to a simple economic fact: oversupply. Based on our analysis of existing merchant capacity and planned, publicly announced capacity additions, Dataquest believes that there is an oversupply of 1Mb and 4Mb DRAMs. We believe that this condition is likely to continue.

DRAM SUPPLY AND DEMAND

Dataquest maintains a worldwide fab database that contains wafer start capacity for individual semiconductor companies. From our fab database we determine current DRAM capacity in wafer starts and add to it all the announced plans for building future DRAM capacity. This DRAM wafer start capacity is converted to DRAM unit capacity by applying the set of assumptions for die size and yield shown in Table 1. Unit DRAM capacity is then compared with Dataquest's forecast of DRAM demand to determine if there is or will be an imbalance of DRAM demand and supply.

We believe that our capacity assumptions are on the conservative side. For example, all fab lines that produce non-DRAM devices in addition to DRAMs were excluded from the analysis. If these fabs and some appropriate fraction of their capacity were included in the analysis, the resulting DRAM capacity numbers would be much higher.

Many fabs in our database are listed as capable of producing either 1Mb or 4Mb DRAMs. Thus, this study is based on an aggregate analysis of 1Mb and 4Mb DRAM capacity. In this newsletter, we provide three scenarios regarding the mix of fabs capable of either 1Mb or 4Mb DRAM production. These scenarios reflect assumptions for low

TABLE 1
Assumptions for DRAM Die Size, Probe Yields, and Good Die Per Wafer

	Die Size (mm^2)	Probe Yield (%)	Good Die per 6-Inch Wafer
1Mb DRAM	40	79	293
4Mb DRAM	96	48	66
4Mb DRAM (Shrink)	71	65	128

Source: Dataquest (March 1991)

SEMMS Newsletters Manufacturing: Semiconductor Manufacturing/Industry Trends

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capacity, high capacity, and intermediate capacity for 1Mb and 4Mb DRAMs.

The low-capacity scenario assumes that all 1Mb DRAM fabs that are also capable of 4Mb DRAM production will indeed shift their production to 4Mb DRAMs. This scenario is low capacity because fewer 4Mb DRAM die can be fabricated from a wafer than 1Mb DRAMs. (The die for 4Mb DRAMs are larger than the die for 1Mb DRAMs.)

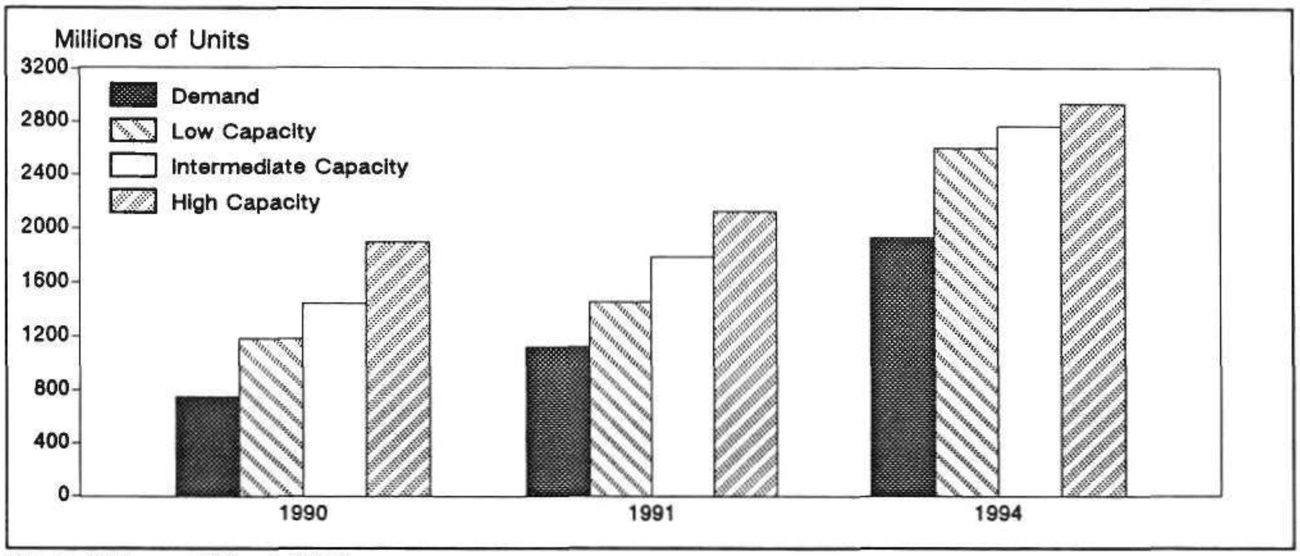
The high-capacity scenario assumes that none of the fabs listed as capable of either 1Mb or 4Mb DRAMs will shift production to 4Mb DRAMs. This scenario is high capacity because more 1Mb DRAM die than 4Mb DRAM die can be fabricated from a wafer.

The intermediate-capacity scenario assumes that 50 percent of the fabs listed as capable of producing both 1Mb and 4Mb DRAMs will actually shift production to 4Mb DRAMs.

DRAM demand and our estimated DRAM capacity for the three scenarios are shown in Figure 1. What is striking about this figure is that the combined capacity of 1Mb and 4Mb DRAMs—under all three of our capacity scenarios—exceeds the projected combined demand for these devices by a substantial margin. For example, in 1994, the low-capacity scenario projects a capacity of slightly over 2,500 million units and a demand of just under 2,000 million units, an excess of over 25 percent.

Table 2 evaluates the supply-and-demand estimates in Figure 1 in terms of percentages. For example, in 1994, demand will be only 66 percent of the potential supply under the high-capacity scenario and 74 percent of supply under the low-capacity scenario.

FIGURE 1
Estimated Aggregate of 1Mb and 4Mb DRAM Supply and Demand



Source: Dataquest (March 1991)

TABLE 2
Estimated Merchant Demand as a Percentage of Worldwide Merchant Capacity for 1Mb and 4Mb DRAMs Combined

	Low Capacity	Intermediate Capacity	High Capacity
1990	63	52	40
1991	77	63	53
1994	74	70	66

Source: Dataquest (March 1991)

DATAQUEST CONCLUSIONS

It should be emphasized that this large DRAM capacity has to be utilized for oversupply to occur. In the short term, DRAM producers could very well choose not to use their full-production capacity. This happened in fall 1990 when Japanese producers announced cutbacks in production of 1Mb DRAMs.

A longer-term strategy to reduce overcapacity is to switch some DRAM capacity to other products, such as SRAMs or ASICs. An example of this strategy would be Motorola's recent announcement that its MOS 11 fab in Oak Hill, Texas, will be used to produce SRAMs rather than 4Mb DRAMs as originally planned. A third alternative strategy is that a DRAM fab facing overcapacity could aggressively pursue foundry relationships to fill unused capacity.

In the early and mid-1980s the industry faced a similar, although not identical, situation. There were too many DRAM manufacturers, and oversupply resulted. Many DRAM producers decided to leave the DRAM business for what they hoped were more profitable product lines. Capital spending fell more sharply than ever before. Equipment companies folded, merged, restructured, laid off staff, and some even cut back on R&D.

Since the mid-1980s, the industry has been much more circumspect about adding capacity. The growth rate of capital spending was much less in the second half of the 1980s than in the first half. Inventories, because of just-in-time deliveries and closer supplier/vendor relationships, are much better managed than in 1985. Since the shakeout in the mid-1980s, the industry has matured.

However, new DRAM players have emerged since the mid-1980s. These companies (Motorola, Asia/Pacific companies, and second-tier Japanese companies) have added capacity in order to gain market share. The capacity from the new, plus the capacity from the established players, today add up to overcapacity. Clearly, the industry faces a challenge: how to manage overcapacity without the corrective of another shakeout.

George Burns

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Research Newsletter

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 newsletter 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 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. (For more information on the causes of rising fab costs, see Dataquest's Dataquest's SEMMS newsletter entitled "Technology Trends and Fab Costs," November 1990.)

TABLE 1
Fab Cost per Monthly Square Inch of Capacity

		Monthly Capacity		
Year	Fab Cost (Millions of Dollars)	Wafers	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)

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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)

COSTS AND WAFER SIZE

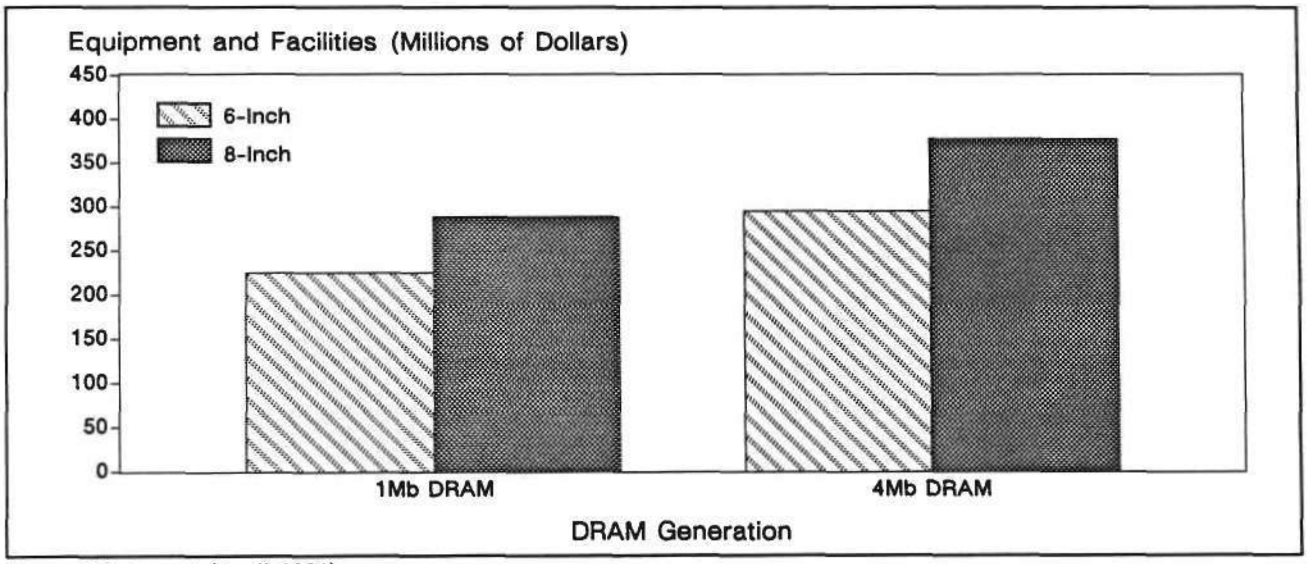
However, semiconductor manufacturers need not be helpless in the face of increasing capital costs. Our analysis indicates that if semiconductor manufacturers increase the size of their wafers, they will slow the rise in initial fab cost per square inch of silicon capacity. And, perhaps more important, 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.

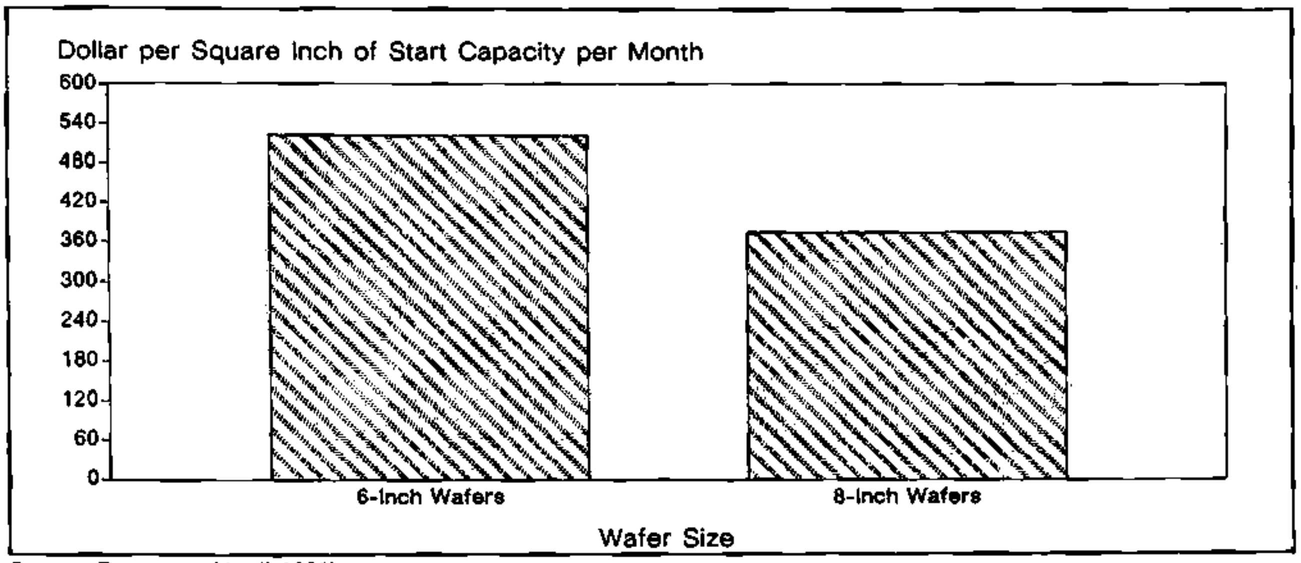
As Figure 2 shows, however, within a DRAM generation, fab costs per square inch of capacity decline as larger wafers are used. For example, initial facility and equipment cost per square inch of capacity for a 20,000-wafer-start-per-month fab making 4Mb DRAMs is over $500 per square inch if 6-inch wafers 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.

FIGURE 1
DRAM Fab Costs by Wafer Size



Source: Dataquest (April 1991)

FIGURE 2
Capital Cost/In² of a 20,000 Wafers/Mo. 4Mb DRAM Fab by Wafer Size



Source: Dataquest (April 1991)

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. 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 that 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 semiconductor manufacturer that can maintain yields and move to larger wafer sizes will have a tremendous cost advantage over those that stay with the smaller wafers.

INCREASING WAFER SIZE INCREASES PROCESS COMPLEXITY

The main focus of this newsletter has been on the cost advantages of moving to larger wafer sizes. 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.

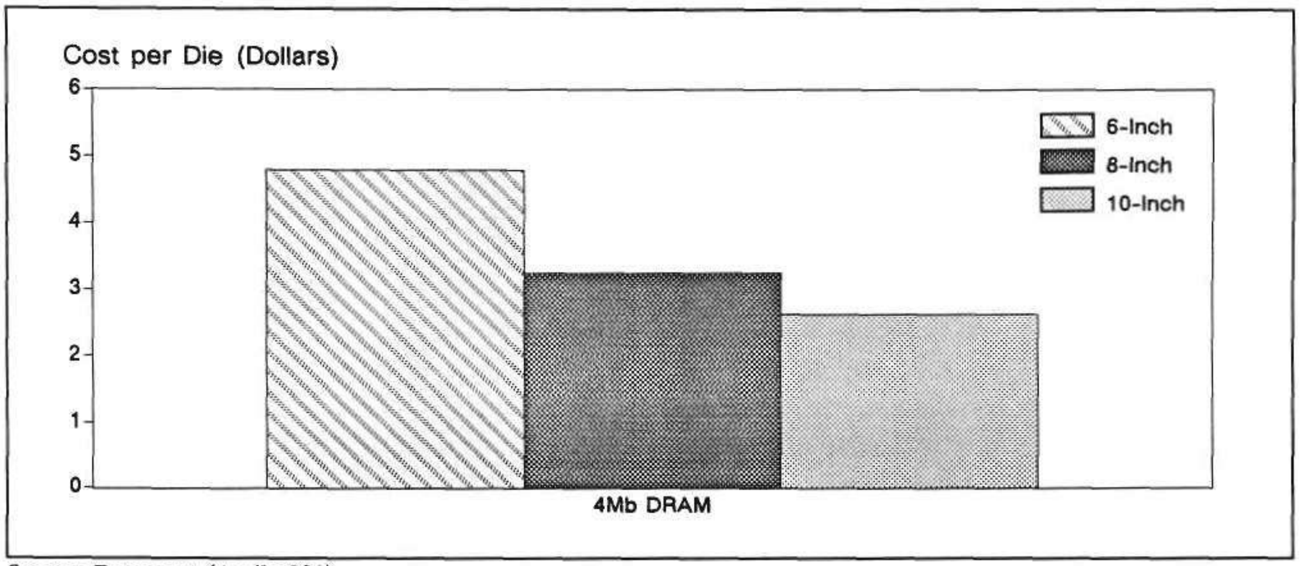
Solving these and other problems will cost equipment and materials vendors time, effort, and money and require much effort. Additionally, after the equipment and materials are available, semiconductor manufacturers will have to transfer their working processes to the larger wafers, which also requires 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 their leadership: an initial loss of yield.

DATAQUEST CONCLUSIONS

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 the move to larger wafer sizes is inevitable. Semiconductor manufacturers can achieve substantial savings in initial fab cost per square inch of capacity and in the manufactured cost of a yielded die by using larger wafers.

Although for years IBM was the only major manufacturer using 8-inch wafers, today other

FIGURE 3
DRAM Cost per Die by Wafer Size



Source: Dataquest (April 1991)

companies 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 widespread use of 8-inch wafers, 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 (for example, materials suppliers, equipment vendors, and leading-edge semiconductor manufacturers) that wish to remain ahead of their 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.

George Burns

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Research Newsletter

THE ROLE OF AUTOMATION IN SEMICONDUCTOR MANUFACTURING

SUMMARY

The purpose of this research newsletter is to highlight some of the major development activity that is currently being undertaken in the area of semiconductor factory automation. Increasingly large automation investments are being made in all regions of the world, especially Japan. These investments are being directed toward robotics, cell controllers, and automated data collection systems in an effort to help manufacturing managers better manage their fabs. Semiconductor manufacturers plan to realize positive returns on their automation investments through increased equipment utilization, reduced cycle times, improved yields, increased labor productivity, elimination of misprocessing, and inventory reduction.

DEVELOPMENT ACTIVITY

The Robotics Market

Robotics are playing an increasingly important role in factory automation because submicron geometries mandate that manufacturing managers maintain tighter control over their processes. Tighter control will be achieved by using equipment that requires minimum operator intervention, which, in turn, will decrease wafer misprocessing, reduce contamination, and reduce cycle time. Reduced cycle time is important for three reasons: the probability of contamination increases the longer the processing time, a reduction in cycle time translates into lower manufacturing costs, and yield learning rates improve.

The increasing demand for robots in the manufacturing process is pushing robotic technology forward. For example, robotics are a key part of automated material control/transfer systems. These systems contribute to increased fab productivity by performing wafer transfer machine load/unload functions and through effective work in process (WIP) management. Robotics designed for Class 10 clean room environments are being used extensively in Japan for both inter-bay and intra-bay material transport. At least one U.S. robotics manufacturer recently developed a cell automation system that will provide cassette-to-cassette automation for an entire cell of process equipment or throughout the complete fab. The cell may contain equipment such as a preprocess wafer-cleaning tool, a stepper, a post-process metrology station, and a WIP management station to disposition the wafers after cell processing.

Cell Controllers

A cell is a set of process equipment, material-handling equipment, and metrology equipment designed to perform related functions under central control. The cell controller is a combination of software and hardware tools that manage and coordinate cell resources by acquiring data and adjusting operations based on the results of that data. Cell-control software developers are challenged to develop software that is compatible across computers with different architecture. Compatibility is necessary to accommodate the diversified computer product line that exists today.

Semiconductor manufacturers are looking for equipment that has the capability to operate in an "independent" manner. Independent operation refers to having equipment that is capable of shutting down and restarting through the use of remote control. The restart capability should include automatic initialization of both the equipment status and fault-detection systems. With these systems initialized at start-up, the equipment will automatically return to a steady state that is ready for processing.

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Automated Data Collection

The demand for automated data collection systems will increase as process complexity increases (over 500 process steps may be required to manufacture a 16Mb DRAM) and line geometries get smaller. Automated data collection systems are designed to help manage process complexity, improve yield through statistical process control, and manage inventories more tightly through WIP management programs.

Bar code systems represent one of the largest growth areas in automated data collection. The demand for bar code systems is derived from a low-cost product that is easy to install and maintain in a manufacturing environment.

THE INTELLIGENT MANUFACTURING SYSTEMS PROJECT

The Japanese Ministry of International Trade and Industry (MITI) determined that there was a demand for factory automation systems that have the capability to integrate across companies. As a result, MITI formed an international cooperative effort called the Intelligent Manufacturing Systems (IMS) project. The purpose of the project is to formulate an integration strategy. The effort is financed equally by the participants, and its mission is to develop intelligent, advanced computer-aided manufacturing systems. Projects currently being considered include zero-defect quality programs and concurrent engineering. The key to IMS success will be the equitable exchange of technology between the participants.

CIM DEVELOPMENT AT SEMATECH

SEMATECH is also working on an advanced computer-integrated manufacturing (CIM) architecture program that is scheduled for demonstration and transfer of capability to its member companies during the third quarter of 1991. The purpose of the project is to develop and adopt a common architecture for the integration of CIM system elements and provide a framework for technology transfer to its member companies.

AUTOMATION BARRIERS

Common barriers to automation include lack of investment capital, lack of commercially available hardware, nonstandard equipment interfaces, the inability to quantify benefits of automation to senior management to overcome investment hurdles, and the lack of qualified automation hardware and software engineers. The demand for engineers is being driven by manufacturers that want factory automation suppliers to train their own engineers as well as provide on-site support.

DATAQUEST CONCLUSIONS

Factory automation is feasible and practical for the semiconductor industry. The majority of Japanese semiconductor manufacturers view factory automation as a strategic necessity. For instance, the majority of new 0.8um Japanese DRAM fabs will have both inter-bay and intra-bay automated material-handling systems. The same material-handling systems are also being installed in their ASIC fabs. As wafer sizes increase, WIP inventories will be extremely expensive, so lengthy throughput times and large WIP inventories will tie up equally large amounts of working capital. Factory automation can help control these costs. Dataquest believes that factory automation has the potential to give semiconductor manufacturers who exploit its capabilities a competitive advantage in the 1990s by allowing those manufacturers to maintain tighter control of their manufacturing processes. The semiconductor industry's capital-intensive nature demands competitive yields, high throughput rates, and maximum utilization of resources to achieve a competitive cost per wafer.

Jeff Seerley

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Research Newsletter

SEMATECH'S CONGRESSIONAL REVIEW: IS THE BEST IT CAN BE GOOD ENOUGH?

"SEMATECH could meet all of its R&D objectives on schedule and still not restore U.S. manufacturing leadership." *SEMATECH 1990: A Report to Congress*

SUMMARY

The National Defense Authorization Act for fiscal years 1988 and 1989 established the Advisory Council on federal participation in SEMATECH and charged it with, in the council's words, "reviewing SEMATECH's operations each year and assessing continued federal participation." The Advisory Council, chaired by John A. Betti, Under Secretary of Defense for Acquisitions, has once again recommended to Congress that the federal government continue its funding of America's most visible high-technology consortium.

The Advisory Council report, however, also raises issues about SEMATECH's long-term effectiveness. In particular, the report expresses concerns about the following:

- SEMATECH has not been a sufficient antidote to continuing erosion in the U.S. semiconductor manufacturing equipment and materials base.
- SEMATECH's focus on external R&D activities has "exposed a division of interest among the consortium's participants."
- SEMATECH's Phase 2 and 3 objectives rely too much on current-generation lithography.

Although these concerns may seem to reflect a gloomy assessment of the consortium's future, the report as a whole shows a healthy sense of pragmatism. Dataquest has been concerned that SEMATECH might be held accountable for goals that are simply unrealistic, given the consortium's structure and resources. Overall, the Advisory Council report views SEMATECH's main benefits to Americans as "indirect" in the sense that they are "likely to come from the continued operation of commercially vigorous U.S.-based manufacturing firms ready and able to exploit emerging technologies." The value of such indirect contribution to U.S. competitive strength, in the Advisory Council's opinion, is sufficient justification for continued federal support.

This newsletter reviews the conclusions of *SEMATECH 1990: A Report to Congress* and focuses on the Advisory Council's assessment of SEMATECH's progress in 1989 and the concerns it raises about the program's future.

REORGANIZATION IN 1989

The Advisory Council report attributes much of SEMATECH's progress in 1989 to its reorganization, which signaled a shift in balance between the two models that have guided the consortium since its founding. The report said that the first of these models concerned "the development and demonstration of world-class manufacturing processes on-site, and the transfer of resulting technology directly to members in large, integrated, connectable chunks." Yet another operative model for the consortium was that of a facilitator and testing ground for leading-edge semiconductor equipment and materials.

Although SEMATECH theoretically adheres to both of these models, the consortium's limited resources have made it impossible to develop an ambitious in-house production strategy as well as invest in the preservation of domestic sources of first-class tools and materials. According to the Advisory Council report, "The consortium cannot

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afford to address strategic interests of the industry at large *and* install fully integrated high-volume production lines at the same time."

Under the late Bob Noyce, SEMATECH increased its emphasis on the second of its two underlying models. The June 1989 reorganization called for an increased volume of off-site R&D projects to meet specific equipment, materials, and manufacturing process requirements for 0.50- and 0.35-micron production. The consortium amended its mission statement to read (SEMATECH's mission is) "to provide the U.S. semiconductor industry the domestic capability for world leadership in manufacturing." To SEMATECH, domestic capability translates into U.S. equipment and materials suppliers. In preserving this capability, SEMATECH has crystallized its mission into the following two highly strategic objectives:

- Protect U.S. semiconductor manufacturers from dependence on foreign sources of supply
- Ensure that new and improved equipment and materials are developed "in place with chipmakers; purchasing cycles for the next two generations of semiconductor device technology"

Resource Reallocation

Given its objectives, SEMATECH underwent a major reallocation of its resources in 1989. In rationalizing its form with its function, the consortium canceled plans for a second fab, scaled back hiring projections, and doubled its original budget for off-site R&D. Of SEMATECH's $260 million 1990 budget, 53 percent ($137 million) was set aside for R&D contracts. In contrast, external R&D accounted for only 20 percent of the consortium's 1988 budget. Whereas plant and equipment accounted for $75 million of SEMATECH's 1989 expenditures, the current operating plan calls for plant and equipment spending to fall to $19 million in 1991—9 percent of the consortium's projected budget.

Beyond the issue of resources, the report expresses other doubts concerning SEMATECH's success in the in-house demonstration of a high-volume production capability. The report states that "to establish and operate a fully integrated fab line...SEMATECH would have been obliged to produce some version of a saleable device and to rely on its members to supply the necessary device and process designs. Whether members would have provided such support is uncertain."

Impact on Programs

The Advisory Council credits SEMATECH's reorganization with progress in the following areas:

- Technology development
- Technology transfer
- Improving supplier relations
- Strengthening the U.S. technology base

Technology Development

At the heart of SEMATECH's project-based operating system is its Master Deliverables List (MDL). This list is the result of SEMATECH's competitive analysis and comparison of U.S. and foreign manufacturing capabilities. Out of this analysis has come the current targeting of the following major thrust areas: lithography, metrology, multilevel metallization, furnace and implantation technology, and manufacturing methods and processes. At the time of the Advisory Council report, SEMATECH's MDL included 56 projects in various stages, more than one-half of which were being generated through joint-development projects (JDPs).

The Advisory Council report reveals that the increased momentum of JDP activity observed during the latter half of 1989 was due not only to changes in the consortium's structure and budget, but, more importantly, to changes in the development contract process. Quoting from an SEMI/SEMATECH annual report, the Advisory Council notes that "intellectual property proved an insurmountable barrier to starting up the development contract process." The Advisory Council report cites progress in making the participation agreements more flexible and observes that "SEMATECH now negotiates the rights to jointly developed technology (e.g., preferential purchasing and licensing rights) on a case-by-case basis, with final arrangements largely dependent on how project costs are shared and the market strength of the contractor."

With the removal of intellectual property barriers, contracting activity accelerated at SEMATECH during the second half of 1989. As a result, the Advisory Council report states that "senior officials at SEMATECH and DARPA report that the consortium's R&D program is on track and on time." Table 1 lists SEMATECH contract activity, as observed by Dataquest, organized on the basis of major technology thrust areas.

Table 1
SEMATECH External Development Contracts

SEMATECH Thrust Areas	Contract Partner	Program Type	Contract Date
Lithography			
Submicron Reticle and Mask Exposure System	ATEQ	JDP	May-1989
Optical Wafer Stepper	GCA	JDP	May-1989
Advanced Photoresist Processing	Silicon Valley Group	JDP	Dec.-1989
X-Ray	Hampshire	JDP	Mar.-1990
I-Line Steppers	GCA	EIP	NA
Laser Mask Writer	ATEQ	Other	May-1990
Advanced Reticle and Mask Exposure System	ATEQ	JDP	Jul.-1990
Ion Implant			
High-Energy Implantation Technology	Ion Implant Services	TAA	Feb.-1990
PECVD			
Dielectric CVD	Applied Materials	EIP	Apr.-1990
Global Planarization Process	Westech Systems	JDP	May-1990
Dry-Etch Technology			
Metal-Etch Systems	Lam Research	EIP	Nov.-1989
Plasma-Etch Technology	Oak Ridge Nat'l. Lab.	TAA	Dec.-1989
Electron Cyclotron Resonance (ECR)	Lam Research	JDP	Jan.-1990
Low-Temperature Etch	Drytek	EIP	Mar.-1990
Sputter Cluster Tool	Eaton	JDP	Jul.-1989
Metrology			
Wafer Defect Detection	KLA	JDP	Dec.-1989
Critical Dimension Measurement Systems	Angstrom Measurement	EIP	Jan.-1990
Metrology Standards	NIST	JDP	Aug.-1989
Process Architecture/Integration			
Test Chips	HP	JDP	May-1989
Advanced Isolation	NCR	JDP	Aug.-1989
Manufacturing Methods			
Ultrapure Gas Management Systems	SemiGas Systems	JDP	May-1989
Establishment of SETEC	Sandia Nat'l. Lab.	TAA	Sep.-1989
Manufacturing Specialist Training Program	Texas State Tech. Inst.	TAA	Dec.-1989
Furnaces			
Vertical Furnace	SVG	EIP	Jun.-1990

JDP = Joint-Development Program, EIP = Equipment Improvement Program, TAA = Technical Assistance Agreement
NA = Not available
Source: Dataquest (January 1991)

Technology Transfer

Prior to its reorganization, SEMATECH had stressed a horizontal transfer of technology to its member companies. This strategy was largely predicated on on-site technology development. The Advisory Council report observes that SEMATECH now relies more heavily on two-way vertical technology transfers "mediated by SEMATECH but occurring with increased frequency in direct exchanges between members and suppliers."

Although some of the tool development and prototype testing that originally was planned for the consortium's canceled tool applications process facility (TAPF) will be performed in its main fab, most of this work will be assigned to member companies. An example of such an arrangement involves GCA. At an estimated cost of $24 million to $32 million, SEMATECH is buying between 15 and 20 GCA i-line steppers to distribute to five or more member companies. With technical support from GCA, the member companies will use the steppers in their production lines, compare them with foreign alternatives, improve upon them, and share the resulting information with GCA.

With its emphasis on vertical relationships, much of SEMATECH's horizontal transfer of technology will take place through its member company assignees and through SEMATECH technology transfer teams that regularly visit member companies.

Improving Supplier Relations

The Advisory Council concludes that, in a broad sense, SEMATECH has improved communication among equipment suppliers and users through its program of workshops, symposia, and joint sessions of the SEMATECH and SEMI/SEMATECH boards. SEMATECH also has created a supplier relations action council consisting of senior purchasing and materials managers from its member companies. The purpose of this group, known in SEMATECH circles as "the partnering posse," is to "promote strategic relations with U.S. suppliers at their home companies." The report credits these efforts with the structuring of a joint effort by U.S. semiconductor manufacturers and suppliers to acquire Perkin-Elmer's e-beam and optical lithography divisions rather than risk its acquisition by a non-U.S. company.

Strengthening the Technology Base

In addition to its R&D contract efforts, the Advisory Council report notes that SEMATECH's $10 million investment in 11 universities (the SEMATECH Centers of Excellence, or SCOEs) has "generated some early unanticipated returns." The report cites four cases involving improved scientific understanding, six cases involving new experimental capability, and seven cases involving new product concepts. As of December 1989, SEMATECH had graduated more than 75 employees from its manufacturing specialist program. In August 1989, SEMATECH established a Semiconductor Equipment Technology Center (SETEC) with Sandia National Laboratory. The center, which will receive $10 million in SEMATECH funds during the next three years, is charged with the development of reliability technology for semiconductor manufacturing equipment. In another National Lab program, SEMATECH and the Oak Ridge National Laboratory joined forces in December 1989 to develop electron cyclotron resonance etch reactors for 0.5-micron wafer processing.

THE EROSION CONTINUES

Ironically, although the Advisory Council report on SEMATECH provides Congress with a highly favorable evaluation of the consortium's activities, it also points out that during this period of positive accomplishments, "erosion in the market position of U.S.-owned semiconductor manufacturing equipment and materials companies seemed to accelerate." According to Sam Harrell, president of SEMI/SEMATECH, 65 U.S. equipment and materials companies were acquired during the year of SEMATECH's incorporation. Out of these acquisitions, 37 were made by U.S. companies, 12 were made by European companies, and 16 were made by Japanese companies.

In addition to the issue of consolidation, the report runs through a now-familiar litany of industry woes such as declining U.S. market share in equipment and materials, greater size and business diversity of foreign competitors, lower hurdle rates on prospective investments for foreign competitors, and lower rates of capital spending by U.S. semiconductor companies compared with their Japanese rivals.

In the face of such broad and pernicious environmental factors, the report concludes that "even at their most successful, SEMATECH and similar measures are palliatives—selective and temporary efforts to compensate for general conditions in the U.S. economy that have contributed to competitive weakness in a range of domestic industries." Moving from palliative to competitive antidote would, however, make SEMATECH a much more expensive prescription for the industry's ills. The Advisory Council states the recommendation of the National Advisory Committee on Semiconductors (NACS) that SEMATECH be used "to channel increased R&D support to the U.S. SME (semiconductor manufacturing equipment) and materials industry." However, the NACS report estimates that "a full-scale effort to meet the needs of U.S. equipment and materials firms would require an additional $800 million over the next three years."

Areas of Concern

Beyond the question of financial resources, the Advisory Council report raises interesting queries about SEMATECH's future based on some implications of its 1989 restructure. First, the report notes that "SEMATECH intends to sustain or create one world-class U.S. producer in each major category of chipmaking equipment, second-sourcing only in special cases where the back-up company uses an entirely different tool architecture or represents a particular high-risk/high-return investment opportunity." This objective seems to confirm fears voiced by equipment makers during SEMATECH's creation that the consortium would be a catalyst to further attrition in the U.S. semiconductor equipment base rather than a force for healthy diversity.

The report also says that SEMATECH's project-based approach and external R&D activities has "exposed a division of interest among the consortium's participants." The nature of this division as characterized by the report has to do with the desire of smaller members for major infusions of leading-edge process technology. SEMATECH's focus on the preservation of domestic sources of first-class tools and materials is more in keeping with the priorities of its larger members, which already have advanced processing capability. Under SEMATECH's 1987 Partnership Agreement, December 1989 marked the first time that consortium members could give the required two-year notice activating their option to leave the alliance. As the report observes, "some of the consortium's smaller firms may have reassessed their ability to support the considerable cost of membership" (which is 1 percent of the previous year's semiconductor sales with a $1 million minimum and a $15 million cap).

The Advisory Council report also expresses concern over the implications of SEMATECH's emphasis on short-loop rather than full-flow wafer processing. The report concludes that this approach "will be insufficient for conclusive demonstrations of equipment and will impose some limitation on the development of important process technologies." In addition, the generic process architectures on which SEMATECH will base its Phase 2 and 3 objectives "could omit important steps or tools that member firms would need to make their own 0.50- or 0.35-micron products." The Advisory Council, however, recognizes that the establishment of an in-house, high-volume capability for SEMATECH is more than just a matter of financial resources. "To establish and operate a fully integrated fab line...SEMATECH would have been obliged to produce some version of a saleable device and to rely on its members to supply the necessary device and process designs. Whether members would have provided such support in uncertain."

The report's concern over SEMATECH's long-term effectiveness extends also to its R&D contracts, which its notes "focus mainly on wafer processing rather than important antecedent steps (e.g., product design, materials development) or final chip assembly and packaging." The Advisory Council also worries that SEMATECH's Phase 2 and 3 objectives rely too much on current-generation lithography rather than "technologies that may be the basis of competitive high-volume production at the end of the 1990s."

Reconciling Public and Private Interests

In coming to grips with the adequacy of SEMATECH's Phase 2 and 3 goals, the Advisory Council correctly concludes that increasing SEMATECH's funding would not necessarily provide a solution. The problem is more in the very nature of SEMATECH's public/private identity. The report points out that SEMATECH's "tendency to shorten planning horizons appears to be a recurrent pattern in consortia exposed to market pressures." Although a key objective of publicly supported cooperative R&D would seem to be the extension of private investment horizons, the aim of industry leadership is to keep such programs responsive to market requirements—in other words, keep R&D in phase with chipmakers' purchasing cycles.

DATAQUEST CONCLUSIONS

The Advisory Council views the NACS recommendation of increasing the SEMATECH budget by $100 million in the near term as a way to "reduce the risks inherent in the consortium's R&D enterprise" through the development of a full-flow demonstration environment and increased on-site testing of unsolicited equipment and materials. Increasing federal funding by a larger amount would allow the consortium to address high-cost, long-term projects such as X-ray and excimer laser lithography technology, advanced device concepts, and new materials. What concerns the Advisory Council about such a funding increase is the strain it could place on the SEMATECH alliance. An increase in federal funding in support of long-term projects (and the consequent increase in membership fees to preserve the public/private balance) would "appeal mainly to SEMATECH's largest members (and) would conflict with the consortium's evolving corporate culture, which is inclusive, cooperative, and responsive to near-term market conditions."

Based on this evaluation, the Advisory Council argues for the status quo in terms of federal support to the consortium while concluding that the SEMATECH program may not be sufficient on its own to revitalize the global competitiveness of the U.S. semiconductor industry. However, SEMATECH clearly is a means to that end and has played a major role in facilitating the application of technology from existing sources within industry, academia, and government for the improvement of existing manufacturing tools and the creation of new ones. The Advisory Council concludes that to hold SEMATECH accountable for the ultimate salvation of the U.S. semiconductor industry is to ignore the responsibilities of its member companies to incorporate the technologies it fosters and "the role of national policy in general."

Note: This newsletter was produced as a cooperative effort between the Semiconductor Industry Service (SIS) and the Semiconductor Equipment, Manufacturing, and Materials Service (SEMMS).

Jeff Seerley
Michael J. Boss

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Research Newsletter

THE FAB DATABASE SERIES: THE SHIFT TO SUBMICRON GEOMETRIES

SUMMARY

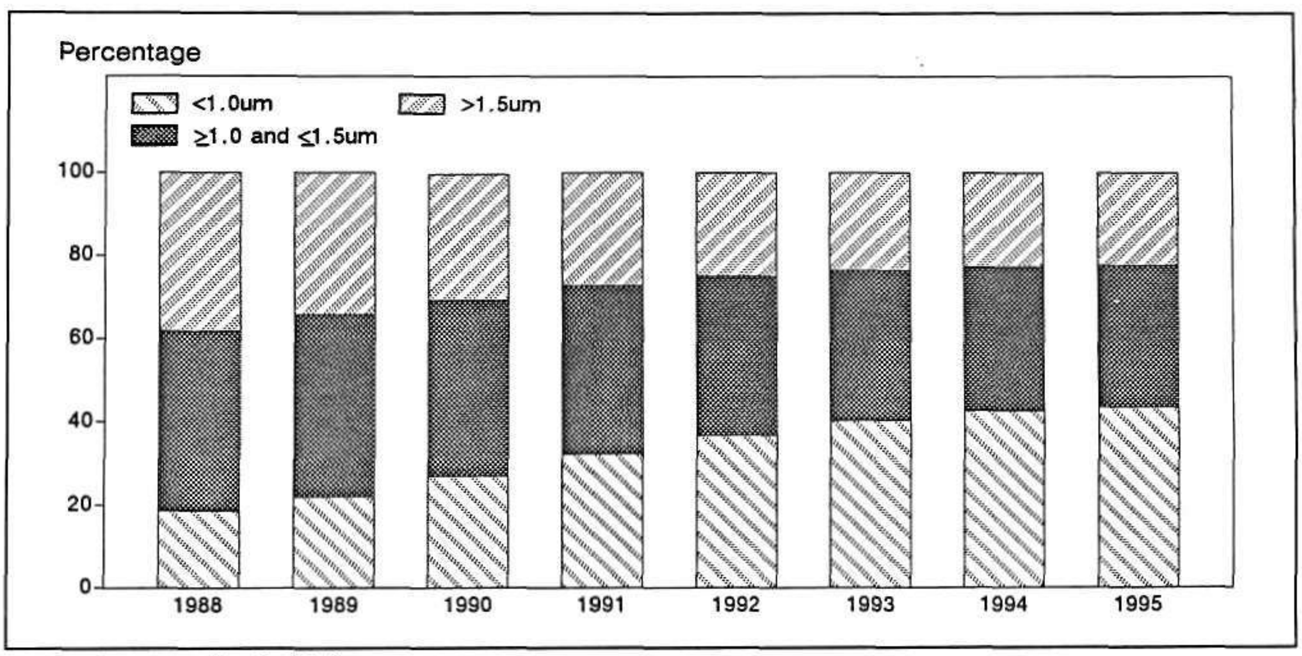
This research newsletter analyzes production wafer fab capacity trends by minimum drawn linewidth. The Semiconductor Equipment, Manufacturing, and Materials Service (SEMMS) worldwide fab database is the foundation of this analysis. Dataquest defines a production fab as one that is capable of front-end processing more than 1,250 wafers per week. Minimum drawn linewidth is defined as the minimum linewidth at the critical mask layers as drawn.

The crossover point at which submicron processing accounts for the highest percentage of worldwide production will occur in 1993; this point is illustrated graphically in Figure 1. DRAMs, SRAMs, and MPUs will account for the majority of submicron production when crossover occurs.

IMPLICATIONS FOR SEMICONDUCTOR EQUIPMENT SUPPLIERS

Figure 2 illustrates 1991 worldwide theoretical submicron production capacity measured in millions of square inches. In 1991, submicron production represents 32 percent of the total worldwide semiconductor production capacity. In 1992, submicron production will represent 37 percent of the total worldwide semiconductor production

FIGURE 1
Worldwide Production Fab Capacity by Minimum Linewidth (Millions of Square Inches)



Source: Dataquest (April 1991)

SEMMS Newsletters 1991 Manufacturing—Worldwide Fabs

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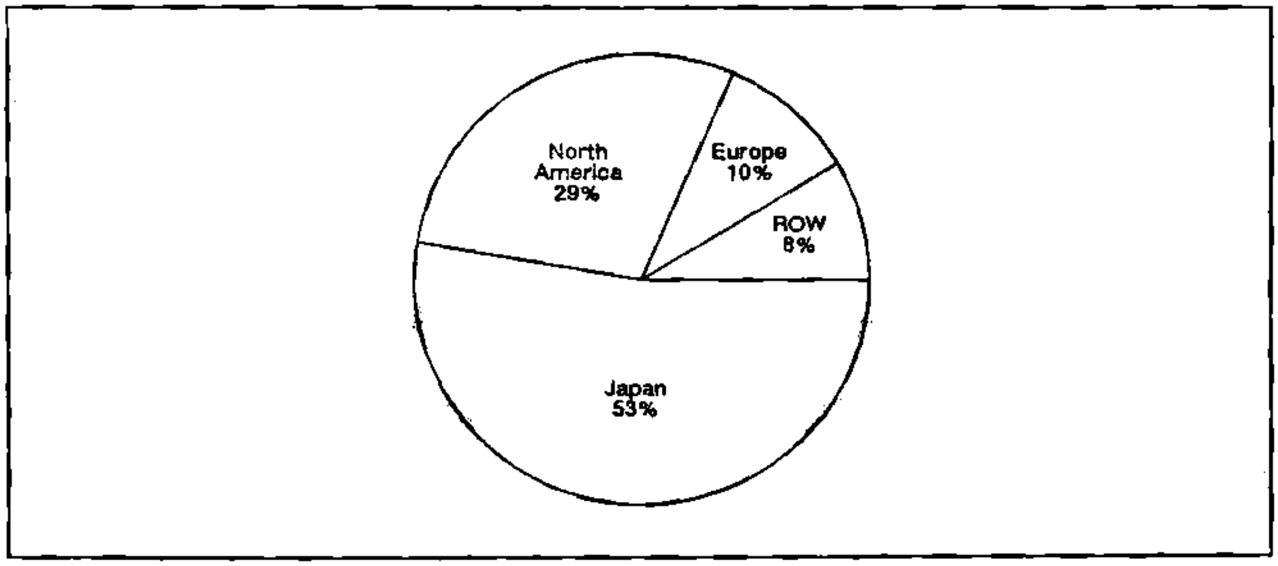
FIGURE 2
Worldwide Submicron Production Capacity–1991
(Millions of Square Inches)



Source: Dataquest (April 1991)

capacity; in1993, submicron capacity will represent 40 percent of the total worldwide semiconductor production capacity. It is no surprise that Japan is the land of opportunity for submicron semiconductor equipment manufacturers, commanding 53 percent of the worldwide submicron capacity in 1991. Because 8-inch wafers will play an increased role in submicron processing, many equipment suppliers are offering or will soon offer 8-inch tools.

Submicron leading-edge DRAM fabs have a substantial influence on the tool development process. However, DRAM fabs are not the only ones converting to submicron 8-inch tools. For example, Motorola's MOS 11 fab in Austin, Texas, will start microprocessor and fast static RAM production on 8-inch tools. Japanese, U.S., and European equipment suppliers are developing 8-inch tools with 0.5-micron process capability. Motorola claims that 87 percent of all MOS 11 equipment dollars were spent with U.S. equipment suppliers rather than foreign equipment suppliers. If this is the case, then U.S. equipment suppliers have already completed a substantial amount of 8-inch tool development.

IMPLICATIONS FOR SEMICONDUCTOR MANUFACTURERS

The submicron era will bring a multitude of changes to manufacturing. Semiconductor manufacturers have experienced a 30 percent increase per generation in tool costs. To offset such increases, manufacturers need to set competitive goals such as achieving at least 75 percent tool utilization, maintaining fab yields of 98 percent or greater, and maintaining at least 75 percent wafer sort yields.

Automation will play a stronger role in managing the manufacturing process. Single wafer processing will become more common as wafer sizes increase. Cluster tools will be utilized, but not throughout the fab. Equipment selection will consist of a mix-and-match strategy employing both standalone and cluster tools. Semiconductor manufacturers will thoroughly characterize these tools and processes in an effort to eliminate manufacturing variability. Concurrent engineering will become a way of life to ensure that new processes and products are transferred into production at competitive yields.

IMPLICATIONS FOR SEMICONDUCTOR MATERIAL SUPPLIERS

Semiconductor material suppliers will see an increased demand for gases and chemicals that meet the ultrapure specifications required for submicron processing. Japan dominates the semiconductor materials market. If the United States continues to become dependent on foreign sources for semiconductor materials, it may not be granted access to the most advanced materials as quickly as will its foreign competitors, putting the United States at a severe disadvantage.

THE RISK ADVERSE STRATEGY

To avoid or at least reduce the risks involved with new overseas submicron fab investments, companies are adopting innovative financing strategies such as advance payments from customers, joint ventures, or foreign government incentives. Texas Instruments (TI) is one of the most innovative companies when it comes to diversifying the risk associated with a new submicron fab. For instance, in exchange for technology, TI received $125 million toward the initial investment of $250 million from the Italian government for its fab in Avezzano, Italy. Also, one year ago TI entered into a joint venture with Kobe Steel to manufacture VLSI logic and ASICs in Japan. The company has also entered into a joint venture with ACER to manufacture 4Mb DRAMs in Taiwan. TI's strategy of diversifying both financially and geographically is an example of true global thinking.

DATAQUEST CONCLUSIONS

Submicron processing will pose a multitude of challenges for the semiconductor industry throughout this decade. During this time, manufacturers will go from 6-inch wafers to 8- or 12-inch wafers. Factory utilization and yield improvement will become the driving forces behind efforts to remain competitive.

In 10 years, leading-edge DRAM production will go from 0.50-micron 16Mb DRAMs with an excess of 400 process steps to 0.15-micron 1Gb DRAMs with about 700 or more process steps. Equipment and materials suppliers will play a key role in semiconductor fab design and operation throughout the 1990s.

Jeff Seerley

Capital Spending

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Research Newsletter

U.S. MERCHANT SEMICONDUCTOR CAPITAL SPENDING: THREE LONG-TERM TRENDS

Dataquest has just completed an analysis of U.S. merchant semiconductor manufacturers' capital spending plans. The analysis reveals evidence of long-term structural change in the industry, and this newsletter highlights those structural changes. (For results and detailed analysis of individual U.S. merchant manufacturers' spending plans, please see the accompanying SEMMS newsletter entitled "1990-1991 U.S. Merchant Semiconductor Manufacturers' Capital Spending: Moving Beyond Tactical.")

We have identified three types of structural change that have taken place:

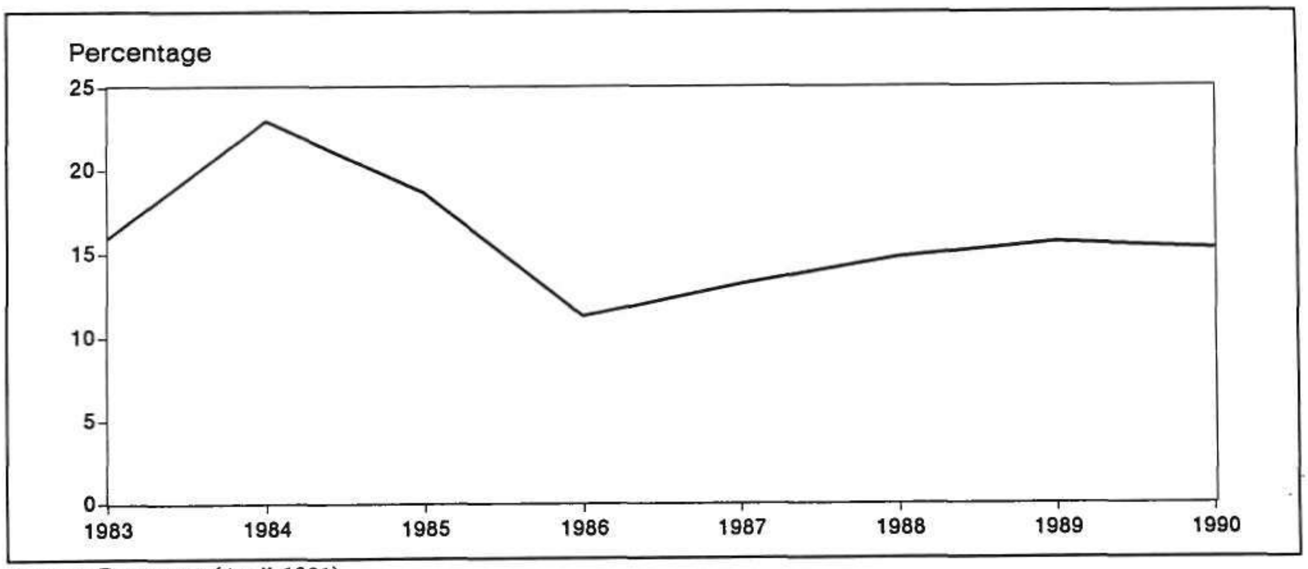
- A tendency for semiconductor capital spending as a percentage of semiconductor revenue to increase
- A tendency for the top three U.S. merchant semiconductor companies to account for a larger portion of total U.S. merchant semiconductor company capital spending (concentration of buying power)
- A tendency for total U.S. merchant semiconductor company capital spending to account for an ever smaller portion of total worldwide merchant semiconductor company capital spending

LONG-TERM TRENDS

Capital Spending as a Percentage of Revenue

Figure 1 charts the change in the ratio of capital spending to revenue since 1983. Capital

FIGURE 1
U.S. Merchant Capital Spending as a Percentage of Revenue



Source: Dataquest (April 1991)

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spending as a percentage of revenue was at an all-time high of 23 percent in the boom of 1984. With the industry downturn of 1985 and 1986, however, the ratio of semiconductor capital spending to semiconductor revenue fell to 11 percent. After 1986, it rose steadily to 16 percent in 1989; in 1990, the ratio declined ever so slightly to just over 15 percent.

The question of whether the ratio of capital spending to revenue will resume its climb is difficult to answer. There are very strong forces pushing it up: The continuous increase of device and manufacturing complexity will increase the cost of both equipment and facilities. Offsetting these forces will be the efforts of manufacturers to cut capital costs through automation, use of microenvironments, simplifying both process flow and recipes, and increasing equipment reliability and throughput.

Concentration of Buying Power in the Top Three

Motorola, Texas Instruments, and Intel are the top three in U.S. merchant semiconductor device market share, with 44 percent of the total U.S. merchant semiconductor company revenue. Not surprisingly, these companies are also the top three in capital spending for the U.S. merchants. In 1990, these top three companies accounted for 56 percent of all U.S. merchant capital spending.

This share of 1990 U.S. merchant company capital spending is much larger than the top three's share of U.S. merchant company capital spending just a few years back. In 1984, the top three U.S. merchants (Texas Instruments, Motorola, and National Semiconductor) accounted for 45 percent of all U.S. merchant semiconductor capital spending.

A Smaller Piece of the Capital Spending Pie

U.S. merchant semiconductor companies as a whole represent a declining share of total worldwide capital spending. In 1984, U.S. merchant semiconductor capital spending accounted for 40 percent of total worldwide merchant capital spending. By 1990, the U.S. merchant share of total capital spending had declined to 29 percent. This decline is due to two factors. First, the U.S. merchant semiconductor companies have lost market share in the worldwide semiconductor marketplace—from 48 percent of the total worldwide merchant market in 1984 to 36 percent in 1990. Second, U.S. merchants' share of total worldwide capital spending has also declined because U.S. merchant semiconductor companies have not spent as high a proportion of their revenue on capital spending as have the Japanese and Asia/Pacific companies. For example, in 1990, U.S. merchants spent 15 percent of their revenue on capital spending, Japanese companies spent 20 percent, and Korean companies spent 63 percent.

Dataquest Conclusions

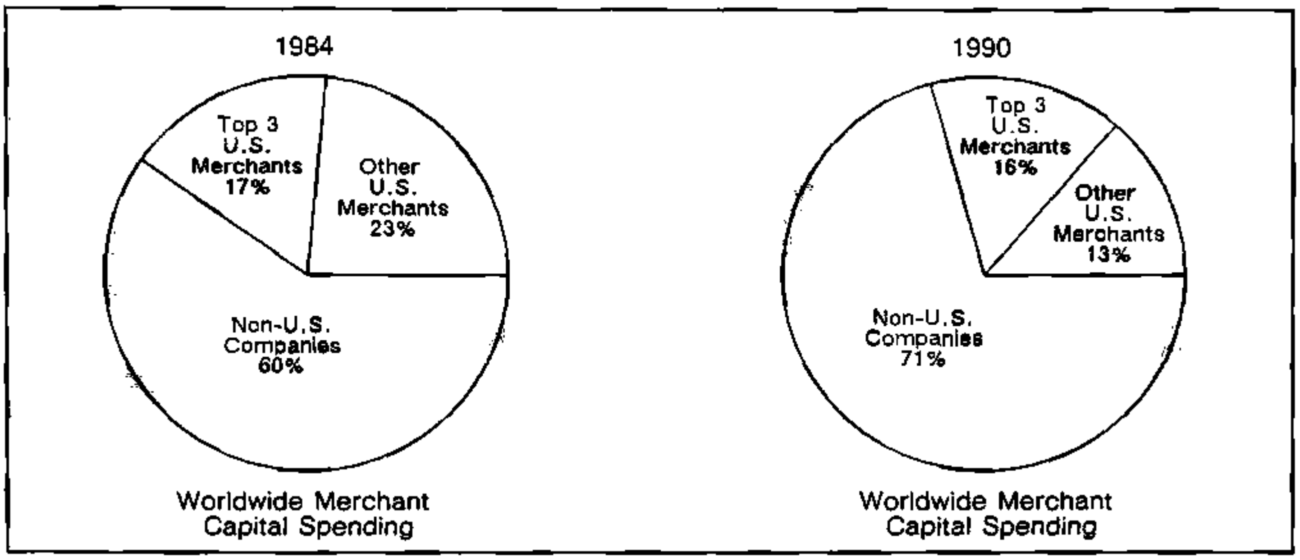
The semiconductor industry is already so capital intensive that many new companies have chosen to go fabless rather than undergo the expense of constructing and operating their own manufacturing facilities. Even companies with fabs, such as Intel, have chosen to use foundries for their lower-margined product lines. If the ratio of capital spending to revenue continues to increase, Dataquest expects to see more fabless companies, especially start-ups, and an increased use of foundries by even the largest semiconductor companies for their low-margined products.

Whether the ratio of capital spending to revenue will rise again or the efforts of semiconductor manufacturers to hold down the growth of capital intensity will bear fruit, one thing is clear—semiconductor manufacturing will remain capital intensive. As such, the cost of capital, which is higher in the United States than in other regions, will remain a competitive disadvantage for U.S. merchants.

Much attention has been paid recently to the loss of worldwide market share by U.S. merchant semiconductor companies. One effect is that U.S. merchants as a whole buy a smaller piece of the worldwide capital spending "pie." Those equipment vendors that focus on U.S. merchants as their primary target customers, therefore, are targeting a piece of the pie that, relatively speaking, has become smaller, even as the size of the pie has grown larger.

Because the top three U.S. merchants now represent over 50 percent of the U.S. merchants' capital spending, those vendors that target only U.S. merchants and are unable to sell successfully

FIGURE 2
U.S. Merchant Semiconductor Company Share of Worldwide Merchant Capital Spending



Source: Dataquest (April 1991)

to the top three are relegated to operating within a very thin slice (13 percent) of the whole worldwide capital spending pie (see Figure 2). That slice does not represent a very strong growth strategy. Dataquest believes that a more robust strategy (but one difficult for start-ups to follow) is to target worldwide semiconductor companies, regardless of the country where their headquarters are located.

George Burns

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Research Newsletter

U.S. MERCHANT SEMICONDUCTOR CAPITAL SPENDING HIGHLIGHTS: 1990-1991

Dataquest has just completed its survey of U.S. merchant semiconductor manufacturers' capital expenditures and plans for 1990 and 1991. This newsletter highlights the major features of those plans and expenditures.

The U.S. merchant semiconductor companies responding to this survey represent 78 percent of U.S. semiconductor merchant revenue. Their plans indicate that U.S. merchant, company-funded, semiconductor capital spending will increase 3 percent in 1991 over 1990 (see Table 1). However, when Texas Instruments' (TI's) joint-venture expenditures (TI/Acer, TI/Kobe, and TI/Singapore) are added, total (company funded and TI's joint ventures) U.S. merchant semiconductor capital spending will increase by 15 percent in 1991 over 1990.

U.S. MERCHANT SEMICONDUCTOR CAPITAL SPENDING: 1990-1991

Advanced Micro Devices (AMD) is planning to spend approximately $150 million in 1991, down from $275 million in 1990. The company's Submicron Development Center (SDC) fab was completed in Santa Clara, California, in 1990. The SDC is both a production fab and development fab and is one of the most advanced fabs in the world.

TABLE 1
U.S. Merchant Semiconductor Capital Spending (Millions of Dollars)

Company	1989	1990	1991	Percent Change 1990-1991
AMD	159	275	150	-45
Analog Devices	44	38	53	41
AT&T	150	100	170	70
Cypress	40	36	60	67
General Instrument	20	NA	NA	
Harris	68	74	70	-5
IDT	57	48	34	-29
Intel	380	550	900	64
LSI Logic	115	71	100	41
Micron Technology	230	107	100	-7
Motorola	540	550	640	16
National Semiconductor	200	146	140	-4
TI	641	707	460	-35
Vitelic	36	35	20	-43

(Continued)

SEMMS Newsletters 1991 Manufacturing—Capital Spending

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TABLE 1 (Continued)
U.S. Merchant Semiconductor Capital Spending
(Millions of Dollars)

Company	1989	1990	1991	Percent Change 1990-1991
VLSI Technology	50	55	55	0
Western Digital		106	40	-62
Others	416	330	326	-1
Company-Funded Total	3,145	3,228	3,318	3
Percent Change	15	3	3	
TI Joint Ventures		150	550	267
Percent Change		NA	267	
Total	3,145	3,378	3,868	15
Percent Change	15	7	15	

NA = Not available
Source: Dataquest (April 1991)

AMD's 1991 spending will be down because of the completion of this major project. The company's efforts in 1991 will be directed toward ramping up capacity for its 80386 microprocessor in Austin, Texas. It is possible that AMD will build a new fab in two years.

Analog Devices recently acquired Precison Monolithics and is in the process of consolidating its manufacturing operations. As part of its consolidation process, the company recently closed its Greensboro, North Carolina, fab.

AT&T's capital budget has been low in recent years as the company struggled with reorganization. Its Orlando, Florida, fab originally was underutilized, but in the last two years it has been the site of significant foundry activity for AT&T. It has been rumored that the Orlando facility has been short of capacity and late on some semiconductor deliveries recently. We expect AT&T to continue to ramp production at its fab in Spain and add new capacity at its Allentown, Pennsylvania, and Orlando fabs.

Cypress Semiconductor recently acquired Control Data Corporation's fab in Bloomington, Minnesota, for $13.7 million. This fab is one of the few fabs in the world that is fully equipped with standard mechanical interface (SMIF) technology. In addition to its Minnesota fab and its fab in San Jose, California, Cypress also has a fab in Roundrock, Texas, that it shares with Altera Semiconductor. Under this agreement, Altera paid Cypress $7.4 million and manufacturing rights for Altera's Multiple Array matriX (MAX); in return, Altera gains access to a certain portion of the fab's capacity.

Harris is reorganizing its semiconductor operations. It has announced that it is delaying plans to construct a new fab and assembly and test facility in Plymouth, England.

IDT is ramping up its new Technology Development Center fab in San Jose. This fab is a 26,000-square-foot Class 1 facility that is both a development and production fab. It currently has a capacity of 5,000 6-inch wafers per month.

Intel has the most aggressive capital spending plan ($900 million) of any company in the semiconductor industry. Its *increase* alone of $350 million in 1991 capital spending exceeds the 1991 capital budgets of all U.S. merchant companies except Motorola and Texas Instruments.

Intel is upgrading its D2 development line in Santa Clara from 6- to 8-inch wafers. The company is building a new 8-inch fab MPU development line in Aloha, Oregon, and is also building its first European fab (also an 8-inch fab) in Leixlip, Ireland. The company plans to begin production at fab 9.2 in Albuquerque, New Mexico, by mid-1991 and is continuing to add equipment to fab 9.1 in Albuquerque and to its fab in Israel.

LSI Logic has transferred high-volume ASIC production from its facility near London to its fabs in Tsukuba, Japan, and San Jose. LSI plans to manufacture low-volume analog/digital devices at its fab in the United Kingdom near London. LSI is currently spending $150 million to build an additional fab in Tsukuba. This fab is planned to be ready for equipment by this October.

In the first quarter of 1991, Micron Technology completed the conversion of Fab I/II from 5- to 6-inch wafers. Micron has no major plans for expansion this year. It continues to add capacity through shrinking its die size. For example, by shrinking the die for its 1Mb DRAM, Micron claims to have increased its 1Mb capacity by 100 percent.

Motorola completed MOS 11 at its new facility in Oak Hill, Texas, in 1990 and will run first silicon in May. This 8-inch fab is the industry's first for non-DRAM products. Motorola is also adding capacity for 1Mb DRAMs at its East Kilbride, Scotland, facility and building a new bipolar developmental and production line in Chandler, Arizona.

National Semiconductor recently sold Matsushita its Puyallup, Washington, BiCMOS fab that it acquired when it bought Fairchild Semiconductor. National is transferring processes that were formerly run at its Puyallup fab to its Santa Clara fab. The company plans no significant capacity additions in 1991.

TI's company-funded capital spending plans are down significantly in 1991 because the company recently completed adding significant new capacity to its Avezzano, Italy, facility and its joint-venture facility (TI/Acer) in Hsin-chu, Taiwan. However, the company continues to vigorously upgrade its existing facilities and add capacity through noncompany-funded joint ventures such as KTI, the joint venture between Kobe Steel and TI in Japan. TI recently announced that it will build a $330 million joint-venture DRAM fab in Singapore with the Singapore Development Agency (SDA), Canon, and Hewlett-Packard (HP). TI and SDA will each own 26 percent of the new company, and Canon and HP will each own 24 percent. Construction of the new fab will begin by this summer, and production is expected by mid-1993.

Vitelic broke ground for a new fab in Hsin-chu in late 1989, but stopped construction in late 1990 because of weak demand for its products. It is currently discussing a merger with Hualon Semiconductor, a Taiwanese company. Our estimate for Vitelic's 1991 spending level is based on the assumption that these discussions will result in a merger. Vitelic also bought a fab in Hong Kong from El Cap in 1989 to use as a pilot line and as a means to penetrate the People's Republic of China.

VLSI expanded and upgraded its San Jose fab in 1990 and plans to continue to facilitize its new San Antonio, Texas, fab in 1991.

Western Digital produced first silicon at its new submicron fab in Irvine, California, in March 1991. Manufacturing at this facility will be primarily for the production of engineering prototypes and production volumes aimed at facilitizing early market penetration. Total cost of the facility and equipment was just under $120 million.

DATAQUEST CONCLUSIONS

In a year of a general and nagging economic recession and uncertainty, the expansion of U.S. merchant capital spending and capacity is significant. AT&T, Cypress, Intel, LSI Logic, and Motorola are increasing their spending plans and adding significant capacity now. Of the eight U.S. merchant semiconductor manufacturers that reported a decline in capital spending, five have recently completed significant state-of-the-art capacity additions. One of these companies, TI, is still adding significant new capacity through its noncompany-funded joint ventures.

With all the new capacity currently being added and recently having been added by U.S. merchant semiconductor manufacturers, the claim can no longer be made that U.S. merchant capital spending is cut back during a downturn or a period of business uncertainty. With the inclusion of TI's noncompany-funded joint ventures, total U.S. merchant semiconductor capital spending will increase 15 percent in 1991.

By adding capacity now, U.S. merchant semiconductor manufacturers are moving beyond the tactical and are looking forward to the next expansion. U.S. merchant capital spending is strategic in nature, at least for this business cycle.

George Burns

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Research Newsletter

FIVE-YEAR CAPITAL SPENDING FORECAST: IT'S A GOOD WORLD IN SPITE OF 1991's UNCERTAINTY

SUMMARY

The year 1991 will be a year of uncertainty. Dataquest's forecast for worldwide spending on semiconductor property, plant, and equipment (PPE) calls for 11 percent growth (see Table 1), assuming that there will not be a war in the Persian Gulf. If there is a war, we predict that it will be short and that its economic effects will be limited. We are also assuming, independently of the crisis in the Persian Gulf, that the major economies of the developed world will not slide or tumble into a recession. If any of these events occur, investment plans currently under way or about to be implemented will almost certainly be pushed back.

Although the passage through the first year of our five-year forecast may contain hazards such as war and recession, we are optimistic about the five-year period as a whole. Demand for devices will continue to grow as clever engineers from around the world find new applications for ever more complex and sophisticated devices. Historically, semiconductor capital spending has doubled every five years. We believe that this doubling will continue. Capital spending will grow at a compound annual growth rate (CAGR) of 15 percent over the period from 1990 to 1995. We expect worldwide capital spending for PPE to reach $25 billion by 1995.

TABLE 1
Regional Capital Spending Forecast
(Millions of Dollars)

	1989	1990	1991	1992	1993	1994	1995	CAGR (%) 1990-1995
Capital Spending								
Japan	5,348	5,381	6,045	7,270	8,651	9,169	10,178	14
Percent Change	16	1	12	20	19	6	11	
United States	3,846	3,949	4,265	5,223	6,267	6,831	7,515	14
Percent Change	12	3	8	22	20	9	10	
Asia/Pacific	1,961	1,736	1,875	2,581	3,665	4,214	4,425	21
Percent Change	16	(11)	8	38	42	15	5	
Europe	1,141	1,313	1,575	1,989	2,466	2,811	3,233	20
Percent Change	22	15	20	26	24	14	15	
Worldwide	12,296	12,379	13,760	17,062	21,049	23,026	25,352	15
Percent Change	22	1	11	24	23	9	10	

Source: Dataquest (January 1991)

SEMMS Newsletters 1991 Capital Spending

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The regions of Europe and Asia/Pacific will continue to be the fastest-growing markets for capital spending, although Japan and the United States will continue to be the two largest markets for capital expenditure.

Although we are optimistic about the upcoming five-year period, we note that there is currently an excess of DRAM capacity and if recently announced DRAM capacity additions take place as planned, then an excess capacity situation will extend throughout our forecast period. This excess is a negative factor in the forecast and could both change individual companies' plans and slow down the growth rate of capital spending.

REGIONAL MARKETS

The discussion that follows is about regional markets. Spending in these regions is defined to include spending by both domestic and foreign-based companies taking place within that region. Spending by domestic companies that takes place offshore is included within the region where it takes place. For example, spending by a U.S. company in Japan would be counted as spending within the Japanese regional market and not as spending within the U.S. regional market.

Japan

Japan is the largest market for capital spending in the world. Total spending in Japan for PPE in 1990 was $5.4 billion, up 1 percent from 1989's level of $5.3 billion. Measured in dollars, these are record levels of spending. However, it should be pointed out that spending in the peak years of 1984 and 1985, measured in yen (¥924 billion and ¥794 billion, respectively), was higher than in 1989 and 1990 (¥754 billion and ¥767 billion, respectively).

Growth in spending in Japan will be fueled mainly by Japanese company spending, in both the near term and long term. This spending will be to maintain market share, as well as technological parity and technological leadership in device technology and manufacturing. In addition to defending their leadership position in commodity DRAMs, Japanese companies will continue to invest in ASIC and noncommodity DRAM markets such as application-specific DRAMs.

In evaluating the strength of the Japanese regional market, it is important to note that a growing percentage of Japanese company spending will take place outside of Japan, in the United States and Europe. As evidence of this, we note that in 1985 there was only one Japanese fab line operating outside of Japan. However, in 1990, we count 13 such fab lines, and we expect that there will be 27 fab lines operating outside of Japan by 1992.

This trend of Japanese companies building fabs outside of the Japanese region will slow down the long-term growth rate of spending in Japan. We expect capital spending in Japan to almost double by 1995 to $10.1 billion. The CAGR for the 1990 through 1995 period is expected to be 14 percent, which is less than the growth rate expected for the European and Asia/Pacific regions.

United States

The United States is the second largest regional market for capital spending in the world. Total spending in the United States for PPE in 1989 was $3.8 billion. In 1990, the market in the United States increased 3 percent to $3.9 billion. This spending increase was led by capital spending increases by major U.S. merchants and by the increasing presence of Japanese manufacturers in the United States. We estimate that spending by Japanese companies in the United States increased from more than $400 million in 1989 to more than $600 million in 1990.

Overall spending in the United States as a region was influenced negatively by the fact that a substantial portion of spending by companies such as IBM, LSI Logic, Motorola, National Semiconductor, and Texas Instruments was done outside of the United States. Cutbacks in spending by many of the second- and third-tier U.S. companies also brought down the 1990 growth rate for the U.S. region.

We expect capital spending in the United States to almost double by 1995 to $7.5 billion. The CAGR for the 1990 to 1995 period is expected to be 14 percent. One of the major reasons for this low growth rate is that U.S. companies will continue to spend a substantial portion of their capital expenditure offshore.

Asia/Pacific

Asia/Pacific includes the Pacific Rim countries, excluding Japan. The size of capital spending in Asia/Pacific exceeds that of capital spending in Europe. Capital spending in the Asia/Pacific region declined 11 percent from $1.9 billion in 1989 to $1.7 billion in 1990. This decline was due to cutbacks in spending by South Korean companies. Part of this decline was made up by an increase in spending in Taiwan. However, because South Korea is the largest market for capital investment in the Asia/Pacific region, the overall trend in 1990 will be down.

Dataquest expects fairly robust growth in spending in South Korea in 1991, spurred by additions of DRAM capacity and also by the recent commitment of South Korean companies to become major players in the ASIC markets.

Spending in Taiwan could be flat in 1991. This could be due to a rapid decline in the Taiwanese stock market (about NT$11,000 in the first quarter of 1990 to about NT$3,000 in the third quarter of 1990). Partly as a result of this crash, and also because of a general uncertainty about business conditions, Taiwanese semiconductor manufacturers are now delaying orders by a quarter or two.

We expect capital spending in the Asia/Pacific region to grow over the five-year forecast period at a CAGR of 21 percent and to reach $4.4 billion by 1995.

Europe

Spending in Europe by all companies increased by approximately 15 percent in 1990. This spending increase in Europe was fueled primarily by offshore companies from the United States and Japan building new fabs in Europe. We expect that capital spending will increase 20 percent in Europe in 1991, again primarily because of the increased activity of offshore manufacturers. Japanese companies will approximately double their spending in Europe in 1991 to about $800 million. Fujitsu, Hitachi, NEC, Mitsubishi, and perhaps Toshiba will have fabs or be building fabs in Europe by the end of 1991.

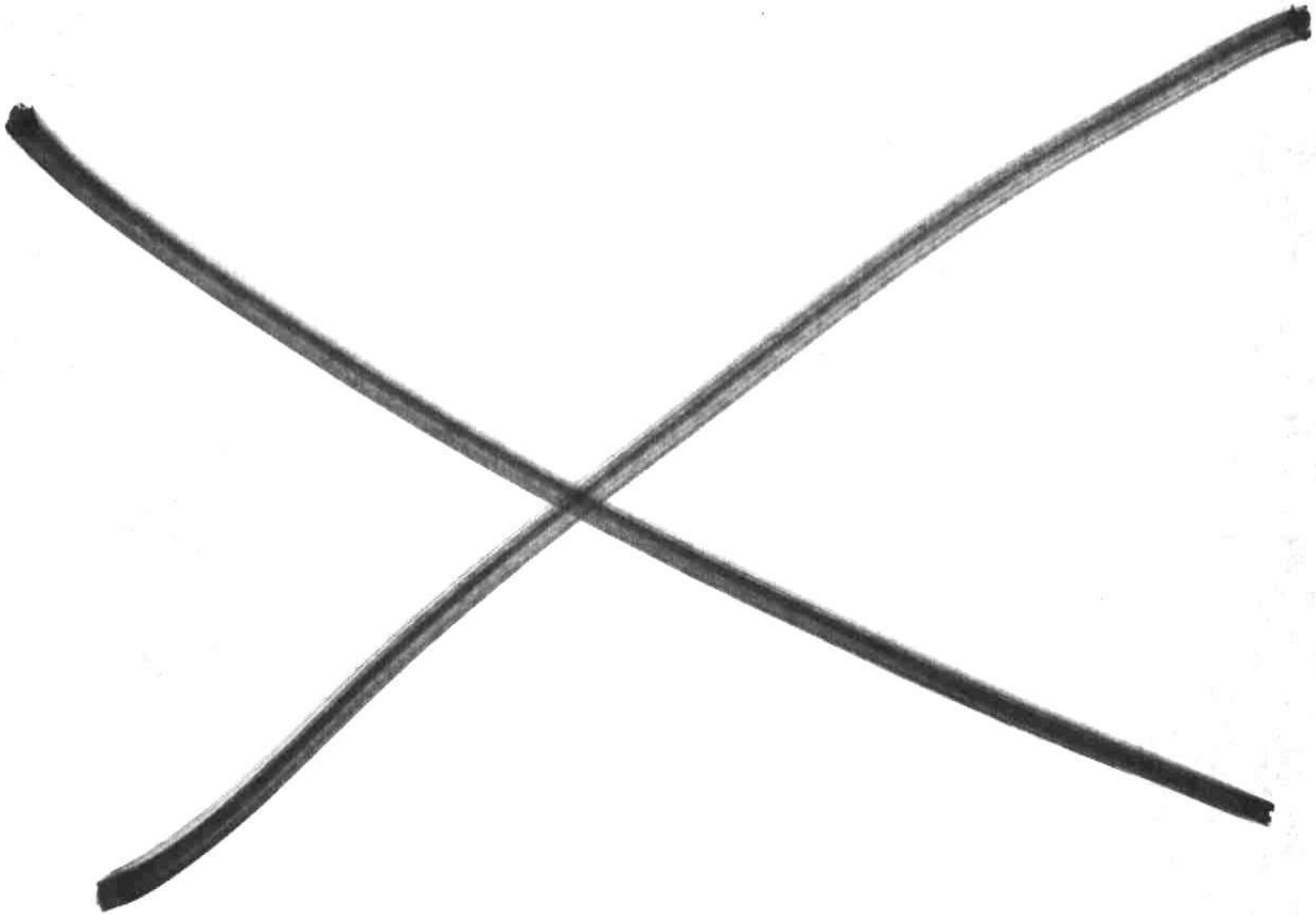
We expect capital spending to reach $3.2 billion by 1995 and to grow at a CAGR of 20 percent from 1990 to 1995. This growth will be fueled by the general economic growth that will be the result of the integration of the EC and the desire of major non-European manufacturers to have a fab line close to their customers and also adjacent to Eastern Europe.

Dataquest Conclusions

In a year in which the possibility of war and recession are the major topics of conversation, forecasters and businesses necessarily concentrate on the short run. The year 1991 could be one of moderate growth in capital spending, or it could be a year in which, because of war and recession, there is no growth. In the short run, semiconductor companies are planning to go ahead with their expansion plans as if there will be no major adverse effects from the crisis in the Persian Gulf or from a possible recession. However, orders can be canceled and implementation of plans can be delayed. Our forecast for 1991 is for capital spending to increase by a modest 11 percent. This forecast is fringed with uncertainty.

In the long term, however, we do not see a future clouded with any more uncertainty than is usual. We expect semiconductor capital spending to continue to increase at healthy rates for the five-year period to 1995. This increase will be fueled by semiconductor companies buying equipment and building fab lines for half-micron fabs; by new entrants into the industry, such as the Taiwanese and South Koreans; and by the need for all large manufacturers to have a manufacturing presence in every region of the world.

George Burns



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Research *Bulletin*

SEMIGAS: THE BALANCE BETWEEN TRADE POLICY AND OPEN MARKETS

The Antitrust Division of the Department of Justice announced on December 28, 1990, that it will sue to prevent the sale of SemiGas Systems to Nippon Sanso. SemiGas is a manufacturer of high-purity gas distribution and control systems sold to semiconductor manufacturers. Nippon Sanso is a Japan-based supplier of industrial and specialty gases and one of the five largest industrial gas companies in the world, with 1990 estimated revenue of ¥177,000 million. The Justice Department plans to file a civil antitrust suit in U.S. District Court within the next few weeks.

The Justice Department pointed out that its suit is an antitrust action based strictly on market share concentration. It emphasized that the suit is not politically motivated although its investigation into the sale was initiated by a complaint from Sematech. Sematech is an R&D consortium of U.S. semiconductor companies that receives $100 million annually in funding from the Federal government. The sale would work in direct opposition to Sematech's stated purpose of preserving a U.S. supplier base.

ANALYSIS

According to Dataquest's 1989 market share estimates (see Table 1), the combined SemiGas and Matheson/Nippon Sanso sales would equal 44.4 percent of the U.S. market for gas cabinets. Nippon Sanso's concentration in the industry following the sale would exceed the threshold in the Justice Department's Merger Guidelines, namely 1,800 points on the Herfindahl-Hirschman Index and a change in that index of 50 points.

However, if the the Justice Department's Merger Guidelines were applied to the other bidders, all would be excluded except for the management lead buyout. Purchasers with even the smallest existing North American gas cabinet sales would exceed the threshold because SemiGas has such a dominant market share of a very small market. Dataquest expects Hercules Corp., the U.S.-based parent of SemiGas, to fight the Justice Department's suit, arguing that the Justice Department's Merger Guidelines should not apply for these very reasons.

Indeed, Hercules has a very strong incentive to fight the suit, because a successful challenge by the government is widely expected to result in a much lower selling price. Nippon Sanso's bid, estimated to be $23 million, was well above the second place bid, estimated to be $18 million. In addition, if Hercules must go out for bids again, Dataquest estimates that the current market will not support the price multiples originally bid in April 1990 because of overall market conditions. In

TABLE 1
North American Gas Cabinet Market—1989 (Millions of Dollars)

North American Production	
SemiGas Systems	16.9
Air products	8.8
ASGT/Air Liquide	5.2
SCI	4.0
FloPure/Union Carbide	2.0
Scott Specialty Gases	1.2
Airco/BOC	1.0
Matheson/Nippon Sanso	0.8
Total North America	39.9

Source: Dataquest (January 1991)

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today's market, Dataquest estimates that SemiGas would sell for $12 million to $15 million.

The only potential buyer is the SemiGas management team. The management team faces the problem of putting together a leveraged buyout at a time when banks are avoiding such deals. Dataquest believes that a likely resolution is for an industrial gas company, i.e., Airco, Nippon Sanso, or another semiconductor equipment manufacturer, to take a minority stake in a management lead buyout. It is also possible that Hercules will decide to pull SemiGas off the market.

DATAQUEST CONCLUSIONS

Although the SemiGas sale is relatively small in terms of dollars, Dataquest believes that there are significant ramifications to the Justice Department's suit. First, it is widely recognized that the Committee on Foreign Investment in the U.S. (CFIUS), which is under the Treasury Department and is vested with protecting technology critical to national interest, has lost much of its credibility. Consequently, Dataquest expects high-technology trade policy to be pursued more actively through the Justice Department's antitrust arm and new legislation currently being proposed in Congress.

Second, the government's decision to challenge the sale of high-technology companies will have the downside effect of lowering the competition for these assets. In the case of SemiGas, Dataquest expects this effect to translate into a lower selling price for the company. Hercules is expected to receive $8 million to $11 million less in today's market for SemiGas because of the Justice Department's action. Government policymakers must carefully balance their public policy objectives and the impact of these policies on the market.

Mark FitzGerald

Silicon

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Research Newsletter

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.

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 (March 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 (March 1991)

SEMMS Newsletters 1991 Materials—Silicon

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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.

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, the voltage is applied between the front and back sides of the wafer, and the current flows through the wafer using metal electrodes placed on both sides. Relatively thin doped FZ wafers are used, and 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 CONCLUSIONS

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. The demand for FZ silicon in the Asia/Pacific region is estimated to be small relative to the other regions of the world.

Historically, volume growth of silicon wafers has lagged the 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 seems

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 (March 1991)

reasonable to assume that silicon volume growth rate 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 during the next five years. The high-power segment is estimated to grow even more slowly, at a 5 to 7 percent CAGR. This trend, coupled with the fact that many of the new power transistors will probably use epitaxial films, points to a future FZ market CAGR of less than 5 percent for the 1990-to-1995 time frame.

Mark FitzGerald

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Research Newsletter

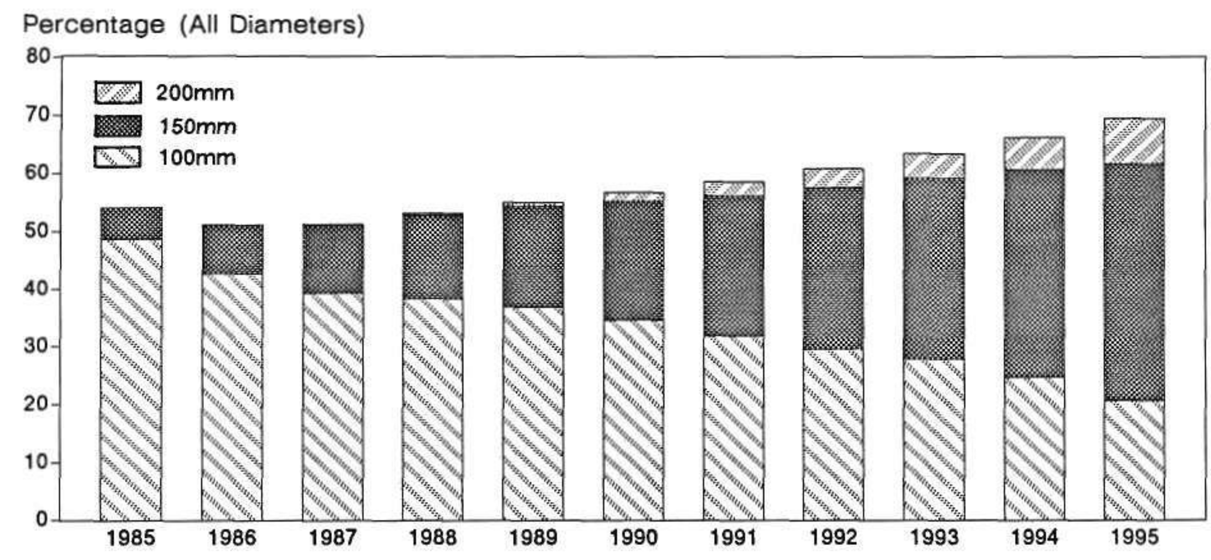
THE DECLINE OF THE 100mm WAFER MARKET

The glory days of 100mm (4-inch) silicon wafers are in the past. The rise of 150mm wafers in the latter half of the 1980s and the current push to 200mm wafers have eclipsed the dominance of 100mm technology (see Figure 1). Dataquest is forecasting the worldwide consumption of 100mm wafer slices to shrink during the next five years at a compound annual growth rate (CAGR) of 6.3 percent (see Table 1). Although the 100mm wafer market is in decline, Dataquest expects worldwide sales to total a healthy 27.80 million slices or roughly $300 million to $400 million in revenue in 1995.

REGIONAL MARKETS

U.S. fabs have the largest 100mm wafer-start capacity, estimated at 18.01 million slices. Moreover, U.S. production capacity is highly leveraged on 100mm wafers; it accounts for 37.6 percent of the total wafer-start capacity (all wafer diameters) in 1991 (see Table 2). The dependence on 100mm wafer technology can be understood in terms of plant investment cycles. U.S. manufacturers invested heavily in new 100mm plants from 1976 to 1984, the peak of 100mm process technology.

FIGURE 1
Worldwide Silicon Wafer Consumption
Percentage of Wafer Starts



Note: Data do not add to 100 percent because 2-inch, 3-inch, and 125mm data are excluded.

Source: Dataquest (February 1991)

Dataquest Incorporated, 1290 Ridder Park Drive, San Jose, CA 95131-2398 / (408) 437-8000 / Telex 171973 / Fax (408) 437-0292

Table 1
Estimated 100mm Silicon Wafer Consumption (Millions of Slices)

	1990*	1991	1992	1993	1994	1995	CAGR (%) 1990-1995
United States	14.67	14.58	15.84	15.38	14.01	13.84	-1.2
Japan	15.01	14.07	13.27	12.54	10.10	6.42	-15.6
Europe	5.80	5.84	6.03	6.30	5.73	4.97	-3.1
Asia/Pacific	3.07	2.81	3.07	3.17	3.29	2.57	-3.5
Total	38.55	37.30	38.21	37.38	33.13	27.80	-6.3

*Actual
Source: Dataquest (February 1991)

Table 2
1991 Fab Capacity (Millions of Slices)

	Total Wafers*	100mm Wafers	Percent 100mm
United States	47.89	18.01	37.6
Japan	65.37	15.86	24.3
Europe	27.61	11.78	42.7
Asia/Pacific	18.79	3.46	18.4
Total	159.66	49.10	30.8

*All wafer diameters
Source: Dataquest (February 1991)

As 150mm technology evolved following the 1984 to 1985 recession, U.S. investment in new larger-diameter plants did not keep pace with the other major regions of the world.

Japanese fabs also have a large 100mm wafer-start capacity, second only to the United States, with an estimated 15.86 million slices. However, unlike the United States, Japanese 100mm wafer capacity accounts for only 24.3 percent of total Japanese wafer-start capacity. Japanese companies invested heavily in 100mm wafer plants from 1976 to 1984 but also continued to invest in new 150mm plants after the 1984 to 1985 recession. The capacity of these larger-diameter plants quickly surpassed the installed 100mm wafer capacity. In addition, Japanese companies have historically been more aggressive in upgrading older fab lines.

European fabs have a smaller 100mm wafer-start capacity than do U.S. or Japanese fabs. Total 100mm capacity is estimated to be 11.78 million slices, in part reflecting a much smaller total semiconductor capacity. Although European 100mm capacity is relatively small, this region, like the United States, is highly leveraged on 100mm wafer technology, with 42.7 percent of its fab capacity dedicated to 100mm wafers. Europe, like the United States, invested heavily in 100mm plants in the 1976 to 1984 time frame. In the latter half of the 1980s, European investment in larger-diameter plants lagged behind the other regions of the world, leaving European capacity exposed to 100mm wafers.

The Asia/Pacific region is the new kid on the block; as such, its semiconductor industry benefited by growing up in the second half of the 1980s, when 150mm technology was widely adopted. Consequently, 100mm fab capacity in this region totals a mere 3.46 million wafers and accounts for only 18.4 percent of wafer-start capacity, the lowest of any region of the world.

Dataquest Conclusions

Many merchant silicon-wafer manufacturers are moving their production out of 100mm into the larger-diameter wafers. The 150mm and 200mm products have better margins, and the larger-diameter wafers are the fastest-growing segments of the silicon wafer market. Yet the demand for 100mm wafers, although declining, is going to persist well into the latter half of this decade.

In the short term, this trend is creating a shortfall in the supply of 100mm wafers. Dataquest anticipates that the supply/demand imbalance will grow more serious through 1993, which we forecast to be the top year in the next silicon cycle. Spot-market purchasers and those semiconductor manufacturers that do not have an established relationship with a wafer vendor are at greatest risk.

In the long term, Dataquest expects prices to edge up 5 to 10 percent per year during the next five years. Dataquest expects the average selling price of 100mm wafers, now $10, to rise to the $13 to $15 range by 1995. The higher prices will be a large enough incentive for some of the smaller wafer vendors to maintain and even add 100mm wafer-production capacity.

Mark FitzGerald

Photoresist

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Research Newsletter

HEALTHY FORECAST FOR U.S. POSITIVE RESIST

INTRODUCTION

In 1990, the number of gallons of photoresist used in front-end semiconductor processing grew 7.7 percent in the United States. The United States was the second largest regional market for photoresist after Japan with sales totaling $97.5 million or 366,700 gallons.

The growth in the U.S. market is attributable to positive-type resists. In 1990, consumption of positive resist totaled 266,600 gallons (see Table 1), an increase of 11.9 percent. The consumption of negative resist totaled 100,100 gallons (see Table 2), a decrease of 2.2 percent. Dataquest expects positive-resist volumes to continue to grow during the next five years; negative-resist consumption is expected to decline.

TRENDS

The average selling price (ASP) for negative resist is estimated to be $95 per gallon. Dataquest expects negative-resist prices to remain flat because they are used in less-critical applications (e.g., discrete devices). Negative-resist prices are largely

TABLE 1
1990 U.S. Optical Photoresist Market—Positive Resist

Company	Gallons (K)	Share (%)	Sales* ($M)
North America			
J.T. Baker	2.2	0.8	0.7
Dynachem	30.0	11.3	9.9
KTI Chemical	19.5	7.3	6.4
Olin Hunt	54.0	20.3	17.8
Shipley	91.0	34.1	30.0
Subtotal	196.7	73.8	64.9
Japan			
Mitsubishi Kasei	0.2	0.1	0.1
Sumitomo	0.5	0.2	0.2
Tokyo Ohka	20.7	7.8	6.8
Subtotal	21.4	8.0	7.1
Europe			
Ciba Geigy	1.5	0.6	0.5
Hoechst	47.0	17.6	15.5
Subtotal	48.5	18.2	16.0
Total	266.6	100.0	88.0

*ASP = $330
Source: Dataquest (January 1991)

SEMMS Newsletters 1991 Photoresist

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Dataquest Incorporated, 1290 Ridder Park Drive, San Jose, CA 95131-2398 / (408) 437-8000 / Telex 171973 / Fax (408) 437-0292

TABLE 2
1990 U.S. Optical Photoresist Market—Negative Resist

Company	Gallons (K)	Share (%)	Sales* ($M)
North America			
Dynachem	8.0	8.0	0.8
KTI Chemical	25.0	25.0	2.4
Olin Hunt	57.0	56.9	5.4
Subtotal	90.0	89.9	8.6
Japan			
Tokyo Ohka	0.1	0.1	0
Europe			
Ciba Geigy	10.0	10.0	1.0
Total	100.1	100.0	9.5

*ASP = $95
Source: Dataquest (January 1991)

set on a cost-plus basis. The estimated ASP for positive resist is $330 per gallon. This figure is expected to increase because consumption of the new higher-priced submicron optical positive resist is forecast to grow faster than the overall positive resist market.

The prices for submicron optical positive resist run in the range of $450 to $500 per gallon. Prices are significantly above the positive-resist ASP because of the increased costs associated with meeting tougher specifications. Resist suppliers are faced with tighter metal and particulate specifications. In addition, semiconductor manufacturers are requiring more uniform performance characteristics of a resist from batch to batch. These trends are driving up the capital investment required to manufacture submicron resist.

At the same time, the volume of resist used per mask step is dropping off significantly because of improvements made in track equipment. Leading-edge track equipment uses 1.5 to 2.0 milliliters of resist per mask level on a 150mm wafer; earlier generations of track equipment typically delivered 4.0 milliliters of resist per layer. New track equipment installation will have the greatest impact on submicron optical resist volumes because the lion's share of new track equipment is purchased for submicron semiconductor processes.

A counterbalance to the impact of reduced dispense volumes is the trend toward more mask layers driven by increasing process complexity and increasing levels of metallization. Devices such as DRAMs and ASICs will have many more masking steps than do previous generations. For example, Dataquest forecasts that the 64Mb DRAM will have more than 25 mask levels (see Figure 1). The increase in mask steps will partially offset the impact of smaller volumes of resist used per layer.

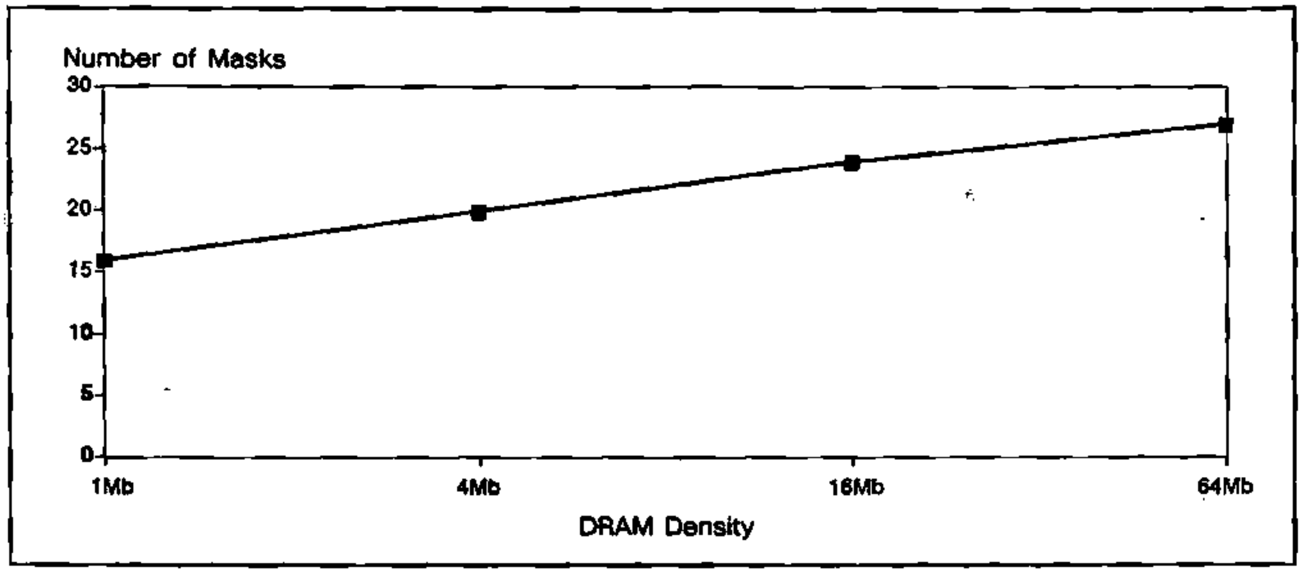
DATAQUEST CONCLUSIONS

Taking into account these trends and using Dataquest's 1991 silicon wafer forecast for the United States, we estimate that the total demand for photoresist in semiconductor front-end processes will reach 534,800 gallons in 1995 (see Table 3). The compound annual growth rate (CAGR) for photoresist will be 10.7 percent from 1990 to 1995. Positive resist will total 442,800 gallons and negative-resist demand will shrink to 92,000 gallons.

North American companies dominate the positive-resist market, accounting for 73.8 percent of the gallons sold. Shipley has approximately one-third of U.S. positive-resist market share. Ranked just behind it are two other U.S. companies, Olin Hunt and Dynachem, and one European company, Hoechst, having shares that fall in the 10-to-20-percent range. Also noteworthy is Tokyo Ohka, a Japanese entrant to the U.S. market, which has won a 7.8 percent share of the positive market since 1987.

North American companies also dominate the negative-resist market, accounting for 89.9 percent of negative resist. Olin Hunt and KTI Chemical own most of the negative market with 56.9 and 25.0 percent shares, respectively.

FIGURE 1
DRAM Mask Levels



Source: Dataquest (January 1991)

TABLE 3
1991 U.S. Photoresist Market Forecast
(Thousands of Gallons)

Volume	1989*	1990*	1991	1992	1993	1994	1995	CAGR (%) 1990-1995
Positive	238.2	266.6	272.0	309.2	366.6	420.6	442.8	10.7
	NA	11.9	2.0	13.7	18.6	14.7	5.3	
Negative	102.3	100.1	98.6	98.2	102.0	95.9	92.0	(1.7)
	NA	(2.2)	(1.5)	(0.4)	3.9	(6.0)	(4.1)	
Total	340.5	366.7	370.6	407.4	468.6	516.5	534.8	7.8
	NA	7.7	1.0	10.0	15.0	10.2	3.5	

*Actual
NA = Not available
Source: Dataquest (January 1991)

However, Dataquest believes that Japanese suppliers will increase their market share over the next five years by targeting the i-line resist market. Japan Synthetic Rubber, Sumitomo, and Tokyo Ohka have been successful in Japan with their i-line products. Dataquest expects Japanese companies to use these resists to gain share in the i-line segment, which will be the fastest-growing area of the U.S. photoresist market during the next ten years.

Mark FitzGerald

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Gases

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Research Newsletter

CALIFORNIA FABS WILL SURVIVE THE DROUGHT

The fifth year of drought in California poses more of a long-term threat to the state's semiconductor industry than an immediate problem for the 66 production fab lines (see Table 1), which currently account for 17.6 percent of the North American wafer capacity. Although the semiconductor manufacturing process is water intensive, Dataquest believes that local water authorities have worked closely with most companies in the past two years to cut their consumption. Most companies will easily achieve current targets. However, the drought is expected to further tarnish California's appeal as a site for future production fabs or expansion of existing fabs.

The water shortage has not affected all areas in California to the same degree. The preponderance of the state's semiconductor fabs are located in Silicon Valley and the Los Angeles basin, two areas that are suffering the most serious shortfall because they import the lion's share of their water. On the other hand, the Sacramento area, where NEC recently built a fab and is planning to expand, is not as severely affected because local sources are more plentiful.

WATER USAGE

Dataquest estimates that a production-scale semiconductor plant uses from one to three acre feet of water a day (an acre foot equals 326,000 gallons). Numerous factors determine an individual plant's usage. Device production levels, the age and design of the water system, and past spending on capital-intensive reclaim programs are a few of the more prominent factors that determine usage.

Although deionized (DI) water is a critical material in the manufacture of semiconductors, the DI water plants located at a fab account for only 25 to 30 percent of the water consumed in that fab. Secondary services such as cooling towers and loops, wet scrubbers, and ancillary services use far more water than does the actual manufacturing process.

TABLE 1
Production Fabs in California by Company

Company	Location
AMCC	San Diego
AMD	Santa Clara Sunnyvale
Avantek	Santa Clara Newark
Cypress	San Jose
ECI Semiconductor	Santa Clara
Exar	Sunnyvale
Exel	San Jose
FEI Microwave	Sunnyvale
Foxboro ICT	San Jose
GI Quality Tech. Corp.	Palo Alto
Gigabit Logic	Newbury Park
Harris Microwave	Milpitas
Holt	Irvine
Hewlett-Packard	Santa Rosa Palo Alto
IC Sensors	Milpitas
IDT	Santa Clara Santa Clara Salinas
IMP	San Jose
Intl. Rectifier	Rancho California El Segundo
Linear Technology	Milpitas Milpitas

(Continued)

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TABLE 1 (Continued)
Production Fabs in California by Company

Company	Location
Litton Microwave	San Jose
LSI Logic	Milpitas
M/A-Comm Phi, Inc.	Torrance
Micrel	Sunnyvale
Micro Power Systems	Santa Clara
Microwave Tech.	Fremont
National Semiconductor	Santa Clara
	Santa Clara
	Santa Clara
	Santa Clara
	Santa Clara
	Santa Clara
NEC	Roseville
Northern Telecom	Rancho Bernardo
Nova Sensors	Fremont
Opto Diode	Newbury Park
Orbit Semiconductor	Sunnyvale
Raytheon	Mountain View
	Mountain View
Rockwell	Newbury Park
Rohm	Sunnyvale
Samsung Semiconductor	San Jose
Semicoa	Costa Mesa
Semtech	Newbury Park
SI-Fab	Scotts Valley
Siemens	Cupertino
Signetics	Sunnyvale
	Sunnyvale
Silicon General	Garden Grove
Silicon Systems (TDK)	Santa Cruz
	Tustin
Siliconix	Santa Clara
Spectra Diode Labs	San Jose
Spectro Labs (Hughes)	Sylmar
TRW	Redondo Beach
Unisys Components Group	Rancho Bernardo
Vitesse Elect.	Camarillo
VLSI Technology	San Jose
Xicor	Milpitas
	Milpitas

Source: Dataquest (February 1991)

The secondary uses of water, which account for 70 to 75 percent of water usage, provide manufacturers an opportunity to reclaim and recycle large volumes of water. Unlike the DI water used in manufacturing processes, the purity of the water used in the secondary services is not critical and can be reclaimed cost-effectively. Because such a large volume of water is used in these secondary services, manufacturers can dramatically lower their water consumption by implementing reclaim programs.

Little opportunity exists to use reclaimed water as a feedstock for the DI water systems. The expense of operating these systems is closely tied to the quality of the water fed to the system. Savings associated with using reclaimed water can quickly be offset by the higher resin usage required to polish a lower-quality feedstock. For this reason, most fabs will continue to use water delivered from the local municipality to supply their DI water plants.

Many semiconductor plants in California have achieved water conservation over the last several years through careful planning. IBM in south San Jose recycles water four to five times prior to discharging it. Cypress Semiconductor has reduced its water consumption by a factor of two since 1987 by upgrading its water system.

LONG TERM

Although Dataquest believes that semiconductor companies are positioned to meet the planned cuts in water consumption for 1991, a statistically unlikely sixth year of drought may well leave some companies scrambling to implement reclaim programs. The gravity of the overall water situation can easily be understood by reviewing the water balance sheet—supply and demand—for Santa Clara County. Santa Clara County encompasses most of Silicon Valley, so the drought's impact on this area is representative of other areas in the state with concentrations of high-tech companies.

The Santa Clara Valley Water District manages the water supply for the county. There are 16 retailers supplying water within the county; 13 of these are city municipalities and 3 are private companies. The Water District's job is to balance the county's supply and demand. The use of imported water must be balanced with the use of local water supplies. In its position, the Water District sets pricing and sourcing policy for the retailers.

The Water District has three sources for imported water—other counties with a surplus of water; the state of California, whose water resources are managed by the Department of Water Resources; and the federal government, whose water resources are managed by the Bureau of Reclamation. Both the state and federal governments are planning to severely curtail their sale of water to Santa Clara County. The county's supply, both local and imported (see Table 2), should just meet demand, assuming a 30 to 35 percent conservation level. The county's forecast water usage in 1991 totals 255,000 to 275,000 acre feet. The forecast usage assumes a 30 to 35 percent savings over 1987 actual consumption. Water consumption in the Silicon Valley peaked in 1987 and totaled 393,000 acre feet per year; consequently, 1987 is used as the base year for the county's planning purposes.

The downside to the worst-case scenario is that two of the largest sources for the county will be depleted. If 104,000 acre feet of ground water are used in 1991, the county will be perilously close to a ground water level at which point ground subsidence begins. In addition, the federal government's sources will be completely depleted except for water levels required to sustain wildlife habitats. If the drought were to continue into 1992, the loss of these two critical water sources would cause a severe shortage, assuming that no other sources are found.

The Santa Clara Valley Water District is pursuing a conservative forecast strategy. However, two wild cards may put the county in a better position than the current analysis might suggest.

First, there is considerable upside to conservation efforts that have not been realized. The shortage could be solved simply by setting strict priorities on water use, recognizing that one-half of water usage in the county goes to landscaping. Second, the county is dumping large volumes of water from water treatment plants into the San Francisco Bay. The water being dumped almost meets drinking-water standards. In the future, this water could be used for most industrial and agriculture applications, provided changes were made in

Table 2
Santa Clara County Water Sources and Use
(Thousands of Acre Feet per Year)

	Normal Entitlement	1991 Estimated Entitlement	1991 Worst-Case
Sources Imported			
Federal Government	152	25-50%	38
State Government	97	15-50%	14
Yuba County	26	100%	26
Hetch Hetchy Reservoir	76	50%	38
Imported Subtotal	351	NA	116
Sources—Local			
Natural Inflow	NA	NA	40
Coyote Canyon	NA	NA	5
Gound Water	NA	NA	104
Local Subtotal	NA	NA	149
Total	NA	NA	265
	Base Year 1987 Actual Consumption	**1991 Targeted Percentage Cuts (%)**	**1991 Targeted Consumption**
Use			
Santa Clara County	393	30-35	255-275

NA = Not available
Source: Dataquest (February 1991)

state laws that currently prevent local water districts from recycling this water.

DATAQUEST CONCLUSIONS

Because water has been so inexpensive to date, Californians have paid little attention to the consumption of this resource. The current drought is expected to force the state to seriously pursue conservation strategies for residential, agricultural, and industrial end users. It is also expected to result in a permanent increase in water prices.

Dataquest believes that it is unlikely that the operations of the state's semiconductor plants will be adversely affected by the drought. Semiconductor companies are at the forefront of conservation efforts. Moreover, significant savings can still be realized by pursuing reclaim programs.

The drought is expected to add to the growing list of reasons that argue against locating future semiconductor production facilities in California. However, Dataquest believes that California will continue its leadership position as the corporate headquarters and research and development center for the North American semiconductor industry.

Mark FitzGerald