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Semiconductor Contract Manufacturing Worldwide—SCMS-WW

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☐	SCMS-WW-DP-9703	May 12, 1997	Semiconductor Contract Manufacturing Wafer Pricing Trends ✓
☐	SCMS-WW-DP-9704	June 9, 1997	1996 Fabless Semiconductor Review ✓
☐	SCMS-WW-DP-9705	June 16, 1997	System-Level Integration ASICs Add Embedded DRAM ✓
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☐	SCMS-WW-MT-9701	September 15, 1997	Midyear 1997 Forecast: Semiconductor Contract Manufacturing ✓
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- SCM/foundry market forecasts
- SCM turnkey services
- Semiconductor market forecasts
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Digital Goes Fabless with Intel as Foundry

Early in the morning of October 27, Digital Equipment Corporation and Intel Corporation announced a peaceful resolution to the intellectual property dispute that led Digital to sue Intel last May and Intel to file a counterclaim in August. The deal includes a 10-year mutual patent cross-licensing agreement; the sale of Digital's Hudson, Massachusetts, semiconductor manufacturing facilities to Intel at net book value; a foundry agreement in which Intel will manufacture Alpha microprocessors for Digital; and an opportunity for almost 2,000 Digital semiconductor employees to become Intel employees. Assuming the agreement passes muster with the Federal Trade Commission, the lawyers representing Digital and Intel will need to find other battles to fight. Intel can redirect its Digital-weary legal warriors toward the Federal Trade Commission theater of operations, where the action continues unabated.

Dataquest views the Digital-Intel agreement as a win for both companies and the industry, and a loss for the lawyers who stood to earn huge sums representing both parties through a complex maze of legal procedures. This document examines why Dataquest believes the settlement will benefit Digital, Intel, and the industry at large.

Digital Goes Fabless

The transfer of Digital's Hudson semiconductor manufacturing facilities to Intel for $700 million allows Digital to focus its Alpha-related investments on the design of future Alpha processors rather than the manufacturing plant needed to build such devices. The company needed to invest in new equipment to keep Alpha competitive, but with only $271 million in semiconductor revenues in 1996, it lacked the scale needed to fully utilize the equipment already in place. This problem would only have gotten worse in the future. At Dataquest's recent semiconductor conference, SEMATECH indicated that it anticipates semiconductor fabs will go for approximately $10 billion (each) by the year 2008. This rising expense will drive all but the largest vendors to operate on a fabless basis. Digital is not the first company to go in this direction, and Dataquest expects it certainly will not be the last.

Intel, on the other hand, should encounter few problems filling the Hudson fab, once it refits the facility to map into its "virtual factory." (All Intel fabs around the world use identical equipment and procedures to assure consistent product specifications, regardless of the manufacturing site.) At the rate it produced microprocessors on a global scale in 1996, it would have taken Intel just 1.7 days to build the 301,000 Alpha processors Digital sold last year. Intel will reconfigure the Hudson fab to produce devices compatible with its P856 0.25-micron manufacturing process. The transfer of the facility at book value will minimize any impact the transaction might have on either company's financial results. This agreement gives Intel access to the highly trained pool of technology workers in the New England area, and it should further boost that region's already strong economy.

Intel also gets the StrongARM program Digital established in Austin, Texas; the PCI Ethernet development group Digital formed in Israel; and the PCI Bridge group in Palo Alto, California. Although Intel has been closely associated with PCI technology over the past few years, Digital drove much of the effort to define the initial PCI standard. Digital's PCI efforts should be easy to integrate with Intel's activities in this area. Digital's StrongARM processor currently forms the core of the Apple Newton Messagepad 2000 product, and it is planned for the next version of Apple's E-mate. Several other vendors are rumored to be developing personal digital assistants (PDAs), cellular phones, and Windows CE-based handheld PCs, which incorporate the chip. The Digital StrongARM design differs from the classic ARM cores that Advanced RISC Machines has licensed to dozens of vendors. Digital was one of the few "architectural licensees" for ARM, and thus the only vendor to provide an enhanced the core; other licensees merely surround the standard ARM core with a variety of peripherals. Digital's version is far more energy-efficient than most other embedded processors, and thus fits well into battery-powered, handheld applications. Digital and Intel will cooperate in attempting to transfer Digital's architectural license to Intel, but this obviously needs the support of Advanced RISC Machines, as well—not to mention the blessing of the Federal Trade Commission, which just might have more than a passing interest in allowing Intel to acquire a potent product targeted at a market it does not already dominate.

A 10-Year Cross-Licensing Agreement

The agreement between Digital and Intel to cross-license each other for 10 years with regard to their respective patent portfolios played a key role in settling the dispute between the parties. It no longer matters whether Intel borrowed Digital's ideas when it designed its Pentium and Pentium Pro processors, although many inside both Digital and Intel, feeling they have been wronged and/or maligned, would clearly prefer an adjudicated solution, regardless of the expenses incurred or the distractions created. It strikes Dataquest that even if such an adjudicated solution had been obtained, it would have done little to assuage the feelings on either side. Today's legal system can offer little beyond Solomon's recommendation to cut the baby in two. Digital and Intel can now focus their not-insignificant resources toward efforts more likely to increase the value of their respective enterprises, instead of the coffers of American Bar Association members.

This cross-licensing agreement will probably ripple through the product plans of many industry participants other than those directly involved. Digital may opt to redirect its future Alpha designs to utilize a bus architecture and pin-out compatible with Intel's planned Merced processor. This would allow Digital to build platforms that could be configured at final assembly to utilize either Alpha or IA-64 processors, thus leveraging the company's development programs and simplifying its logistics, which are key concerns as margins continue to narrow in the computer industry. Should Digital decide to move from the bus protocol it adopted for its 21264 Alpha processor, AMD may need to rethink its own decision to incorporate that bus protocol in its own K7 program. Similarly, Digital's plan to port its 64-bit version of Digital UNIX--descended from the Open Software Foundations (OSF) UNIX--may cause Hewlett-Packard to revisit its decision to focus its own IA-64 efforts on Windows NT, while it leaves its HP UX offering in a PA RISC-compatible mode on the same chip.

A Win for Digital's Customers and the Industry

This agreement should allow Digital's customers to have their cake and eat it too. Those customers already using Alpha technology, and those considering its use, have always sought an answer to the question of how Digital could afford to make the manufacturing investments needed to keep Alpha competitive. Despite Digital's protestations that size doesn't matter when it comes to semiconductor manufacturing, the industry knows better. This agreement puts to rest any questions about the manufacturing process road map that can maintain Alpha's performance. As long as the Alpha design team continues to turn out designs that offer higher levels of performance than Intel delivers with its IA-32 or IA-64 architectures, Digital will have access to the manufacturing resources needed to produce them, and customers using Alpha-based systems will have easy, software-compatible upgrades to faster systems.

If, as some Digital insiders argue, Alpha can maintain its performance advantage over IA-64 far into the future, the architecture can have a long and prosperous life. Conversely, if Intel's IA-64 comes close enough to matching Alpha's superlative performance, and customers cannot justify ongoing purchases of incompatible systems, then Digital will be far better positioned to migrate all its system business to an industry-standard platform.

Last May, when Digital fired its original shots across Intel's bow, Dataquest held little hope that a quick and clean resolution could be achieved in this matter. At that point, we anticipated that the case would "slowly and expensively wend its way through the legal system. This journey [would] ensure full employment for lawyers and force both companies to redirect their intellectual efforts toward the suit and away from more productive activities." We congratulate Digital and Intel on yesterday's agreement, even if it does invalidate a Dataquest forecast. This is one forecast we are glad did not materialize in the manner we anticipated.

By Nathan Brookwood

Dataquest

Perspective

Semiconductor Contract Manufacturing Services Worldwide

Market Analysis

Semiconductor Contract Manufacturing Wafer Pricing Trends: Fall 1997

Abstract: *In Dataquest's second survey of 1997, foundry wafer prices continued to slide, reflecting the abundance of foundry capacity of the past 18 months. Prices for 0.35-micron wafers were hardest hit as that segment of the market heats up and new capacity comes on line. Introductory prices for 0.25-micron wafers are lower than expected. Prices for 1-micron wafers were the exception, continuing a moderate upward trend. Expectations of a return to price stability in the foundry market have been tempered by the recent Asian financial crisis.*
By James F. Hines

Dataquest's Foundry Wafer Pricing Survey

In September, Dataquest conducted the latest of its semiannual surveys of worldwide semiconductor contract manufacturing (SCM) foundry wafer pricing. A large number of SCM users and providers were surveyed and reported prices paid and charged in September 1997 for 150mm and 200mm foundry-processed CMOS wafers. The survey encompassed a variety of process technologies, categorized by minimum feature size and number of metal levels. Participants were also asked to report prices for a number of special processing options, such as tungsten, chemical mechanical planarization (CMP), salicide, and epitaxial silicon. Finally, foundry users and suppliers were polled to obtain a consensus view on the expected changes in wafer prices over the next six months.

March 1997 SCM Wafer Pricing Update

Table 1 summarizes the results of the most recent foundry wafer pricing survey, conducted in September 1997. Participants were asked to report

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(For Cross-Technology, file in the Semiconductor Regional Markets and Manufacturing binder)

prices paid for foundry processed wafers delivered during September 1997, assuming CMOS, unprobed wafers with 13 to 15 mask levels, single-level poly, and no epitaxial silicon. The minimum volume requirement was set at 1,000 wafers per month. The estimated average price is the average of all prices reported, or in cases of small sample size, Dataquest's estimate of the average price. The price range shows the minimum and maximum prices reported.

Dataquest included 0.25-micron wafers in the pricing survey for the first time. This technology is just becoming available and has not yet begun ramping production volumes, but we wanted to get an early indication of the pricing levels for this most advanced technology in the foundry market. The prices reported for 0.25-micron wafers were much lower than anticipated, ranging from $2,500 to $3,000 per 200mm wafer. The low introductory prices are due in part to the competitive pricing environment of the foundry market in general; they are "pulled down" by lower prices across the board.

However, low prices are also a symptom of overcapacity. Although it is too early to make any sweeping pronouncements about the developing 0.25-micron foundry market, it would appear that capacity is coming up ahead of demand. The leading edge of foundry demand is still concentrated at 0.35 micron, with very few designs ready for 0.25-micron production. With the leading foundries realizing the benefit of their accelerated technology learning curve, we may be seeing these now-familiar pricing pressures extended to the next technology generation.

Table 1
September 1997 Foundry Wafer Prices (U.S. Dollars per Wafer)

	150mm Wafers		200mm Wafers	
Technology	Estimated Average Price	Price Range	Estimated Average Price	Price Range
1.0-micron, 2-ML	568	500 to 700	NA	NA
1.0-micron, 3-ML	565	NM	NA	NA
0.8-micron, 2-ML	550	450 to 590	NA	NA
0.8-micron, 3-ML	563	490 to 635	NA	NA
0.6-micron, 2-ML	608	520 to 670	1,215	1,180 to 1,250
0.6-micron, 3-ML	660	500 to 750	1,345	1,230 to 1,500
0.5-micron, 2-ML	716	680 to 790	1,425	1,350 to 1,500
0.5-micron, 3-ML	759	650 to 850	1,483	1,400 to 1,600
0.35-micron, 3-ML	750	NM	1,865	1,550 to 2,050
0.35-micron, 4-ML	NA	NA	2,020	1,700 to 2,200
0.25-micron, 3-ML	NA	NA	2,600	2,500 to 2,800
0.25-micron, 4-ML	NA	NA	2,763	2,600 to 3,000

NA = Not available
NM = Not meaningful
Note: ML refers to number of levels of metal.
Source: Dataquest (October 1997)

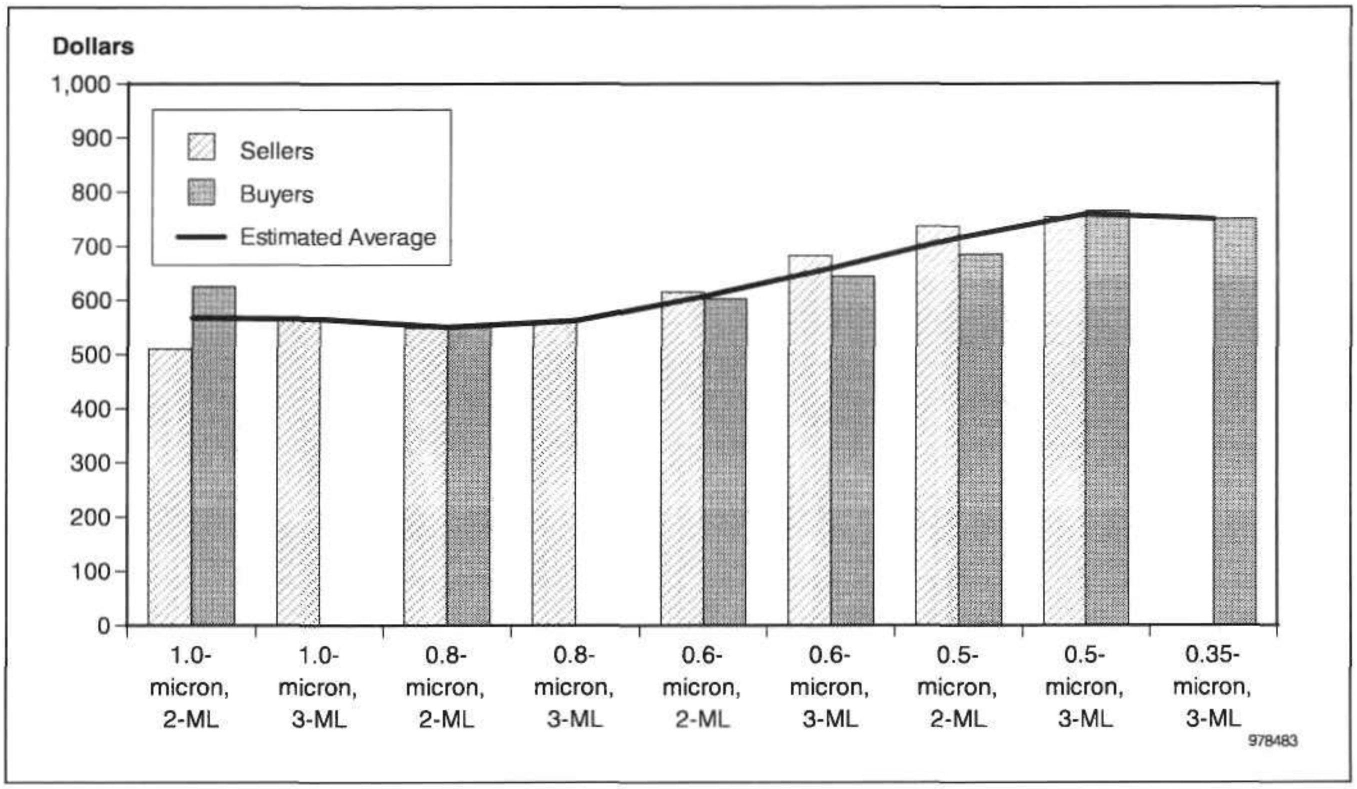
Buyers versus Sellers

Responses of buyers and sellers may differ in a survey of this type, and this difference is shown in Figures 1 and 2. In general, buyers and sellers reported prices that were in fairly close agreement, and when they did differ, sellers usually reported higher prices than buyers. Contrary to our last survey, this trend is consistent with our expectation for a free market, where the "ask" price is slightly higher than the "bid."

The differential in reported prices was greatest at 0.25 micron, which can be interpreted as an indication of a more dynamic pricing environment relative to the other categories. The one category in which buyers reported higher prices than sellers was 1 micron, which also happened to be the only one that showed a price increase relative to March 1997. This could be a reflection of the price stability and slight upward price pressure that exists in this segment of the market.

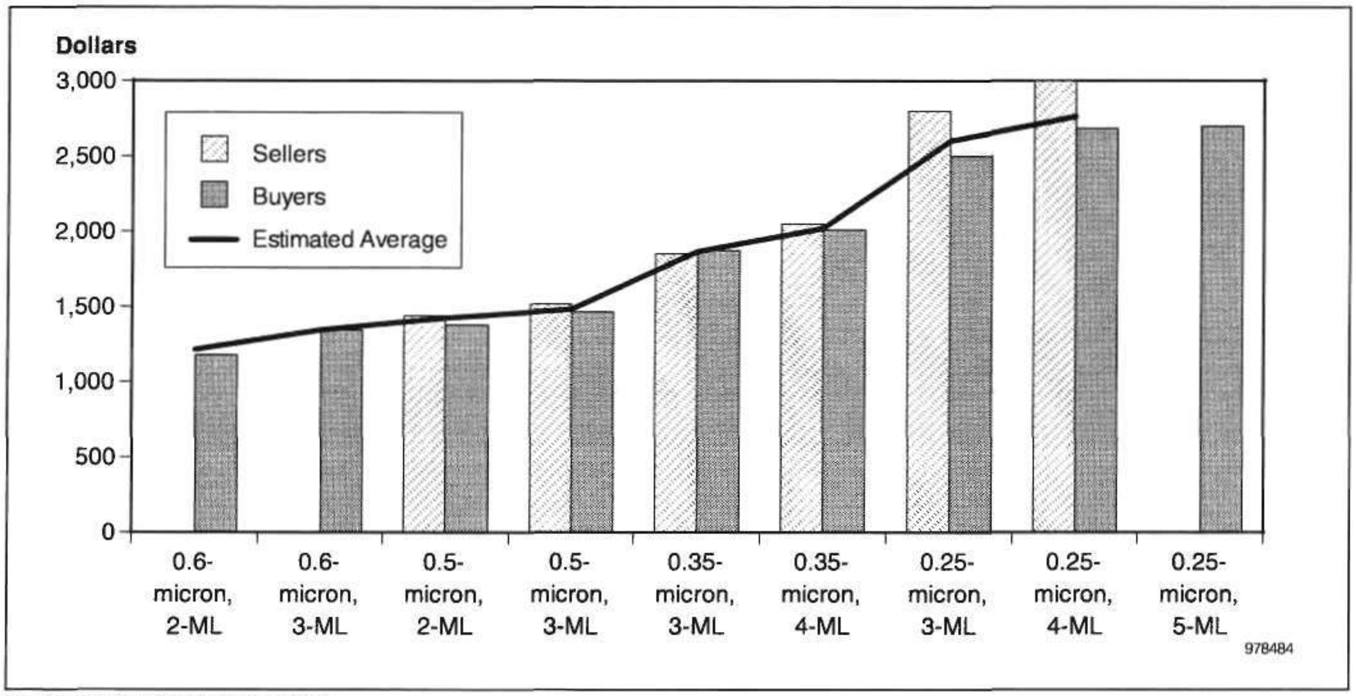
Table 2 compares the average prices reported in September 1997 with those reported in the previous survey of March 1997. Foundry wafer prices have continued to slide during the past six months, reflecting the general overcapacity of the market that has existed since mid-1996. Pricing pressure was greatest in the leading-edge technologies and becomes progressively lighter moving toward the lagging edge. For the second time in a row, prices for 1-micron wafers actually registered an increase over the previous survey.

Figure 1
September 1997 Foundry Wafer Prices: 150mm Wafers



Source: Dataquest (October 1997)

Figure 2
September 1997 Foundry Wafer Prices: 200mm Wafers



Source: Dataquest (October 1997)

Table 2
Change in Average Foundry Wafer Prices—March 1997 to September 1997 (U.S. Dollars per Wafer)

	150mm Wafers			200mm Wafers		
Technology	March 1997	September 1997	Change (%)	March 1997	September 1997	Change (%)
1.0-micron, 2-ML	505	568	12.4	NA	NA	NA
1.0-micron, 3-ML	542	565	4.2	NA	NA	NA
0.8-micron, 2-ML	573	550	-3.9	1,116	NA	NM
0.8-micron, 3-ML	626	563	-10.1	1,283	NA	NM
0.6-micron, 2-ML	641	608	-5.2	1,305	1,215	-6.9
0.6-micron, 3-ML	696	660	-5.2	1,453	1,345	-7.4
0.5-micron, 2-ML	760	716	-5.8	1,547	1,425	-7.9
0.5-micron, 3-ML	793	759	-4.2	1,693	1,483	-12.4
0.35-micron, 3-ML	NA	750	NM	2,347	1,865	-20.6
0.35-micron, 4-ML	NA	NA	NA	2,514	2,020	-19.6
0.25-micron, 3-ML	NA	NA	NA	NA	2,600	NM
0.25-micron, 4-ML	NA	NA	NA	NA	2,763	NM

NA = Not available
NM = Not meaningful
Note: ML refers to number of levels of metal.
Source: Dataquest (October 1997)

What's Happening with Leading- and Lagging-Edge Technologies?

Prices for 0.35-micron wafers, which were first surveyed in September 1996, have experienced the steepest decline. Part of this decline can be attributed to the normal progression along the technology life cycle, from the introductory phase to the volume production phase. During the introductory phase, supply is limited and prices remain relatively high, while demand comes primarily from those users that need the performance the new technology offers and are willing to pay a premium for it. It is during this phase that the suppliers' profit margins are highest, and they begin to recapture some of their large investment in the new technology. For 0.35-micron foundry suppliers, this phase may have been cut short by aggressive capacity expansion and intensified competition brought on by a general overcapacity in the industry.

A look at the current supply and demand situation for 0.35-micron foundry wafers shows what is, in fact, a pretty healthy market. Based on Dataquest's recent analysis of foundry supply and demand for 0.35-micron wafers, capacity and demand are both ramping steeply as new fabs come on line and foundry users bring 0.35-micron designs to production. Even after accounting for the unfortunate loss of United Integrated Circuits Corporation 's 0.35-micron fab to fire last month, supply still leads demand by about four months. This is a market in a healthy state of growth, characterized by relatively high factory utilization rates and a competitive pricing environment, as evidenced by the price trends shown in this document.

An interesting exception to the downward price trend is seen at 1 micron. After reaching a minimum in September 1996, prices for 1-micron wafers have been steadily rising. Again, a logical explanation may be found by considering the position of 1-micron foundry wafers in the technology life cycle. Relative to the other technology categories surveyed, 1 micron represents the "lagging edge," and it is now making the transition from volume production to the sunset phase, which is characterized by lower volumes and higher prices.

A contributing factor may be the changing mix of large and small buyers of 1-micron wafers. It is likely that many of the larger companies that consumed the highest volumes of 1-micron wafers have moved on to more advanced technologies, shifting the mix toward the lower-volume users. Because price is determined in part by volume, a market made up of lower-volume users will result in higher average selling prices.

Special Process Option Pricing

Prices for special processing options are shown in Table 3. These are processes outside the standard process flow that normally involve an additional cost. As noted in the previous report on wafer prices ("Semiconductor Contract Manufacturing Wafer Pricing Trends," SCMS-WW-DP-9703, May 1997), tungsten, salicide, and CMP processes are becoming standardized, at least on 200mm wafers, as indicated by the minimum price of zero for these options. These processes are becoming part of the standard process flow for advanced technologies, which are predominant at the 200mm wafer size.

Table 4 compares average special process option prices in this survey to the previous survey of March 1997. Contrary to the trend in wafer prices, process option prices generally increased, with only a few, relatively moderate, declines. The results are mixed, with prices for tungsten and salicide increasing on 150mm wafers while they decreased at 200mm. This difference could be a further indication of the standardization of these options in the advanced process flows of 200mm wafers. Prices for epitaxial silicon showed the opposite trend, increasing at 200mm, with a slight decrease at 150mm. This pricing behavior can most probably be attributed to the effect of supply and demand dynamics within the silicon wafer market.

Table 3
September 1997 Foundry Wafer Process Option Pricing (U.S. Dollars per Wafer)

	150mm Wafers		200mm Wafers	
Process Option	Estimated Average Price	Price Range	Estimated Average Price	Price Range
Tungsten (per Level)	32	NM	30	0 to 50
Salicide	70	50 to 100	74	0 to 120
Epitaxial Silicon	65	44 to 85	149	102 to 250
CMP	52	48 to 58	52	0 to 100
Additional Mask Levels (above 15)	60	50 to 74	102	60 to 140
Polysilicon (above One Level)	83	50 to 150	120	60 to 150

NM = Not meaningful
Source: Dataquest (October 1997)

Table 4
Change in Average Foundry Wafer Process Option Prices—March 1997 to September 1997 (U.S. Dollars per Wafer)

	150mm Wafers			200mm Wafers		
Process Option	March 1997	September 1997	Change (%)	March 1997	September 1997	Change (%)
Tungsten (per Level)	28	32	14.3	31	30	-3.2
Salicide	60	70	17.0	77	74	-3.3
Epitaxial Silicon	66	65	-1.9	123	149	21.4
CMP	44	52	18.2	49	52	5.4
Additional Mask Levels (above 15)	58	60	2.6	108	102	-5.3
Polysilicon (above One Level)	74	83	12.2	120	120	0

Source: Dataquest (October 1997)

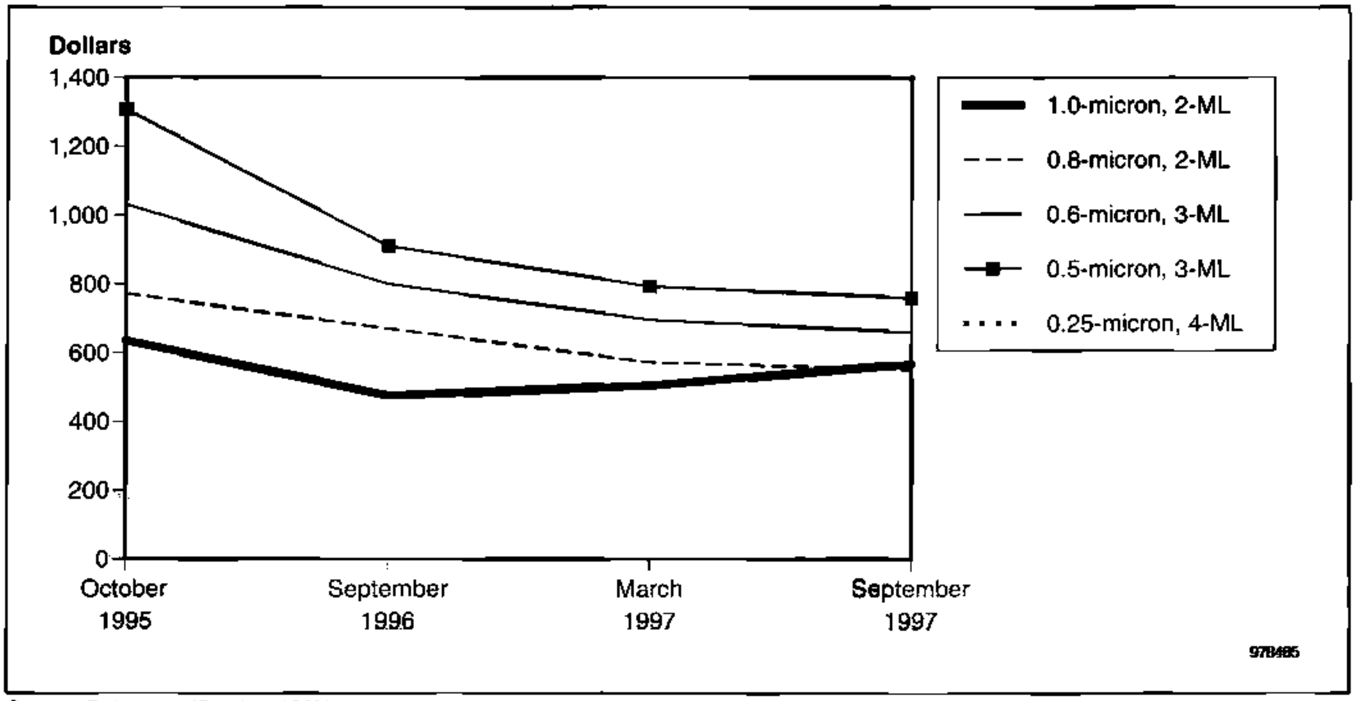
Outlook

Wafer pricing trends over four surveys covering a period of two years are shown in Figures 3 and 4. Selected technology categories for 150mm and 200mm wafers are plotted. The 0.25-micron technology makes its first appearance on the far right side of Figure 4. The downward price trend in all segments of the foundry market is clearly evident in both figures. Also, the rebound in prices of 1-micron, 150mm wafers can be seen in Figure 3.

The downward movement in prices over this period is the direct result of the imbalance of capacity and demand in the foundry market. In predicting pricing behavior, changes in the relationship of supply and demand for foundry services must be considered.

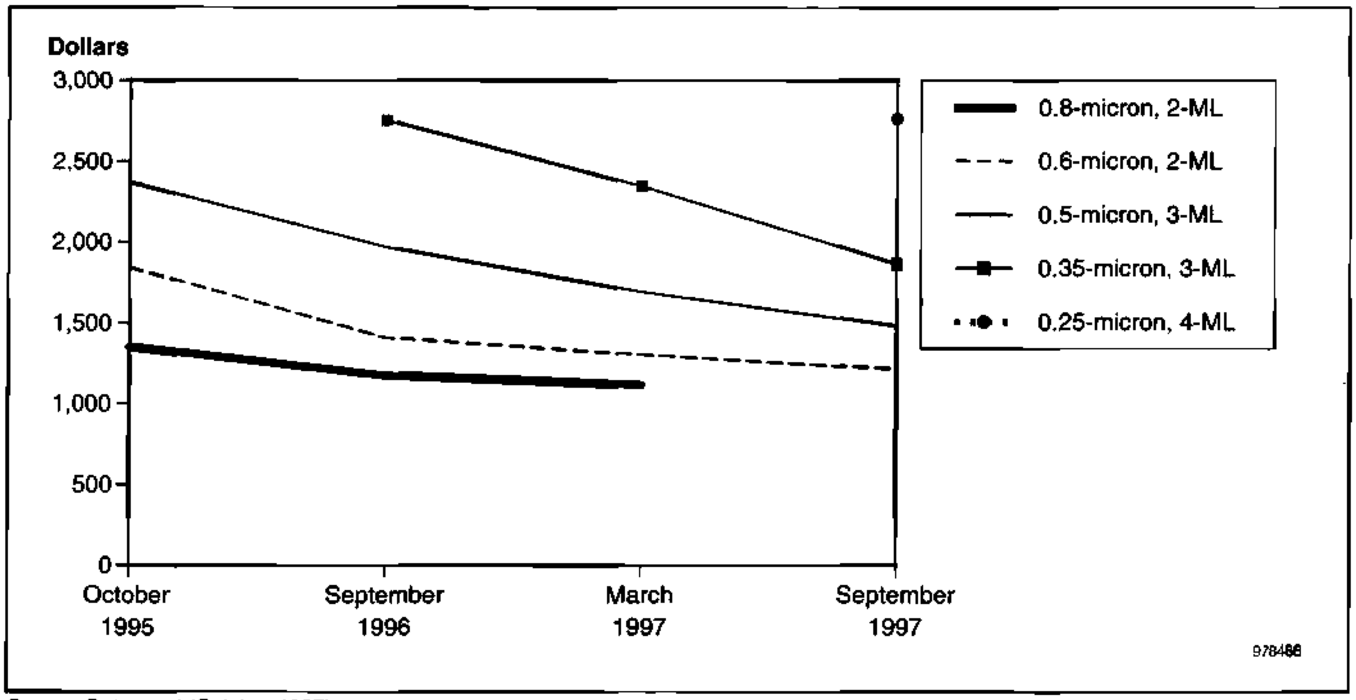
Survey participants were asked to predict the movement of foundry wafer prices over the next six months for 0.5-, 0.35-, and 0.25-micron wafers. Table 5 summarizes the results of this polling. In the last survey, six months ago, everyone predicted lower prices in all segments, the difference lying in the degree of the expected declines. This prediction proved to be pretty accurate. This time, there is more variation in expected pricing behavior, and the magnitude of the changes is much smaller.

Figure 3
150mm Foundry Wafer Pricing Trend



Source: Dataquest (October 1997)

Figure 4
200mm Foundry Wafer Pricing Trend



Source: Dataquest (October 1997)

Table 5
Expected Change in Foundry Wafer Prices over Next Six Months (Percent)

Median Response	0.5 Micron	0.35 Micron	0.25 Micron
Buyers	-5.0	6.3	-2.5
Sellers	-2.5	0	2.5
Combined	-5.0	6.3	0

Source: Dataquest (October 1997)

Update: Asian Financial Crisis

Since this survey was conducted, turmoil has erupted in the financial markets of several Asian countries. The South Korean government has admitted that some outside help will be needed to address the massive liquidity crisis in that country. The International Monetary Fund (IMF) is reportedly working out a plan to provide assistance in the range of $65 billion to $70 billion to Korea and other countries in the region. The Japanese banking system, deeply connected to the emerging industrial economies of these countries, is feeling the strain. The closing of the fourth-largest securities firm in Japan because of lack of liquidity is certainly cause for concern. Meanwhile, the currencies have continued to depreciate relative to the U.S. dollar. Since the beginning of the year, the currency of South Korea has depreciated 20 to 25 percent, Taiwan about 16 to 20 percent, and Japan about 10 percent, relative to the U.S. dollar. How will these events affect the outlook for foundry wafer prices?

Most of the foundry companies located in the region find the bulk of their customers in the United States, with sales denominated in U.S. dollars. The depreciated local currency will have the effect of lowering manufacturing costs relative to revenue, providing these companies with a "cost holiday" and associated improvement in gross margins. Taiwan Semiconductor Mfg. Co. has already released a forecast stating that its gross margins are increasing in a growing market. This advantage will be short lived, however, as other foundries, notably LG Semicon Co. Ltd., seize the opportunity to take business through pricing. LG Semicon and other Korean companies have the capacity, need the cash, and are motivated by the separation in the valuation of the Taiwan dollar versus the Korean won. Dataquest expects this competition to result in another wave of foundry wafer price reductions.

Dataquest Perspective

The results of the current wafer pricing survey are consistent with expectations based on our understanding of capacity and demand in the foundry market. Pricing pressure continues across almost all technology segments, with the greatest pressure in the leading-edge technologies. The sweet spot of the market remains at 0.5 micron, with 0.35 micron ramping up production volumes the most quickly as fabless companies move more of these designs into production. The introduction of 0.25-micron foundry wafers at very low prices (in historical terms) suggests that the current competitive pricing environment will be extended to the next technology generation. Meanwhile, the second consecutive increase in prices of 1-micron wafers is an indication that this technology is moving into the "sunset" phase, with declining volumes and stable prices.

Over the next six months, the most dominant influence on foundry wafer prices is likely to be the depreciation of currencies in Korea, Taiwan, and, to a lesser extent, Japan. The lower cost structures resulting from the new currency valuations are expected to spur another round of price cutting by foundry suppliers, led by foundries in Korea, where the currency has depreciated the most. This factor, combined with ample capacity for foundry wafers, particularly for leading-edge technologies, will result in continued downward pressure on wafer prices.

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A Gartner Group Company

Perspective

Semiconductor Contract Manufacturing Services Worldwide

Vendor Analysis

Amkor Wafer Fabrication Services

Abstract: *Amkor/Anam, the world leader in semiconductor assembly and test contract manufacturing, is entering the front-end foundry market. Through a technology agreement with Texas Instruments, the company is bringing up a new wafer fabrication facility in Buchon, Republic of Korea, that is expected to start production of 0.35-micron logic ICs in early 1998. This move reflects a growing trend toward integration in semiconductor contract manufacturing, and positions Amkor Wafer Fabrication Services as a high-value turnkey supplier.*

By James F. Hines

Corporate Management

Chairman, Amkor/Anam	Jim Kim
President, Anam Semiconductor Ltd.	In Kil Hwang
President, Amkor Assembly and Test Services	John Boruch
President, Amkor Wafer Fabrication Services	Eric Larson
Vice President of Marketing, Amkor Wafer Fabrication Services	John Weekly

Company Overview

As shown in Figure 1, Amkor/Anam consists of two companies with a common management structure: U.S.-based Amkor Electronics and Anam Industrial Co. Ltd. of Korea. Amkor is a privately held company providing assembly and test services to the worldwide semiconductor industry. Anam Industrial Co. Ltd. has been traded on the Korean stock market since 1977, and it is a diversified company with businesses in many industrial and electronics markets.

Dataquest

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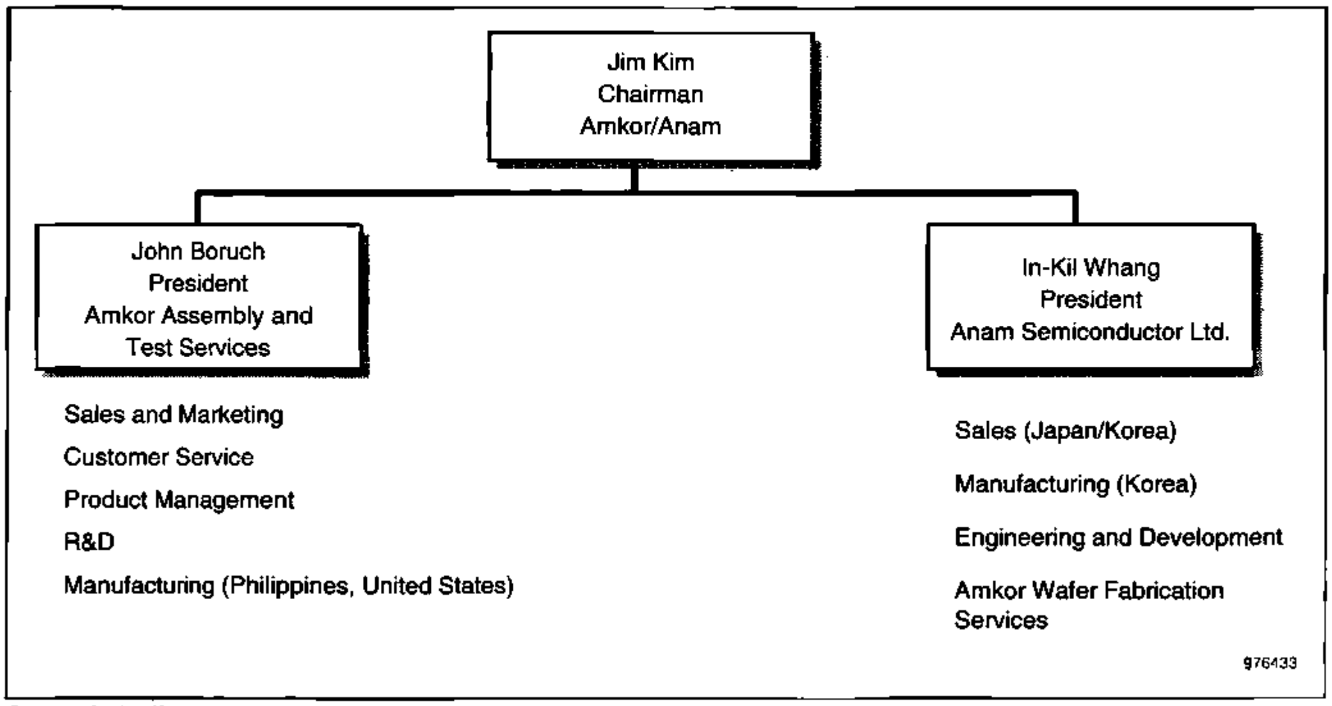
Figure 1
Amkor/Anam Semiconductor Business Group Organization



Source: Amkor/Anam

Established in 1968, Amkor is the leading supplier of IC packaging and test services to the semiconductor industry, with 33 percent of the worldwide market, according to its estimates. By working closely with customers to understand their requirements and developing innovative IC packaging solutions, Amkor has built a successful business and positioned the company as the technology leader in advanced semiconductor packaging.

Anam Industrial Co. Ltd. was founded in 1956. The company has several business units in such areas as construction, telecommunications, and electronics. In 1968, Anam Industrial became the first company to establish a semiconductor manufacturing services company in Korea. Since then, semiconductor manufacturing has played an increasingly important role in the company's business strategy, and IC assembly and test now represents over 50 percent of Anam Industrial's revenue. The companies of the Amkor/Anam Group and their respective areas of business are shown in Table 1.

Company Strategy

The key elements of Amkor/Anam's stated management strategy are as follows:

- Provide customers with turnkey IC manufacturing solutions
- Aggressively expand IC packaging capacity, services and technology
- Enable advantages in product quality, price, and delivery

- Develop empowered leadership in IC packaging development
- Create customer, supplier, and end-user alliances
- Capture increasing market share through high value-added services and products

Table 1
Amkor/Anam Group Companies

Company	Business
Amkor Wafer Fabrication Services	Wafer foundry
Anam/Amkor Korea Amkor/Anam Philipinas Amkor USA	Semiconductor assembly and test
Anam Semiconductor and Test	Lead frames, test, and design services
Anam/Photronics Joint Venture	Photomasks
Anam Instruments Amkor/Anam Precision Machine	Precision tool
Acqutek Corporation	Semiconductor materials
Anam Electronics Korea National Electric	Electronics
Anam Telecom	Telecom
Anam Engineering and Construction	Construction

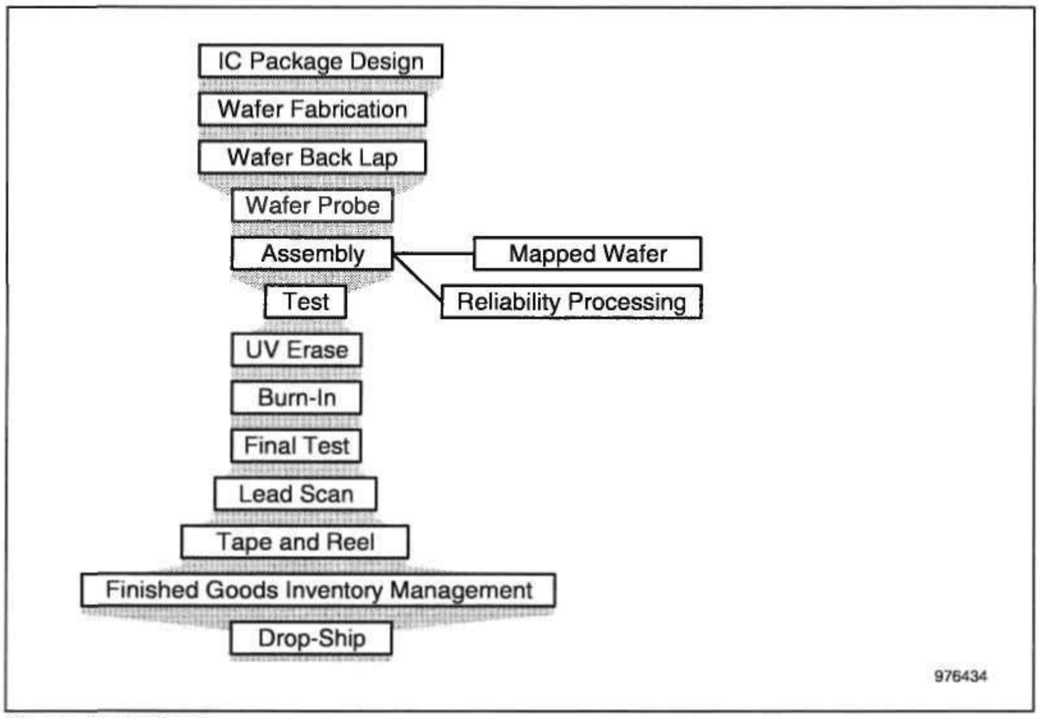
Source: Amkor/Anam

Amkor/Anam's entrance into the wafer foundry business is a realization of several of the ideas contained in this strategy; namely, to provide customers with a turnkey solution, to create alliances, and to provide high-value-added services. In September 1996, Amkor/Anam and Texas Instruments Inc. announced a long-term cooperative agreement for the production of wafers for advanced logic semiconductors. At that time, Amkor/Anam chairman Jim Kim said, "Today's agreement allows us to fulfill a long-term vision to provide turnkey services, from design to wafer fabrication to assembly and test." The elements of the company's vision for turnkey semiconductor contract manufacturing are shown in Figure 2.

Turnkey Semiconductor Contract Manufacturing

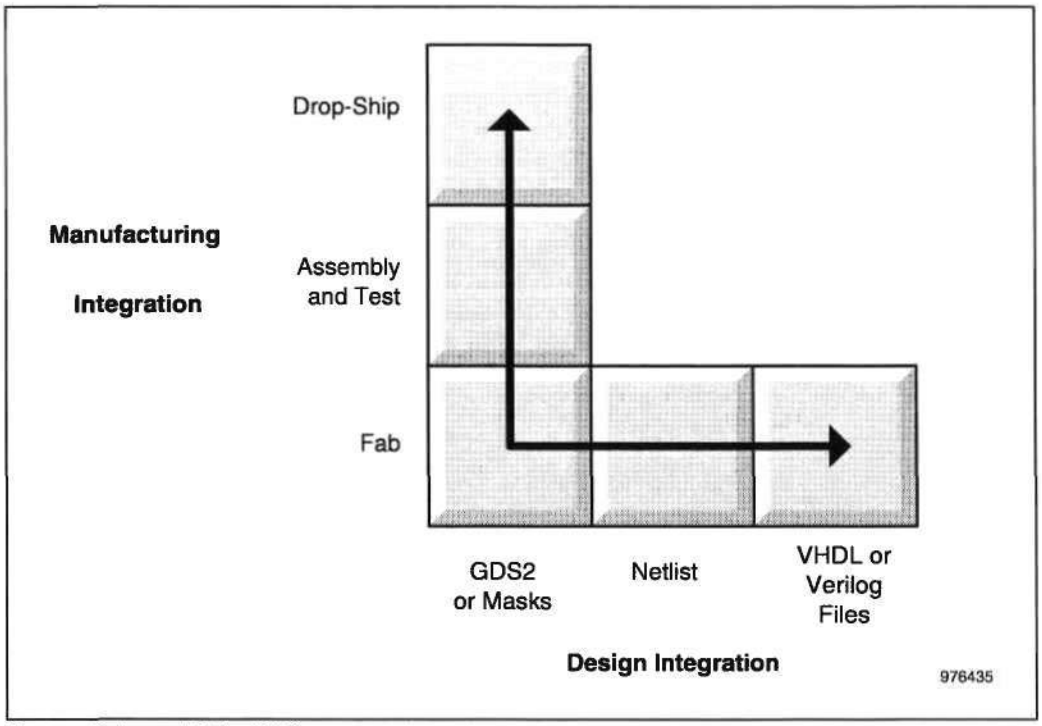
Amkor/Anam's entrance into the foundry business reflects a growing trend toward integration in semiconductor contract manufacturing. Early participants in the semiconductor contract manufacturing market had relatively simplistic product and service concepts. They offered to manufacture wafers for fabless or integrated device manufacturer (IDM) customers that provided them with pattern generator tapes or masks. This model has expanded in two different directions. Dataquest describes one strategy as manufacturing integration and the second strategy as design integration. These two strategies are shown in Figure 3.

Figure 2
The Turnkey Solution to Semiconductor Contract Manufacturing



Source: Amkor/Anam

Figure 3
Semiconductor Contract Manufacturing Strategies



Source: Dataquest (July 1997)

Manufacturing Integration

Amkor/Anam, and other semiconductor "back-end" contract manufacturers, are already well positioned to embark on a manufacturing integration strategy. By combining wafer fabrication, or "front-end," manufacturing services with their existing assembly and test operations, they can offer customers a full turnkey solution for IC production. Amkor/Anam has the additional advantages of a strong reputation for customer service and well-established customer relationships. These are valuable assets in the contract manufacturing business that can be leveraged for a successful entry into the wafer foundry market.

Dataquest believes that the turnkey model will be a strong strategy for semiconductor contract manufacturing. We also think that the strongest turnkey suppliers will offer wafer processing through drop shipment of products to end customers. They will take total responsibility for semiconductor manufacturing and logistics for their customers, freeing the customer to focus on designing and marketing their IC products. The turnkey model may well become the predominant model in the foundry industry in the years to come, and companies like Amkor/Anam, Taiwan Semiconductor Manufacturing Co., Chartered Semiconductor Manufacturing Pte. Ltd., and QPL Holdings Ltd. (Newport Wafer Fab Ltd. and Asat Inc.) are at the forefront of this trend. Among these companies, Amkor/Anam is the largest supplier of contract assembly and test services.

Design Integration

The availability of standard design tools and third-party cell libraries has opened another potential avenue for expansion for semiconductor contract manufacturers: the design integration strategy. Here, the interface between foundry and customer occurs at a higher design level than the traditional GDS-2 tape or mask interface. The foundry supplier begins to look like an ASIC supplier. Examples of foundry companies that can provide this service are TSMC and Chartered Semiconductor, through their Tritech affiliate. This service benefits smaller fabless companies that do not yet have the financial resources to acquire their own electronic design automation (EDA) tools and produce their own GDS-2 tapes.

A Partnership with Texas Instruments and a New Foundry

Under the terms of the cooperative agreement with Texas Instruments, Anam Semiconductor agreed to build a new semiconductor wafer fabrication facility with a 6,000-square-meter clean room in Buchon, Republic of Korea. The new facility is financed completely by Anam Semiconductor, with Texas Instruments providing technical assistance to the new company. The companies are exchanging about 250 engineers as part of the project.

Texas Instruments is transferring its 0.25- and 0.35-micron CMOS technologies to Anam Semiconductor for production in the new facility, which is designed for a maximum capacity of 25,000 200mm wafers per month. In return, Texas Instruments will have the right to purchase up to 70 percent of the output of the fab under certain circumstances. The remaining capacity will be available to Amkor/Anam for sale on the worldwide foundry market. Production is targeted for the first half of 1998 and will be predominantly digital signal processor (DSP) chips for Texas Instruments.

The New Fab Is Coming On Strong

Owing in part to Texas Instruments' experience in transferring technology to its many manufacturing partners, Amkor/Anam's fab project is making rapid progress. Some of the significant milestones in the construction and qualification of the new fab are as follows:

- Certification of the clean room was completed 11 months after groundbreaking for the new facility.
- The first wafer start was achieved in 91 days from the certification of the clean room.
- The first lot through the fab (called the "sweeper lot," it goes through every process step) had good yields, and the results correlated well with those of the parent fab, indicating an effective transfer of process technology to the new fab.
- The fab is on schedule to complete qualification by the end of the year, and it is expected to be ready for production in early 1998.

Advanced Logic Process Capability

The deal with Texas Instruments gives Amkor/Anam access to leading-edge semiconductor process technology for fabricating advanced logic ICs. The fab is being brought up on 0.35-micron technology, but the agreement provides for long-term cooperation on 0.25-micron and successive technology generations. Texas Instruments' DSP is an excellent vehicle for proving in the process because it has relatively high performance requirements. Because it is a logic rather than a DRAM process, it will more closely match the requirements of Amkor/Anam's future foundry customers, which will facilitate successful entry into this new market.

Although the present agreement is limited to the DSP logic process, Dataquest speculates that if the partnership proves successful, it might be extended to other technology areas. In this way, Amkor/Anam may have an opportunity to tap into Texas Instruments' considerable library of semiconductor intellectual property (IP). Of particular interest is Texas Instruments' DRAM technology; it is one of only four companies to have a patented DRAM design that employs a trench capacitor in the memory cell. Suppliers that incorporate a trench capacitor design are expected to have a competitive cost advantage in the embedded DRAM system-level integration (SLI) market. Dataquest expects SLI to play an important role in the future foundry market, and this alliance could put Amkor/Anam in a strong position to capitalize on this opportunity. (For a discussion of the advantages of a trench capacitor design in embedded DRAM, see *The Challenge of Embedded DRAM in ASICs: A Manufacturing Economics Point of View*, SCMS-WW-DP-9707, August 25, 1997.)

Dataquest Perspective

Amkor/Anam's strategy of providing turnkey semiconductor contract manufacturing services should be a successful one. Outsourcing IC assembly and test operations is an established practice in the semiconductor industry, and the trend is toward an even greater reliance on contract manufacturing, for both front- and back-end processing. Foundry customers, like those of any other business, are looking for ways to lower their manufacturing costs, and suppliers that can facilitate this by simplifying the whole manufacturing operation are adding real value. These are the companies that will capture the greatest share of the fast-growing semiconductor foundry market.

Texas Instruments is an excellent partner for Amkor/Anam's venture into the world of front-end semiconductor fabrication. Texas Instruments' strength in semiconductor process technology is well known, and this will give Amkor/Anam a firm technology foundation to build a world-class wafer foundry. For many years now, Texas Instruments has successfully pursued a strategy of transferring its technology to manufacturing partners as a means of developing leading-edge capacity while minimizing capital investment. This deal with Amkor/Anam is a perfect example of the execution of this proven strategy. One need only consider the remarkable speed with which the fab is coming on line to appreciate the skill and efficiency of Texas Instruments' technology transfer methodology. Finally, Texas Instruments has a wealth of intellectual property that could greatly benefit the fledgling foundry. While not explicitly included in the present agreement, the potential for further collaboration, especially in the area of SLI, bodes very well for the future of this relationship.

The current liquidity crisis in Korea, and the general volatility of southeast Asian capital markets, are cause for some concern because the fab is being funded solely by Anam Semiconductor. However, the unique structure of this corporation gives it access to U.S. equity markets, and the recent filing by Amkor Technology Inc. for an initial public offering of up to $402.5 million in common shares now seems a clever move indeed. The project is well on its way, with the facility built, equipment installed, and the first lots through the fab, so it appears that it will avoid the financing woes that have recently plagued Alphatec's foundry venture in Thailand, SubMicron Technology. Another possible concern is the current oversupply in the foundry market. This is a relatively short-term issue, and it is mitigated by the fact that Amkor/Anam already has a major customer, Texas Instruments, waiting to use a large share of the fab's capacity for its DSP chips (a product with very strong prospects).

Amkor/Anam is entering a market that holds ample opportunity for the future. It is adopting a turnkey contract manufacturing strategy that Dataquest believes has a very good probability of success. The company has a solid technology partner. It also has a strong customer base and an excellent reputation for technology leadership and service that it can leverage into its front-end foundry business. Although there are risks present in any venture, Amkor/Anam is positioned to emerge as a strong player in the foundry market.

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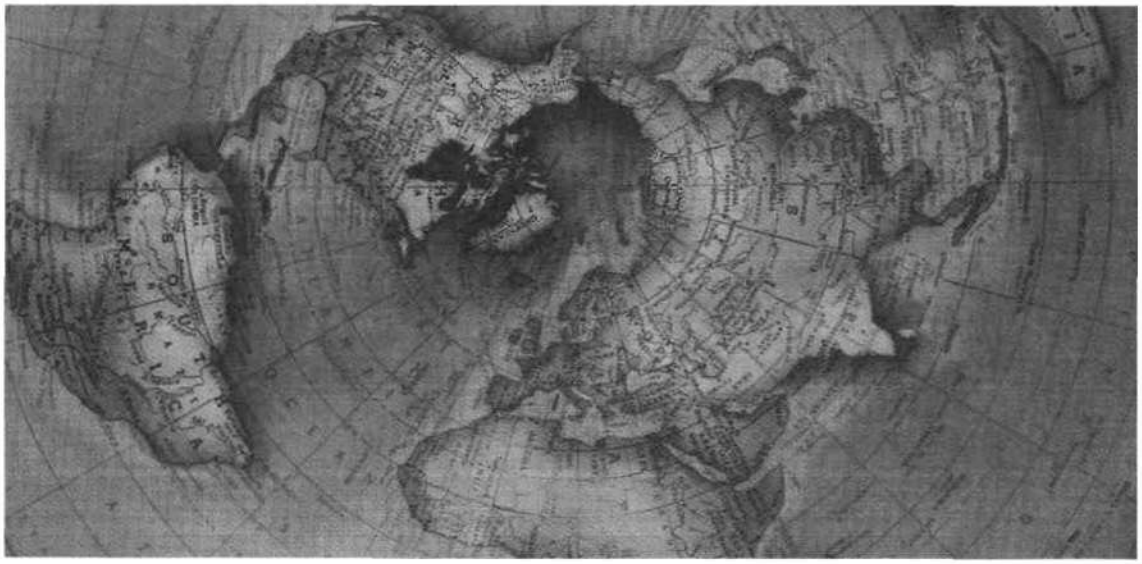
Perspective



Semiconductor Contract Manufacturing Services Worldwide

Vendor Analysis

A Ride Down Intel's Pricing Escalator

Abstract: *For more than 10 years, Intel has lowered its list prices, but the average price for its products, along with its total revenue, keeps increasing. This Perspective sheds light on Intel's pricing strategies and offers an explanation for this apparent paradox.*
By Nathan Brookwood

Revenue Rides Up on a Downward Escalator

Every three months, like clockwork, Intel lowers its prices—usually by amounts ranging from 10 to 25 percent. Often the media seek a sinister motive, usually involving competition, to account for Intel's action. A few Wall Street analysts project the beginning of the end for the company's growth and profitability and recommend quick sales prior to the apocalypse.

Ten weeks later, Intel announces its quarterly results, often (although not lately) exceeding expectations and setting new records. This Perspective sheds light on Intel's pricing strategies and offers an explanation for the apparent paradox of ever-decreasing microprocessor (MPU) prices and ever-increasing MPU revenue—at least as far as Intel is concerned.

The magic behind this phenomenon is deceptively simple. *Despite Intel's price reductions, buyers continue to spend as much as they did before. They just buy faster processors.* Intel prices its PC MPUs from slightly less than $100 at the low end to almost $1,000 at the high end, but all these chips cost about the same to manufacture—between $40 and $80. From Intel's economic perspective, selling a 266-MHz Pentium II for $664 in August of 1997 differs little from selling a 66-MHz 486 DX2 for $682 in August of 1992.

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As shown in Figure 1, the prices for Intel's CPUs fall into eight broad bands. When its development programs hit their targets, every quarter Intel has a new, faster processor to place in the highest band. Its quarterly price reductions merely shift each of the other processors into the next lower price band. The oldest, slowest processor drops off the bottom—and life goes on.

Intel's pricing strategy resembles a conventional escalator running downward. Andy Grove stands at the top, and each quarter puts the latest model MPU on the first step. The escalator slowly descends, taking about eight quarters for the processor on the top to reach the bottom. At this point, the same MPU that set new speed records at its introduction is relegated to the technological trash heap. Figure 2 illustrates the state of Intel's escalator following its recent (November) pricing actions.

If most businesses lowered prices as predictably as Intel, customers would soon notice the trend and redirect their purchases toward the less expensive models capable of providing all the performance they thought they needed just a few months earlier. Two aspects of the current personal computer market minimize this effect. Most importantly, each major increase in computing power permits software developers to tackle new and more ambitious tasks that fully absorb the new level of hardware performance.

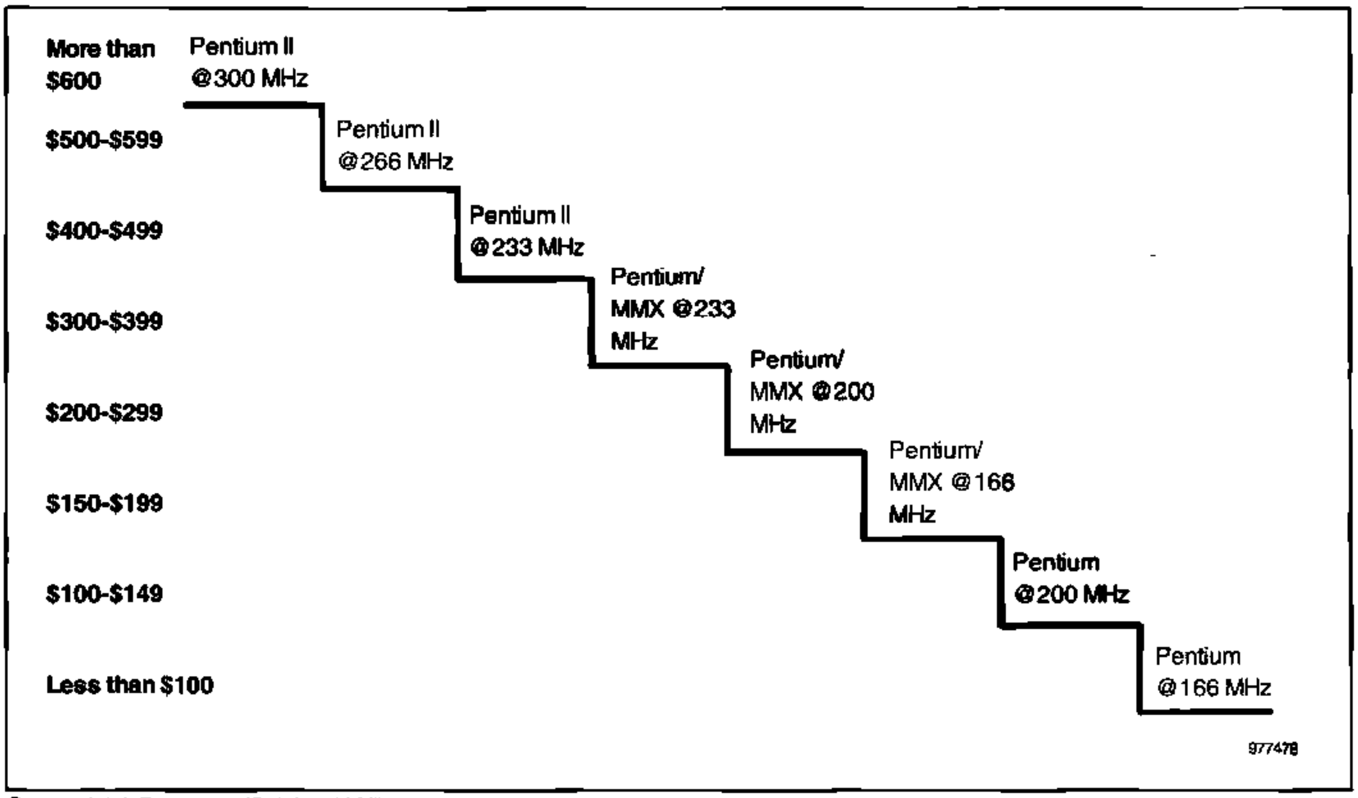
Figure 1
PC MPU Price Bands

Price Band
Above $600
$500-$599
$400-$499
$300-$399
$200-$299
$150-$199
$100-$149
Below $100

977477

Source: Dataquest (October 1997)

Figure 2
Intel's MPU Escalator (November 1997)



Source: Intel, Dataquest (October 1997)

The desire to exploit some program's latest performance-intensive features offsets the purchaser's desire to spend fewer dollars for a constant level of performance. Even the slowest machines available today have more than enough capacity to reformat the largest document or recalculate the largest spreadsheet in the blink of an eye, but even the fastest machines still struggle to process images on the Internet, manipulate 3-D images, or analyze the complex patterns needed to understand natural language.

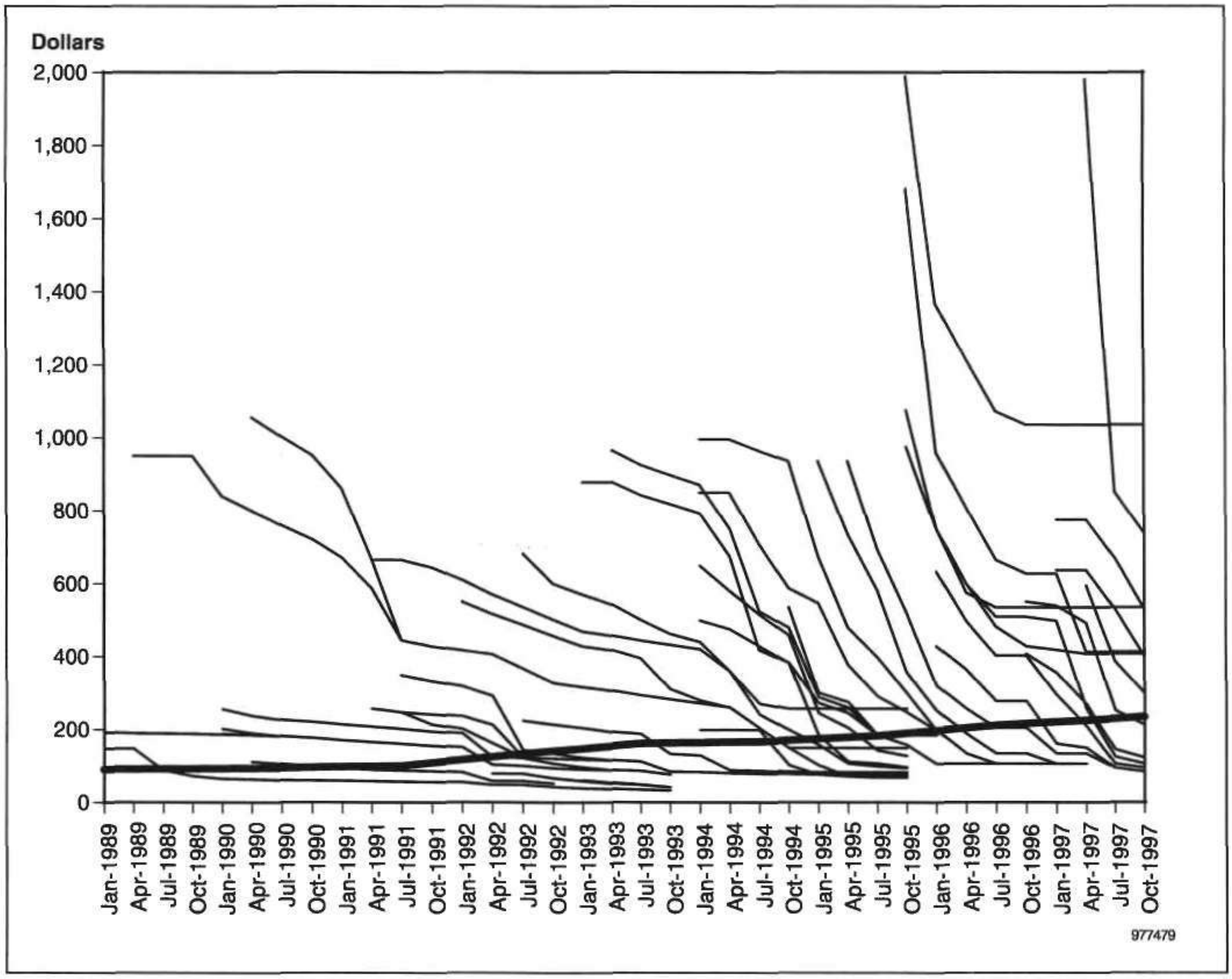
A second factor amplifies the buyer's desire to purchase at a constant or even increasing price level. Although a microprocessor typically accounts for only 10 percent to 20 percent of a system's overall price, it accounts for most, if not all, of the system's performance. The buyer who opts for a $1,000 system instead of a $1,500 system may shave one-third off the purchase price but sacrifices at least one-half of the potential performance. If the user fears that the performance not purchased may have even a minor impact on the user's productivity, the less expensive system loses much of its appeal.

Figures 3 and 4 chart the quarterly price progression of Intel's PC microprocessors since the days of the 386. Most start out at elevated levels, and sink to the bottom of the chart over time. (Figure 4 merely zooms in on the more interesting region below $600.) The prices plotted apply to low-volume (quantity 1,000) purchases. High-volume buyers obviously get large discounts, although Dataquest believes the discount curve has flattened somewhat over the years.

The thick, continuous line near the bottom of each chart represents the calculated average selling price (ASP) derived from our estimate of Intel's MPU revenue and shipments for each period, as shown in Table 1. This figure has doubled over the period, from $91 in 1989 to $235 at the end of 1997. The increase in ASP, accompanied by a huge increase in unit shipments over the period, accounts for the awesome financial results Intel has logged over the past few years. Dataquest would be hard-pressed to cite another market that has experienced dramatic unit growth in the face of increasing ASPs.

When its marketing, development, and manufacturing departments run in synch, Intel's escalator descends at its regular pace of one step per quarter. Occasionally, tactical issues force the company to simultaneously introduce several products in the same price band, as they did last spring when Intel launched its Pentium II series with three versions priced above $600.

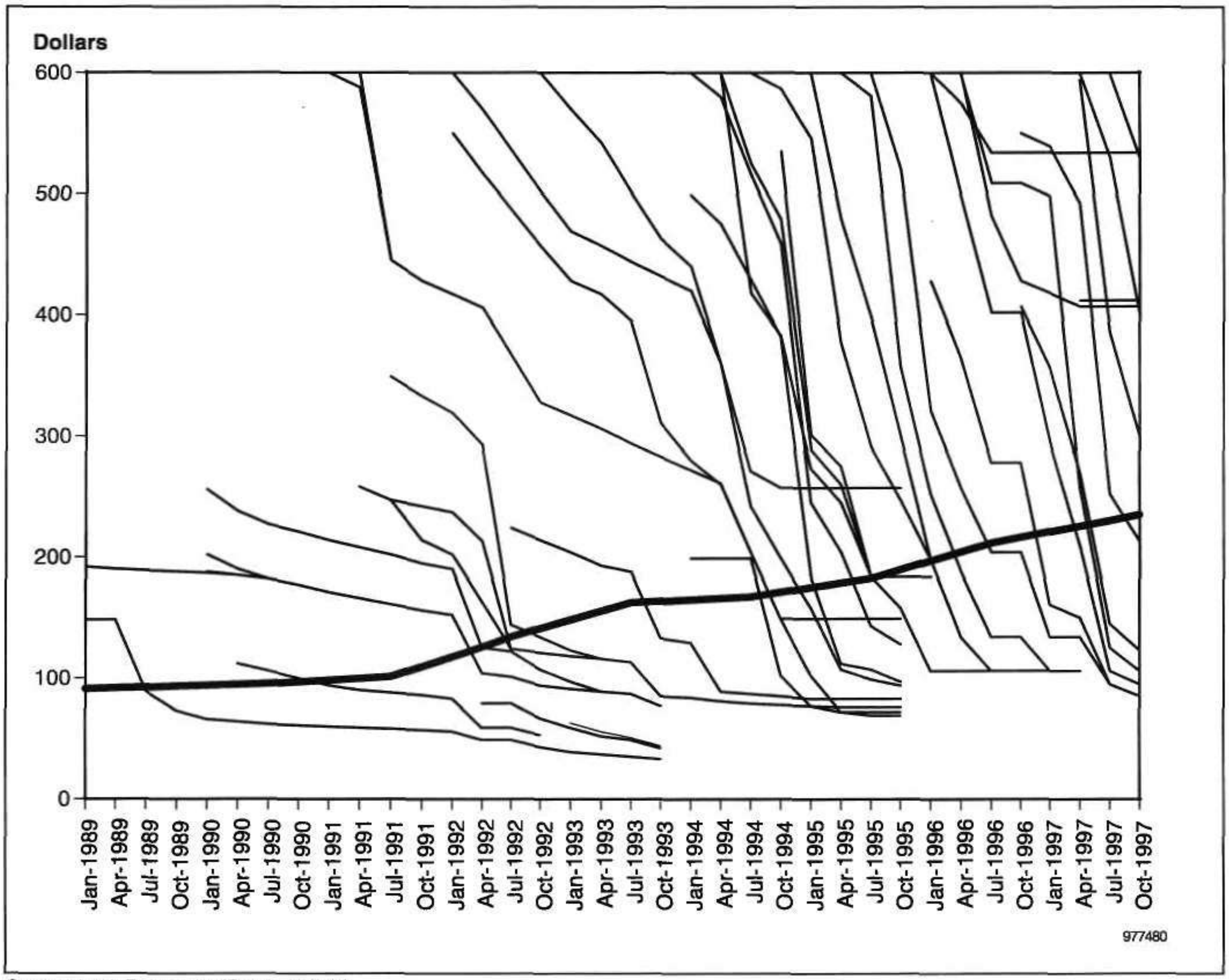
Figure 3
Historic Snapshot of Pricing for Intel x86 Microprocessors, 1989 to 1997 (Dollars)



Source: Intel, Dataquest (October 1997)

Intel then holds off on additional launches until the congestion clears, as it has this fall. A more interesting exception occurred in late spring, when the overwhelming success of the MMX launch caused the market for non-MMX processors to wither. The four lower steps at that point all contained the older non-MMX processors, and under normal conditions, it would have taken a year for these lower bands to cycle out of the market. To keep the products in the proper relative positions, while filling the chasm that had opened at the low end, Intel accelerated the escalator and made all its Pentium products move down two steps in a single quarter. Rather than disrupt the Pentium II line, the company opportunistically inserted a new high-end 233-MHz Pentium with MMX Technology into the gap that it created by shifting the other MMX Pentium products down more rapidly than originally planned. Many stories in the media at that time viewed Intel's moves as a preemptive strike against a developing situation with the AMD K6. Given the limited quantities of product AMD was able to build then, or at any point in 1997, such an explanation seems highly unlikely.

Figure 4
Historic Snapshot of Pricing for Intel x86 Microprocessors, 1989 to 1997 (Dollars)



Source: Intel, Dataquest (October 1997)

Why Would Intel Behave in This Manner?

Few observers familiar with Intel's corporate culture would believe that altruism alone causes the company to lower prices in such an aggressive manner. In the semiconductor industry, size matters. Bigger factories produce wafers at lower unit costs than small factories. Smaller geometries produce faster chips and more of them per wafer. To retain its market position, the company must continually reinvest in new equipment, and it must then find homes for its ever-increasing MPU output.

Because it has no competitor from which it can seize meaningful market share, Intel's strategy focuses on increasing the overall market. It depends on rapid increases in processor performance to drive this growth. Faster, more versatile processors can take on a wider variety of tasks and thus attract users for whom computers had previously served no useful purpose. Witness the growth of computer gaming and entertainment applications. Faster processors also tempt those who already own computers in good operational condition to replace those machines, just to speed up their everyday tasks. These two vectors—selling computers to those who do not already own computers, and selling computers to those who already do, form the basis for Intel's marketing strategy. Increased performance at more-or-less constant prices plays a key part in both campaigns.

Dataquest dates the onset of Intel's aggressive market growth strategy to the start of 1992, when Intel dramatically lowered prices for its 386 devices in an effort to obsolete the large base of 286-based AT-style machines in the field. At that point, the ASP for x86 microprocessors stood at $109. One year later, the ASP had grown to $140, and the company staged additional 486 processors at the high end of the price bands. After one more year, ASP had grown to $164, and the current system was fully operational. (The prices charted in Figures 3 and 4 illustrate these moves as clearly as trails in a cloud chamber reveal the presence of subatomic particles.) Intel's actions have resulted in strong PC market growth, which Dataquest estimates will continue in the range of 16 percent to 18 percent into the indefinite future.

Table 1
Intel's 32-Bit x86 Shipments, Revenue, and ASPs, 1989 to 1996

	1989	1990	1991	1992	1993	1994	1995	1996
Shipments (K)	14,749	19,320	29,250	32,600	40,750	50,790	57,422	68,470
Revenue ($K)	1,362,450	1,842,250	2,955,125	4,361,250	6,619,250	8,488,250	10,478,260	14,497,000
ASP ($)	92	95	101	134	162	167	182	212

Source: Dataquest (October 1997)

Is It Time to Add Another Story to Intel's House?

Until recently, Intel's world fit neatly inside a two-story building with a single escalator, which provided more than enough room to comfortably accommodate its growing family. But the company and the market have grown, and the challenge of designing and selling a single product that can span the entire market has increased. Fortunately, the larger market provides opportunities for the company to differentiate its products to service different market segments with differing price sensitivities.

The first signs of this differentiation have begun to appear in the processors Intel targets toward workstation and server markets. Unlike the high-volume desktop market, workstation and server buyers often willingly pay extremely high prices for marginal performance gains. Intel recently introduced a new version of its mature 200-MHz Pentium Pro product with twice the level-two cache of the former model (1MB total), at a price more than two and a half times higher than the earlier 512KB version ($2,675 versus $1,035). The larger cache provides a performance boost in multiprocessor servers, and, even at these prices, the resulting overall system still provides a competitive level of price/performance.

These $2,000 chips will probably not descend to $100 levels over the next few years. Rather, they will decrease in stages to a $500 price point and then disappear. By the end of 1998, the current server-targeted Pentium Pro will be replaced by a similarly priced Pentium II, with bigger, faster caches optimized for workstation and server applications. These in turn will give way to the 64-bit Merced processor a year or two later.

The full extent of the escalator for workstation and server markets has yet to be shown. The number of steps it contains and the rate at which it descends have yet to be determined, but Dataquest anticipates that it will contain fewer steps and move more slowly than its desktop counterpart.

What Does This Mean for Intel's Competitors?

For those who would compete with Intel, the company's fully staged pipeline of future products poses an awesome competitive barrier. Unless the competitor can match Intel's offerings, which roughly compares with walking up a downward-moving escalator, it will eventually be forced out of the market. (Just consider the point where the escalator's steps re-enter its housing at the bottom of the run, and imagine what would happen if the ridges on those steps were as sharp as knives. This fate awaits the competitor that tires.)

Intel achieves some of its performance gains via manufacturing technology improvements and others via architectural improvements. Changes to the manufacturing process (that is, going to smaller geometries) can double a product's performance in the space of a year, but then the benefits fall off rapidly. Major architectural changes (that is, adding new pipelines, more cache, or new instructions) can increase performance by 50 percent to 100 percent but take three to four years to implement.

This means that to compete successfully with Intel on a long-term basis, a company must have at least two processor development teams working on products with staggered introduction dates. Intel has *three*. With its dominant position, Intel controls the rate at which the escalator descends.

Should Intel experience a development program mishap, it can slow the escalator with only a minor impact to its current quarterly economic performance. Competitors have no such option; a misstep on their part may force them to the bottom of the escalator.

Viewed from this perspective, AMD's 1995 acquisition of Nexgen makes especially good sense. Not only did it acquire an almost mature design for a sixth-generation processor (since introduced as the K6), but it also got a second development center, which doubles its design bandwidth and gives it the opportunity to compete with Intel on a long-term basis. If National Semiconductor plans to keep its newly acquired Cyrix division in the computational MPU business, it would do well to add a second MPU development team, possibly out of the remains of the Israeli group that formerly developed National's proprietary MPUs.

The insatiable appetite for computational performance at relatively constant prices fuels the personal computer industry's growth and fills Intel's coffers. Other MPU vendors dream of turning their factories into gold mines, but to date only Intel has combined the development capacity to enhance processor performance on a quarterly basis with the manufacturing muscle and discipline to move these enhanced products from the lab to the consumer in high volumes and on a somewhat predictable schedule. The opportunity still exists for others to share in the profit potential of this marketplace, but they must demonstrate the strength to walk up Intel's escalator if they are to succeed.

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Perspective

Semiconductor Contract Manufacturing Services Worldwide

Technology Analysis

IBM Transfers First Copper Metallization Process into Production

Abstract: ***IBM announced that an advanced 0.20-micron semiconductor manufacturing process using a copper dual damascene process will be transferred into high-volume production at its Burlington, Vermont, facility. IBM will begin shipping commercially available product during the first half of 1998.***
By Ron Dornseif

IBM announced this week that it has completed development of an advanced semiconductor manufacturing process called CMOS 7S, which it reports is the first IC process to be transferred into production using copper metallization. The process was developed at IBM's Yorktown Heights, New York, facility and is the result of a 10-year effort. IBM is producing chips on a small pilot line at Fishkill, New York, but the process will be transferred into high-volume production at IBM's Burlington, Vermont, facility, and IBM will begin shipping commercially available, high-performance microprocessor products in the first half of 1998. The CMOS 7S process will initially appear in IBM's high-end computers but will also be used to make PowerPC chips. Later this year, IBM is expected to introduce its next generation of application-specific IC (ASIC) products, which will also use the CMOS 7S technology.

The CMOS 7S process is a 1.8V, six-level metal, 0.20-micron process (L_{drawn}) with an effective channel length (L_{eff}) of 0.12 micron, which is stated to be the shortest channel-length structure to be publicly reported in the industry. The process can pack between 150 million and 200 million transistors on a single chip.

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Dataquest Perspective

This announcement has generated quite a commotion in the business press and the TV news organizations—much more than one would normally expect of a manufacturing technology issue. The announcement does not mean that semiconductor sales are about to explode or equipment sales are about to ramp up again or that IBM's technical breakthrough will result in a flood of new electronic products to the marketplace. What it does mean is that IBM's technical prowess is again pioneering ways to stay on the cost-performance targets embodied in Moore's law, the strategic technical projections of the industry. The real significance of this announcement is more in what was not said than in what was said; the issue is not simply a material change from aluminum to copper.

More Process Details

Follow-up conversations with Dr. John Kelly, IBM's vice president of Strategy, Technology, and Operations, disclosed additional technical details of the copper technology. The process (see Figures 1 and 2) will go into production using tungsten technology for the local interconnect layer and contact plugs but will use copper technology for all six interconnect layers. The technology uses dual damascene processing. Although the initial production process will not use low-dielectric constant (low-K) intermetal dielectric (IMD) materials, IBM does plan to incorporate low-K IMD materials at a later date.

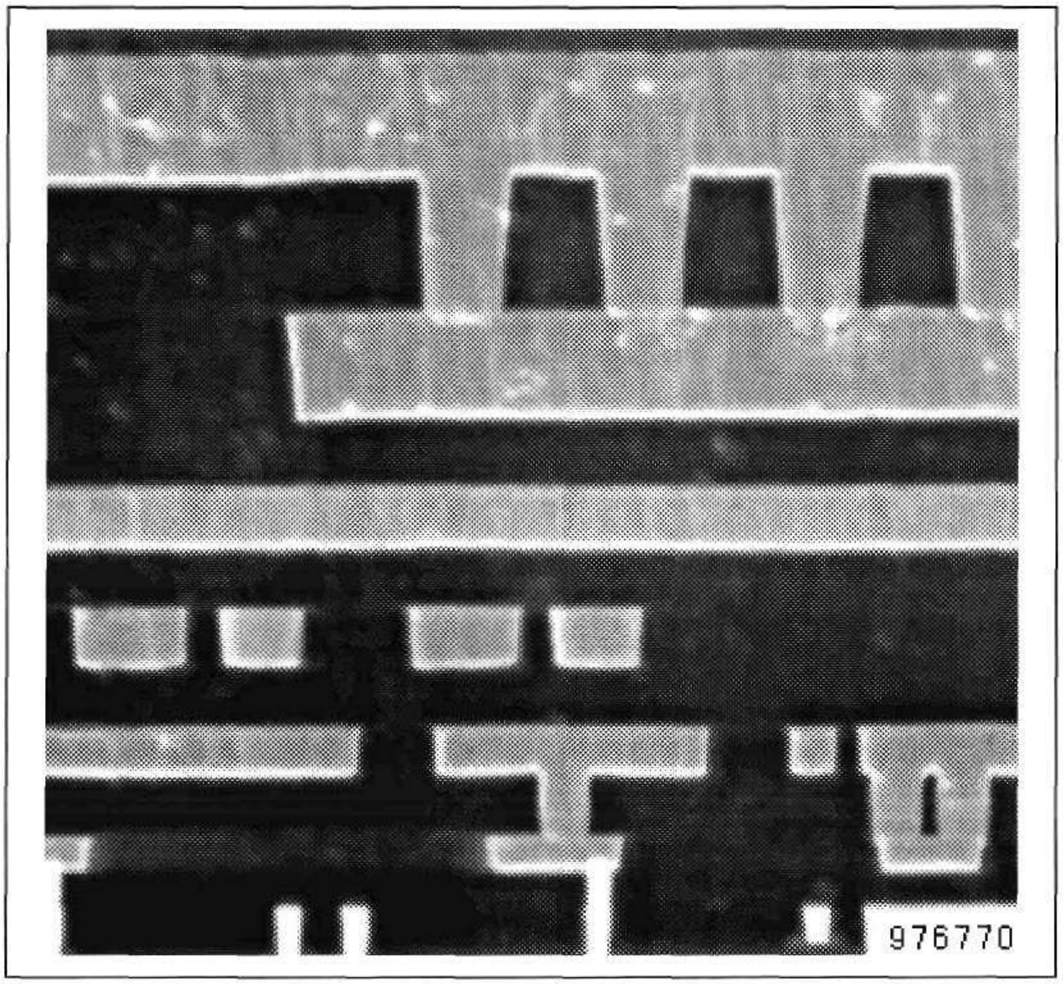
Dr. Kelly considered the technical details of the barrier material(s) and processes, copper deposition methods and equipment, via and trench etch methods, and chemical mechanical polishing (CMP) solutions and methods to be proprietary IBM information. He did, however, comment that the company has been working on this technology for close to 15 years and has evaluated "every feasible way" of depositing copper. IBM firmly believes that the approach it has chosen is "the best available." The barrier materials and their application techniques are critical issues. CMP solutions and techniques are IBM developed. Dr. Kelly also commented that IBM plans to publish additional process details before the end of the year.

IBM has no plans to license the technology to others but has not rejected that option. Several patents exist or are being processed, and other details will be treated as trade secrets. Dr. Kelly believes that IBM is about one to two years ahead of other companies in applying copper to all levels of interconnect. He predicts that some companies will use copper initially for the top one or two layers only, and others will focus initially on low-K IMD instead of copper metallization.

Dataquest Speculation

Based on a review of the scanning electron microscope (SEM) photos provided by IBM and other previously published information about copper process technology, Dataquest is willing to speculate about some of the undisclosed details. We believe the barrier materials are tantalum based, probably tantalum nitride or a combination of tantalum and tantalum nitride in the vias and trenches with plasma silicon nitride as a cap layer, where it also acts as an etch stop for the next via etch. Plasma nitride might also be used to seal the entire wafer from copper contamination before any copper is deposited. Deposition technology probably consists of ionized metal physical vapor deposition (PVD) for the metal barrier, followed by either an ionized metal PVD or a chemical vapor deposition (CVD) copper seed layer. Because the copper via aspect ratios shown in Figure 1 are less than 2:1, a PVD copper seed layer is the likely candidate, at least for these initial geometries. The bulk copper layer is probably deposited by electroplating. Copper CMP is used to "pattern" the copper interconnect, and then the wafer is deposited with a silicon nitride cap layer.

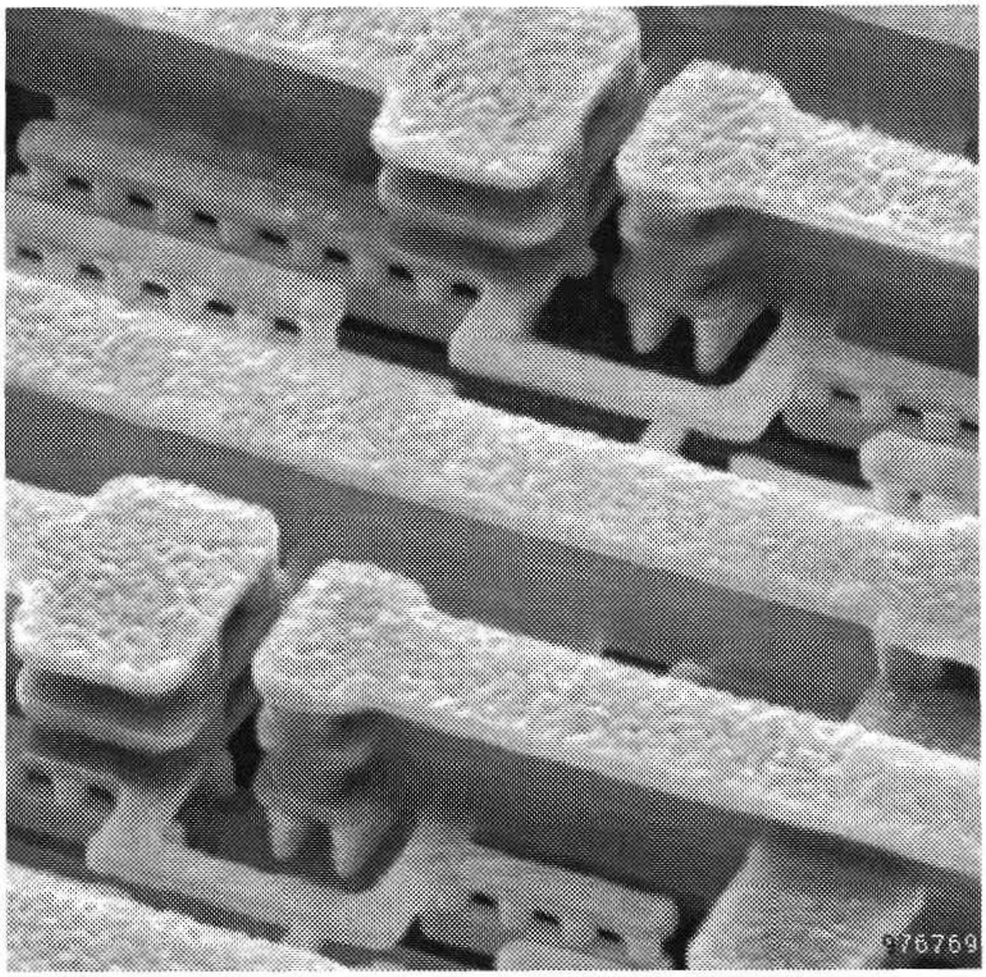
Figure 1
SEM Cross Section of IBM's CMOS 7S Technology with Six Layers of Copper Metallization



Source: IBM

Figure 1 shows exceptional planarization at all levels and the total absence of copper "dishing." Initially, the IMD is likely to be high-density plasma (HDP) CVD silicon dioxide to provide some added margin for CMP control, to minimize integration issues during first production, and to offer an easy transition to HDP CVD fluorinated oxide, if that is IBM's low-K material choice. However, IBM is very experienced with polyimide materials and may choose that approach instead. The dielectric layer is probably put down as a single layer, followed by a dielectric CMP touch-up, if needed. Next, two dielectric litho/etch modules are used first to cut the via and then to etch the interconnect trench using the underlying nitride cap layer over the prior copper layer as an etch stop. These is speculation, of course, and it will have to be seen whether it proves accurate.

Figure 2
SEM Isometric View of IBM's CMOS 7S Technology Showing First Three Layers of Copper Metallization



Source: IBM

Why Change to Copper?

All high-performance logic chips with features below 0.25 micron will need to begin to change their manufacturing processes to copper metallization and low-dielectric constant IMD layers in order to continue to meet the density, power, and speed targets of the marketplace. Most leading-edge semiconductor manufacturers have these new processes under development and will phase them into production between the 0.18-micron and 0.10-micron generations. What is significant is that IBM is the first to do it, continuing a long line of innovative process development necessary to enable this particular breakthrough. Moreover, this milestone is proof that a whole host of complex materials, process integration, and equipment issues have been successfully overcome to produce next-generation, high-performance chips, economically and without loss of chip reliability.

As an example, the 0.35-micron generation of high-performance logic chips has about 12 million transistors connected by more than 0.25 mile of wiring routed on four to five levels of interconnect. By the 0.10-micron generation of designs, industry goals call for over 350 million transistors connected by about four miles of wiring on six to seven levels. During this period, power consumption will double to 160W, and power supply voltages will drop by about one-third, to 1.2V. These demanding requirements must be met economically without loss of chip reliability.

As wiring spaces continue to shrink and the total length of wiring becomes measured in miles, the interconnect propagation delay quickly becomes a serious limitation to increasing the on-chip clock frequency of the semiconductor. Until recently, chip propagation delay was dominated by the CMOS transistor capacitance and load resistance. Because the transistor delay scales about with the channel length, it decreases about 30 percent per CMOS generation. However, interconnect propagation delay increases as more wiring of smaller cross sections is needed and becomes a major problem for the 0.25-micron generation and beyond.

Today's interconnect materials are becoming an unacceptable barrier to meeting industry targets. Lower-resistance (R) metals and lower-capacitance (C) insulators become a necessity. Moreover, shrinking structures stretch the electromigration limits of current metallization schemes; increasing the number of levels of metallization stretches the cost-effectiveness and planarization capability of current structures. Going to copper metallization and new IMD materials with a lower dielectric constant of 2.0 reduces the propagation delay by 60 percent—a 60 percent faster chip. Some IC manufacturers are focusing their new process development priorities on incorporation of new insulating materials, while others are focusing first on the metallization schemes. The fact that IBM is first with copper metallization, however, does not mean that others are behind. Each company can satisfy its next-generation performance requirements with new IMD materials, lower-resistance aluminum structures, or combinations of process techniques, as well as design layout improvements, to be competitive at the 0.2-micron level.

IBM Leads the Way down the Copper Brick Road

IBM, because of its unique set of capabilities, has focused on bringing copper metallization to production first. This is no small accomplishment, because many changes are needed to achieve this. Copper has two major drawbacks: There is no viable etch technology for patterning copper, and copper diffuses easily through many IC materials, quickly contaminating the silicon transistors. These critical issues require new barrier materials and processes to reliably encapsulate copper lines and new methods for patterning copper lines. To get to this point, IBM, over the last 10 years, has had to first create a series of process changes, beginning with a process called damascene to enable tungsten plug technology to give added life to aluminum metallization schemes. It then created CMP technology to provide needed planar surfaces to enable multiple layers of metallization and a further extension of aluminum schemes. IBM then created the dual damascene process, which would enable a viable method for patterning copper lines. Now, IBM has successfully developed an effective barrier material and process to encapsulate the copper reliably and a copper CMP process that can "pattern" copper lines without "dishing." The company has solved a number of sticky integration issues to make the process reliable, production worthy, and cost-effective (reportedly 20 to 30 percent cheaper than IBM's current methods).

Because IBM has indicated that it does not plan to license its technology, does this mean others will not be able to move to copper? No, of course not. There are numerous paths to the same destination, and most leading-edge IC manufacturers have already embarked on their own unique journeys. What is most significant is that the industry now has proof that the destination can be reached and that it is worth the trip.

Dataquest's congratulations to the IBM team for yet another pioneering accomplishment.

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Perspective

Semiconductor Contract Manufacturing Services Worldwide

Event Summary

Capital Spending and Wafer Fab Equipment Midyear Forecast Update: Real Recovery in Progress? Or Is Another Stall in the Works?

Abstract: *Overcapacity in the semiconductor market persists, but recovery is clearly under way. Technology investment continues, but there is a question about when a capacity-driven recovery in the wafer fab equipment market will occur. This document is taken from a telebriefing held by Dataquest on July 11, 1997, concurrent with the release of Dataquest's forecast update on capital spending and wafer fab equipment.*
By Clark J. Fuhs, Ronald Dornseif, James Hines, Takashi Ogawa, and Klaus Rinnen

Opening Statement

The Semiconductor Equipment, Manufacturing, and Materials Worldwide (SEMM) program tracks most aspects of the actual manufacturing of semiconductors worldwide. This document discusses the outlook and forecast for wafer fab equipment and capital spending and presents Dataquest's forecast for silicon wafers, supported by recent demand analysis tied to consumption patterns for semiconductor devices.

Forecast Overview

Dataquest has just released its midyear semiconductor capital spending and equipment forecast, summarized in Tables 1 and 2. The forecast process has several cornerstones, including semiconductor production by region, a worldwide database of existing and planned fabs, and independent comprehensive surveys of the equipment and semiconductor companies. Dataquest has just completed an update of the fab database, and we have scrutinized the planned fab activity worldwide.

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Table 1
Capital Spending Forecast, 1996 to 2002 (Millions of U.S. Dollars)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1996-2002
Total Capital Spending	**44,514**	**40,744**	**44,204**	**54,333**	**77,475**	**90,779**	**89,616**	**12.4**
Percentage Growth	15.1	-8.5	8.5	22.9	42.6	17.2	-1.3	-
Percentage of Semiconductors	31.1	25.4	23.4	22.8	25.7	28.4	23.8	-
Percentage if 300mm Pilot Excluded	31.1	25.0	21.6	21.8	25.5	28.4	23.8	-
Americas	12,668	13,984	16,737	19,820	25,896	29,540	32,199	16.8
Percentage Growth	3.5	10.4	19.7	18.4	30.7	14.1	9.0	-
Japan	10,238	8,775	9,571	11,007	15,483	16,757	17,670	9.5
Percentage Growth	3.3	-14.3	9.1	15.0	40.7	8.2	5.4	-
Europe, Africa, and Middle East	4,627	5,058	5,054	6,466	8,658	9,079	9,905	13.5
Percentage Growth	12.0	9.3	-0.1	27.9	33.9	4.9	9.1	-
Asia/Pacific	16,982	12,927	12,842	17,039	27,437	35,394	29,842	9.9
Percentage Growth	36.6	-23.9	-0.7	32.7	61.0	29.0	-15.7	-

Source: Dataquest (July 1997)

Table 2
Wafer Fab Equipment Forecast, 1996 to 2002 (Millions of U.S. Dollars)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1996-2002
Total Wafer Fab Equipment	**21,684**	**19,612**	**21,007**	**26,442**	**38,149**	**45,030**	**44,560**	**12.8**
Percentage Growth	13.4	-9.6	7.1	25.9	44.3	18.0	-1.0	-
Americas	5,825	6,277	7,234	8,945	11,761	13,116	14,295	16.1
Percentage Growth	10.9	7.8	15.2	23.7	31.5	11.5	9.0	-
Japan	6,650	5,483	5,925	6,880	9,917	10,408	10,566	8.0
Percentage Growth	5.2	-17.5	8.1	16.1	44.2	4.9	1.5	-
Europe, Africa, and Middle East	2,802	2,872	2,932	3,873	5,066	5,265	5,351	11.4
Percentage Growth	18.9	2.5	2.1	32.1	30.8	3.9	1.6	-
Asia/Pacific	6,407	4,980	4,916	6,745	11,405	16,242	14,348	14.4
Percentage Growth	23.3	-22.3	-1.3	37.2	69.1	42.4	-11.7	-

Source: Dataquest (July 1997)

The survey results are one input into Dataquest's several forecasting models, which include analysis of trends in semiconductor production, raw silicon consumption, spending ratios, investment cycles, new fab and fab expansion activity, stepper-to-DRAM price-per-bit analysis, and semiconductor revenue per square inch. Our forecast shows the following highlights:

- The 1997 wafer fab equipment market is essentially on track with the forecast scenario painted at the beginning of the year. Six months ago, Dataquest projected that the first half of 1997 would show sequential strength from the second half of 1996 as chip companies initiated strategic investment plans in leading-edge technology. We also stated that, once these projects were completed with the minimum phase, we would enter a "pause" in growth, because we expected that the overcapacity would not yet be resolved.

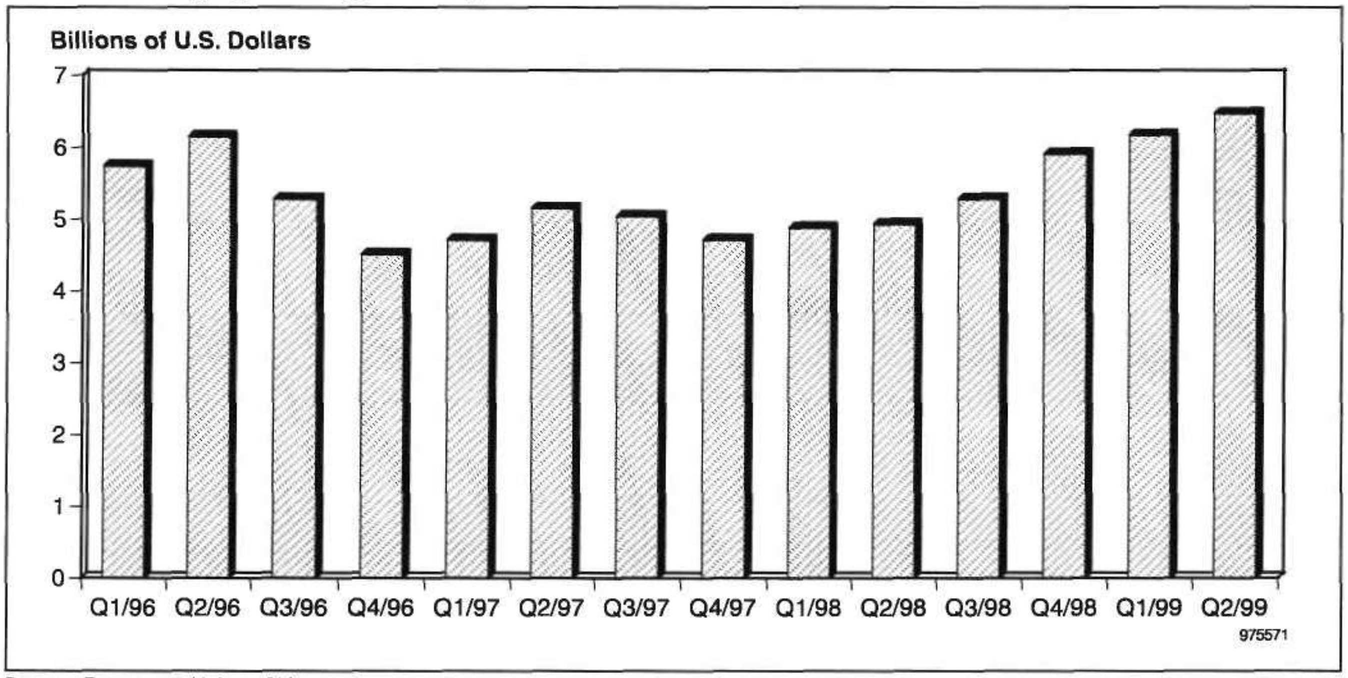
- Indeed, the first-half strength came in slightly better than expected and at the top end of the forecast range.
- As expected, the fundamentals have not changed much in the last six months, and there continue to be several factors that we believe will stall the current momentum in the recovery.
- As a result of the strong first half, Dataquest is adjusting the 1997 wafer fab equipment forecast. A decline of slightly more than 9 percent when compared to calendar year 1996 is now expected.
- We believe the next 12 to 15 months will be a period of sluggish growth characterized by stops and starts before a sustainable recovery is established. Dataquest is therefore continuing to call for 1998 to be a high single-digit growth year (specifically, 7 percent), with technology investments continuing to be the focus.
- The move to put 0.25-micron manufacturing capability in place, coupled with the retooling of fabs to migrate capacity away from DRAM to logic, has been the main focus of investment in equipment thus far in 1997. Equipment areas such as chemical mechanical polishing, factory automation, and epitaxial reactors have benefited.
- Deep UV lithography is expected to be the real star, with a tripling of unit shipments in 1997 over 1996. Deep UV is now expected to account for about one-third of all steppers shipped this year.
- Even though the stronger-than-expected 1997 could lead to weaker growth for 1998 than forecast, the accelerated commitment to build 300mm pilot lines should provide some supporting strength to 1998.

Dataquest's top-line quarterly shipment forecast for wafer fab equipment is shown in Figures 1 and 2. Figure 2 shows a comparison of the sequential quarterly growth rates in today's forecast versus the forecast outlook six months ago. In general, our near-term outlook is unchanged, with the strategic investment growth the industry is experiencing currently expected to last about three months longer than originally thought.

Some specific points in the quarterly outlook are:

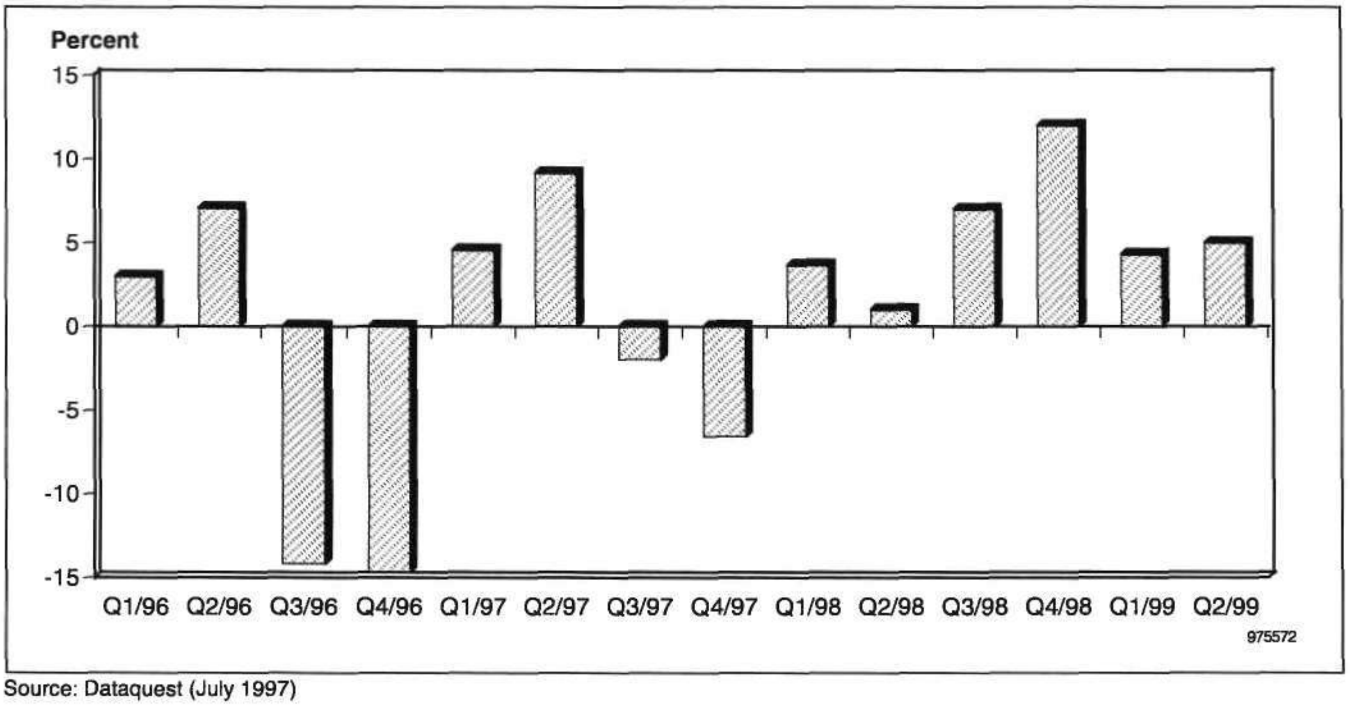
- Dataquest expects demand to be strong in the United States and Taiwan during third quarter 1997 but weaker on a relative basis in Korea and Japan. The addition of a seasonally weak booking pattern from Europe means basically a flat-to-slightly-down quarter.
- However, because U.S. and European equipment companies are better positioned in Taiwan and the United States, these companies will actually have sequential strength in the third quarter, and as a result, the market will "feel" stronger than it really is when looking at such metrics as the Semiconductor Equipment and Materials International (SEMI) North American book-to-bill figures and quarterly reports of public companies.

Figure 1
Wafer Fab Equipment Quarterly Revenue Forecast



Source: Dataquest (July 1997)

Figure 2
Wafer Fab Equipment Quarter-to-Quarter Sequential Growth Rates



Source: Dataquest (July 1997)

- Dataquest expects that the fourth quarter will show significant sequential weakness, and the market will essentially be in a holding pattern through the first half of 1998.

- In a recent survey of purchasing managers published by SEMI outlining the plans for 1997 spending, fourth quarter 1997 looks extremely weak. This survey, which excludes the Japanese companies but does survey more than 80 percent of the remaining market, indicates that orders will be down across all regions and collectively down over 15 percent. We believe the Japanese companies' activities will temper this decline and that some weakness may actually appear sooner, but these results are consistent with the capital spending survey of companies Dataquest just completed.
- During 1998, the industry will shift its focus to 300mm shipments in a big way. The majority of growth will come in the second half, but it does offer some underpinning to stabilize the market in the first half. The vast majority of the growth in the 1998 wafer fab equipment forecast comes from investment in 300mm pilot lines.
- Capacity purchases are expected to be relatively flat at 1997 levels but will accelerate with the Japanese companies, likely starting during fourth quarter 1998.
- Dataquest would expect supply/demand dynamics to be fully corrected by early 1999, driving a robust resumption of growth, with the wafer fab equipment market growing to over $45 billion in 2001, from just under $21 billion in 1998.

A flat-to-down year is expected in 2002. The semiconductor capital markets are cyclical, in response to profitability cycles in the chip market. Dataquest's chip market forecast has a DRAM price decline in 2001, which we have built into a spending decline the following year.

Issues for the Industry to Reconcile in 1997 and 1998

Some dynamics and detail issues have caused us to remain cautious about near-term prospects.

At the beginning of the year, Dataquest pointed out three fundamental issues in the market that caused concern for 1997 and 1998 and that needed to be reconciled before a sustainable upturn could occur.

Overcapacity in the DRAM Market Continues

Fundamental silicon consumption analysis in the sector still points to overcapacity until the end of 1998. Acceleration of the 64Mb DRAM or an acceleration of shrinks in the 16Mb part would only extend the period of overcapacity into 1999, as growth of bits per square inch would accelerate.

The Capital Spending Ratio Is Still Too High

In 1997, for the third year in a row, the capital spending ratio as a percentage of semiconductor revenue will exceed 25 percent. The last years before 1995 to see these levels were 1984 and 1985. Dataquest believes the equilibrium level is closer to 22 percent now, indicating that the industry is still overspending. There are also a few more fabs starting up this year (50) compared to 1996 (48), well above the equilibrium level, which we believe is closer to 35 to 38.

Silicon Shipment Rates to Chip Producers Still below Peak of Q2/96

In the last six months of 1996, the silicon area shipment rate dropped by more than 20 percent. The wafer industry is on a recovery track, but the run rates are still some 5 to 10 percent below the peak of last year, indicating unused chip capacity. This, along with the fact that the industry added significant capacity in the last 12 months, leads us to conclude that factory utilization rates globally are still below 80 percent. Today, these are likely closer to 70 percent in the memory segments but edging over 80 percent in the logic sectors. Dataquest estimates that the industry will add about a net 9 to 11 percent to the installed capacity base in 1997 in terms of square inches of silicon, while only a 3 percent to 5 percent increase is needed to meet production demand.

Where Are the Fabs?

This question is significant because new fab activity tends to fuel large order activity. At last check, only 27 new fabs were planned for a 1998 start, down from 50 for this year. At this time last year, there were 56 planned for 1997. This pattern of a decreasing number of new fabs in the second stage of a slow market is quite normal, because the pattern for new fabs generally lags the equipment slowdown by about a year. We expect that both 1998 and 1999 will see the number of new fabs fall below 30. This means that large orders will be harder to come by until the fundamentals of overcapacity are resolved.

Foundry Industry Update: Growth, but Not Enough to Fuel a Boom

The fifth concern is less a concern than an issue that may create unrealistically high expectations in the near term—the strength of the foundry industry. This market is experiencing strong demand growth.

In 1996, a year of transition for the foundry industry, we saw the market move rather quickly from capacity constraint to oversupply. This change was evident in the price declines that began about midyear and have continued through the first half of 1997. Foundry wafer prices fell about 30 percent in that period, on average. Despite healthy growth in millions of square inches (MSI) demand of about 14 percent, Dataquest expects the market to be essentially flat in dollar terms for 1997 because of lower prices.

The sweet spot of the foundry market is now 0.5 micron, with many integrated device manufacturers (IDMs) beginning to off-load production of 0.6- and 0.7-micron products, while fabless companies are beginning the transition to 0.35 micron. Demand is ramping quickly for 0.35 micron foundry services, but so is supply. Although Dataquest would not characterize the 0.35 micron foundry market as being in oversupply, it is not accurate to say there is a shortage of supply, either. In fact, both are ramping, with supply leading demand by about five months. This means that, although the market has the feel of tight supply, there is real competition for market share among suppliers, resulting in a soft pricing environment that can be expected to continue into 1998.

The long-term prospects of the foundry industry remain very strong. Dataquest is forecasting the worldwide foundry market to grow from $6.5

billion in 1996 to $15.5 billion in 2001, representing a compound annual growth rate (CAGR) of 19 percent. The Americas and Asia/Pacific regions, where the proliferation of fabless companies is expected to be greatest, will lead growth in demand. The success of the fabless model is expected to continue to drive foundry demand growth, with fabless companies accounting for 28 percent of demand in 1996 and 40 percent in 2001. Foundry-processed wafers, from both dedicated foundries and integrated device manufacturers (IDMs), should amount to over 13 percent of worldwide wafer production on an MSI basis by 2001, and we expect this share to continue to grow in future years.

Foundry capacity supply and demand can be used as a proxy for mainstream logic capacity investment. Plans are already in place to supply the market adequately through 1999. This picture shows a fundamental driving force for steady growth but not the accelerating capital spending growth required to drive the industry to and over 20 percent annual growth rates. In short, it is not a market to look to for a boom. The key is that the industry needs a capacity driving force to resume the sustainable high-growth prospects—and for that, it needs the DRAM market.

Dataquest's forecast window is shown in Figure 3. For 1997, it shows a 5 to 12 percent decline from 1996. Taiwan in the third quarter is the wild card of the upside, and the severity of the fourth quarter decline is the wild card of the downside. Japanese companies' spending commitments for the fiscal second half (starting October 1) are key to watch. For 1998, demand issues are the wild card of the range, which is fairly wide. The upside is possibly 15 percent growth if a 25-plus percent semiconductor market growth develops (the current forecast is 18 percent). However, in the worst case, we could see a flat-to-down market for 1998 if PC unit growth stalls.

In summary, Dataquest believes that after the current strategic investment patterns are completed, through third quarter, the wafer fab equipment market will be in for sluggish business conditions through the middle of 1998 before a sustainable bookings recovery can start, coming initially from 300mm equipment shipments and then from DRAM capacity spending. Fundamentals of capacity supply-and-demand balance simply do not support a capacity-based recovery occurring in 1997 for either memory or mainstream logic. The next 12 to 15 months are expected to be dominated by continued investment by IC manufacturers in new technology and 300mm pilot lines.

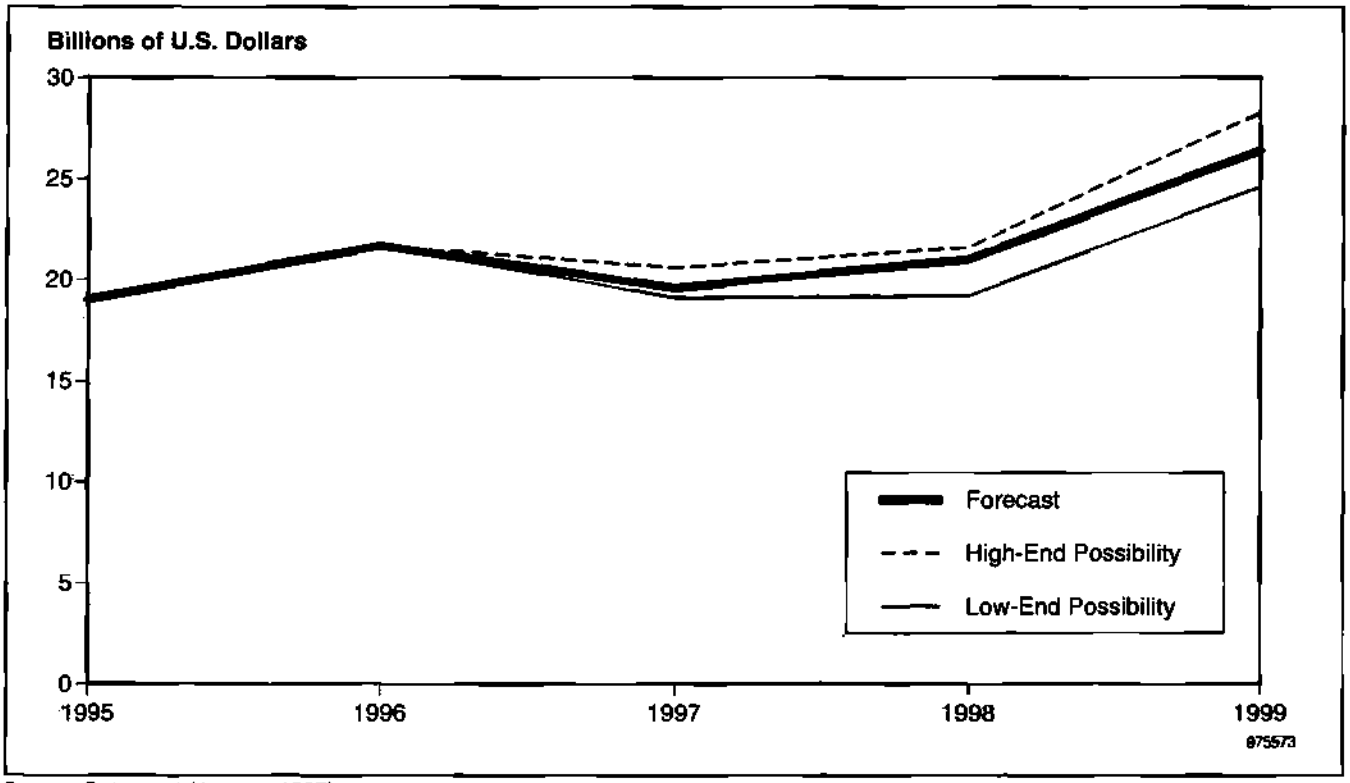
Silicon Wafer Forecast Review: Steady Recovery Under Way

Silicon area growth for 1996 came in at 6.5 percent in terms of MSI. The low point in silicon consumption was fourth quarter 1996, with run rates about 20 percent below the peak achieved in second quarter 1996, as mentioned earlier.

The wafer industry is in a recovery mode, with a sequential quarterly growth of 6 to 8 percent for 1997. This profile calculates to a 5.4 percent MSI overall growth rate for 1997. Growth returns to double-digit rates in 1998 at 11.5

percent, and accelerates into 1999. Dataquest's long-term compound annual growth rate for the industry is near 11 percent.

Figure 3
Wafer Fab Equipment Forecast Window—Downside Risk



Source: Dataquest (January 1997)

Dataquest is in the process of updating its polysilicon supply/demand model, but we can say today that the situation is improving. Although the industry will not be in the safe zone until the end of the year, inventories have been rising for about three quarters now. The next shortage is forecast for 2003 and 2004, as 300mm wafer production begins a rapid ramp.

The industry is ramping 200mm production adequately to fully meet demand in the near term, and Dataquest has a supply/demand analysis under way that should be ready in August. Also, within the next months, we will be releasing our initial supply picture for 300mm wafers. Although specific company information will not be available and plans are still very fluid, we will present a summary of the supply for the market as well as a forecast of when and where demand will develop.

Questions and Answers

Question: On the DRAM side, you seem to be somewhat pessimistic, based perhaps on pricing. From your surveys, do you detect that perhaps users are becoming more inventory conscious, or is it just that there is just too much capacity facing too few markets at this point?

Clark Fuhs (CF): I think the fundamentals of how the DRAM market consumes silicon are at the crux of the matter. When the industry made the transition from 4Mb to 16Mb, there was a tremendous bits-per-square-inch efficiency that came into play. And right now the market, with its current byte demand, consumes the same amount of silicon that it did six quarters ago. So basically all of the DRAM capacity that has come on line in the last six quarters can be quantified as the overcapacity.

The spending rates today are still very high, and the number of fabs coming on line this year is still very high. Although an initial reaction was made to cut capital spending growth and capacity increases, the suppliers have been trying to accelerate technology and the move to 64Mb DRAM as the initial response to the pressure on prices. Unfortunately that is not really the best response. The best response would have been simply to cut spending on new capacity and transition technology in the current fabs.

So the problem now has been exacerbated to a point at which there is still massive overcapacity and pressure on prices. There still needs to be capacity addition restraint in order to come back to balanced levels. Dataquest does have a forecast that tracks silicon consumption into the DRAM market. It would take about three to four quarters to consume all the excess capacity if capacity additions were simply to stop. Of course, there are new fabs coming up, so that will extend the balanced condition to at least the end of 1998.

Q: You had mentioned some issues with PC growth stalling. Can you add some color to that? What are some of the inputs from some of your colleagues about PC growth?

CF: I guess it is fairly well known that several companies that are in the PC area and supporting it are missing their numbers in the second quarter of this year. That has resulted in talk about a potential PC slowdown. There are three possible scenarios for PC demand, and Dataquest's Computer Systems and Peripherals (CAPS) group favors the first two. The first possibility is that the industry is experiencing a normal seasonal summer slowdown.

The second scenario, and the one that is actually more likely, is that the PC industry and Intel Corporation are making the transition to the Pentium Pro. This would naturally create about a couple of quarters' worth of slower growth in the PC unit consumption rate. But Dataquest's CAPS group expects the growth rate to come back on track before the fourth quarter comes around and the winter holiday season hits. The group has recently confirmed 19 percent unit growth for 1997.

The third scenario takes some imagination, and I am going to go a little bit out on a limb. There is a possibility that the year 2000 bug issue may affect PC demand. Dataquest has not done a full analysis nor executed the surveys that are required to really quantify this issue. So what I am proposing is that this is simply an issue to consider in your risk analyses. I am not sure of how many people are familiar with the year 2000 bug problem. Basically it is an issue with a lot of old mainframe computers and legacy systems with older software that does not recognize the year 2000 accurately, but instead recognize the "00" as the year 1900. There are already instances in which credit cards issued with a year 2000 expiration have been rejected by some systems. There are doomsday scenarios all over the Internet on this issue.

Dataquest thinks the doomsday scenarios are a bit overdone. But this is an issue that many institutions and companies have to solve. Bypassing the technical issues, there is some concern on the part of MIS managers for the Fortune 1000 companies as to how money is spent and where the budgets are coming from. A couple of facts are somewhat alarming. There are several surveys that have been initiated in the investment banking community, and J.P. Morgan and Morgan Stanley are really the two leading companies doing research in this area.

They are constantly surveying MIS managers regarding their 1997 and 1998 budgets, and how much of their budget is being allocated to fixing this problem. In 1997, the surveys that I have seen are in the 15 percent range. In 1998, that figure is expected to increase to 30 to 40 percent of the MIS budget of the Fortune 1000 companies that will be allocated to fix this problem. The key question and the risk to the PC and corporate infrastructure markets is whether this is new money that is coming into the budget or is it being taken away from other upgrade programs? That is the answer we do not have. But it does represent a risk in the PC unit growth forecast if budgets for upgrade programs are delayed.

The other side of this issue, however, is that the closer we get to the year 2000, the later it gets for fixing this problem, and the industry may actually experience a slingshot effect in which PC demand will dramatically increase around 1999. Remember that this is a mainframe computer issue. Bill Gates was kind enough to solve the issue with Windows 95, and most computers sold today are year 2000 compliant. As the clock ticks down, people may simply gut their mainframe computers and put in NT servers. This may not happen to a large extent until the back half of 1998, however, because the most convenient solution is simply to fix the currently running software.

Dataquest's IT Services group has also written several reports from the perspective of the companies providing software services for this problem. Dataquest's CAPS group is of the opinion that any PC purchases that are delayed by this issue are offset by the purchase of new mainframes with associated PCs.

Q: You were previously bullish on mask manufacturing equipment. Do you still believe that?

Klaus Rinnen (KR): Yes, the total maskmaking equipment outlook is bullish, especially for 1997. We see both increases in unit growth and very strong average selling price (ASP) growth as capacity to produce 0.25- and 0.35-micron masks ramps. For 1998, this could taper off to some extent but again pick up from 1999 into 2002. So, overall, Dataquest estimates that the CAGR of this segment will outpace the overall wafer fab equipment market.

Q: Where is DRAM pricing going in the next several quarters, and what are the issues around both supply and demand?

CF: I'm not sure that we can adequately answer the pricing forecast specifically here, because we do not have representatives participating in the telebriefing from the Semiconductor Supply and Pricing program to answer that. The general observation is that prices will be highly dependent upon how the suppliers act as gatekeepers in their shipments of DRAM into the market. The capacity issues we addressed earlier. The demand side is heavily dependent on the PC, both in terms of unit growth and byte growth per PC. About 70 percent of the bytes in the DRAM market go into the PC.

Q: Recently there has been a lot of activity with regard to the lowering of the price point in the consumer PC area. What sort of impact is that going to have on PC demand?

CF: Again, I am going to answer from a personal perspective. I think our CAPS group probably has a similar answer. History says that as PC prices come down, unit demand increases. I think that will continue to hold true. The particular trend you note has the potential of spreading the performance range for microprocessors and associated chipsets into the lower end. However, I am not sure that is what is happening. Both Advanced Micro Devices and Intel are experiencing much slower growth with their older-generation chips. I do not know if I can give a better answer than that at this point. Suffice it to say that lower prices have historically stimulated unit growth.

Q: In Figure 2, the quarter-to-quarter sequential revenue growth rates, are the incremental changes seen highly dependent on the DRAM market? For instance, Intel, which is obviously a big part of this whole scenario, does not appear to be changing its forecast for capital expenditure dramatically. Obviously it's up about 50 percent this year. You say Taiwan and the United States are strong, with Korea and Japan weak, and then Asia weakens later. Is that primarily the DRAM market or is that the foundry market or is some combination? In other words, what's going to weaken in Asia as things go forward?

CF: Figure 2 shows the sequential growth rate. So if, for example, the Japanese companies decide that they want to increase their level of spending suddenly, and they tend to make that sort of decision on April 1 and October 1, then the industry will see a jump in the second or fourth quarter. But if they hold it steady from second to third quarter, that represents zero growth. So, as a clarification, what Figure 2 represents is the growth from the previous quarter, not a year-over-year number. Figure 2 specifically looks at the short-term dynamics of the market.

It does appear that the DRAM manufacturers cutting back is what is driving the issue. The DRAM manufacturers started coming back in November and December with strategic investments—as an example, Samsung and Hyundai starting up their plants in the United States to establish 64Mb pilot lines. That spending occurred primarily in the first half. By the fourth quarter, most of these facilities in the world will be set up, but 64Mb pricing is below what suppliers want. Many are now rethinking their 64Mb ramp plans and rethinking just about everything associated with how they are going to ramp capacity. And what we expect to see in Asia is a DRAM incremental decline in the spending levels until the pricing comes back.

Q: From reading the papers, it appears that Micron Technology seems to have ramped rapidly, perhaps because of shrinks and perhaps because of capacity. It's obviously a factor of both, but it's hard to tell which is better. Is this, or the 64Mb capacity in general, something that's throwing a monkey wrench into things? Or is it just the whole market?

CF: I think it's not only Micron Technology. I think everybody is accelerating their move to 0.35- and 0.3-micron in the 16Mb part. The industry, just by the normal shrinking of the device, can increase byte supply by about 30 percent per year without consuming more silicon. During periods of price pressure and oversupply, there is an acceleration of technology implementation in order to try to reduce cost as quickly as possible. So today we are probably in a mode in which device shrink is giving the industry a 40 to 50 percent byte-supply growth just on its own. Micron Technology tends to more aggressive with shrinks than the overall market, as well.

Q: What is the forecast for bit rate growth in 1997 and 1998?

CF: Off the top of my head, I would venture a guess that growth rates will be in the 55-to-70 percent range for the next couple of years. It has been higher than that from a run rate perspective in the last year or year and a half, primarily based on price elasticity.

Q: Do you have any view on the situation in Thailand with respect to the two fabs that are on hold?

CF: From our perspective, they're on hold. They are not incorporated in any supply analysis before the last half of 1999. Actually, I think that Submicron Technology may start to ramp again in late 1999, which we consider a fairly conservative assumption.

Q: During the transition from the Pentium and when Windows 95 came onto the market, there was an overoptimistic forecast for PC and memory demand that seems to have triggered the slowdown that showed up in 1996. Do you know of any software changes that are going to kick up demand? Or are we on a plateau until the year 2000 fix?

CF: Other research companies are talking about Windows NT. But Dataquest has talked with a couple of system suppliers and distributors who are saying that the sweet spot in the upgrade market right now is the upgrade to Windows 95.

Q: So that's still got life in it. It might just be that the bubble is a little bit more stretched out.

CF: That is a better characterization. I think everybody had the size of the market right. It was the timing of that market that was missed, and it ended up showing a flatter distribution. I remember a question I got two years ago in a Semicon/West presentation just before Windows 95 came out. My comment was that I personally was going to have to increase the memory in my PC because of my Microsoft Office and, particularly, PowerPoint applications and other graphics or visual issues. That is probably the fundamental driver of the market, rather than operating systems per se.

Q: So, the Internet and graphics are probably going to drive the growth more than maybe just processing?

CF: Right, as well as operating systems.

Q: If I remember correctly, Dataquest had forecast that there would be a 35 percent oversupply in foundry capacity in 1998. Is this forecast still valid? And what's your oversupply forecast for DRAM in 1997 and 1998, and even 1999?

CF: We actually looked at the foundry market a little bit differently this time to factor out the internal Japanese market from a supply and demand perspective.

From the DRAM perspective, we're still in probably about a 15-to-20 percent oversupply from an absolute capacity perspective. From a silicon consumption perspective, demand accelerates in the second half of 1997, pauses in the first half of 1998 because of seasonal factors, and then accelerates again in the last half of 1998. By the end of this year, the industry will probably come to about a 10 percent overcapacity, hold that level through the middle of 1998, and then slowly close the gap into a balanced market by the end of 1998, from the DRAM side.

Q: Does this take into account the 64Mb that's ramping up now?

CF: It takes into account our 64Mb forecast for the ramp, but this is not as aggressive as other research companies are predicting. By the end of 1998, Dataquest expects the 16Mb part is still going to be the major silicon consumer in the DRAM market. And we expect that to be true until at least the beginning of the year 2000. There are configuration issues associated with how the 64Mb DRAM gets placed into PCs and how the system OEM will buy it. These configuration issues make us believe that the industry will not see a crossover before late 1999, at the very earliest. So our forecast does not take into account a very strong crossover-style ramp through 1998. That results in what is actually the most optimistic view for the supply/demand analysis. If the market were to accelerate to 64Mb DRAMs, with the 64Mb DRAM having at least twice the byte-per-square inch density that the 16Mb does, it basically exacerbates the oversupply problem.

Q: Can you elaborate on what you mean by configuration problems?

CF: Like what we saw in the 4Mb-to-16Mb conversion, the issue of granularity—how the PC manufacturers offer configurations of PCs to the consumer market—will affect how DRAM gets bought into the box. The 4x4 configuration of the 16Mb DRAM with a 64-bit processor in the Pentium class has a minimum configuration of 32MB. And each additional module also has to be configured as 32MB, whereas the 1x16 version of the 16Mb DRAM can be added in 8MB increments. In the near term, we see PC manufacturers offering configurations of 32MB, 48MB, 64MB, and 80MB systems. They clearly want to offer the market something smaller than a 32MB increment. Today, the first 32MB typically use the 4x4 configuration, and then the 1x16 is used for all memory above 32MB.

Going to the 64Mb DRAM complicates this issue. The 4x16 configuration of the 64Mb DRAM configuration has a minimum "nugget" of 32MB. The 2x32 configuration is required even to construct a 48MB or 80MB system. Nobody makes a 2x32 part today; it simply is not available. And there is a manufacturing issue with the transition to the 2x32 part because it requires a different type of package. There is a technology packaging technology barrier that is delaying large-scale production of the 2x32 version of the 64Mb DRAM.

Q: What package type is necessary for the 2x32?

CF: Mary Olsson, the Dataquest analyst who covers that market, could discuss this issue more specifically. I'm less familiar with all the specifics. However, because the shape of the 2x32 is more rectangular, a different way of putting the chip in a package is required, and that deviates from the current standard packages. Suffice it to say that there is a manufacturing technology barrier to making the transition to a 2x32 version of the 64Mb DRAM. So we continue to believe that the sweet spot of the market will be the 16Mb DRAM, at least through 1998, and perhaps even through 1999.

Jim Hines (JH): I'll respond to your question about supply and demand in the foundry market. For our recent analysis of supply and demand in the foundry industry, we excluded the internal Japanese market. There is a quite sizable market in Japan that is essentially captive, and it's a means by which Japanese suppliers concentrate the capacity for lagging-edge products in some older fabs. Right now that market is significantly oversupplied, and because it is older technology and not generally available to the merchant market, it really is not relevant to the overall situation in the foundry industry. So we completed the analysis excluding that portion of the market but including those Japanese suppliers that do export foundry services to other users.

We saw the market make the transition from undersupply to oversupply in 1996. In 1997, we expect the oversupply on an MSI basis to be about 9 percent, peaking in 1998 at 15 percent and then beginning a decline to a minimum of just under 8 percent in 2000, after which it begins to increase again. Again, this is the overall worldwide semiconductor contract manufacturing market, including all technology segments. Compared to our earlier forecast, we expect less oversupply and also that the peak year will come in by about one year, to 1998. One difference is the exclusion of the Japanese internal market, but another reason is that we have seen a more rapid increase in demand for foundry services, stimulated in part by lower prices and the price elasticity that exists in that market. Also, there has been a small amount of push out or reduction in some of the supply capacity additions. But I should emphasize that that change has been relatively small. We still see quite aggressive plans in terms of supply capacity additions in the market.

Q: Would you please comment on general market conditions in the application-specific chips. Does the ASIC market more or less compare to the PC end of the market? Is it a larger share or smaller, or is it enough to make a big ripple in the market, going back to the foundry level?

CF: Our ASICs Worldwide analysts could answer that more fully, but application-specific IC, or ASIC, devices are simply a classification of chip. When you refer to applications that drive semiconductor demand in general, about one-third of all semiconductor demand comes from the PC. And I think that somewhere between 15 and 18 percent comes from telecommunications. ASIC chips are used in both of those markets.

Q: I'm just trying to get a feel for whether that market is so diverse that you really can say whether any swings have an impact in foundry capacity changes. What tends to be the leading predictor of changes in foundry capacity?

CF: We like to view the market from the point of view of the application that's driving semiconductor demand—telecom, industrial, PC-related areas, and so on, and the ASICs that are being used in those specific areas. I think there are some facets of the telecom industry that are among the fastest growing.

JH: Yes, looking specifically at fabless companies, which, as I mentioned earlier, do constitute a large portion of demand for foundry services, we see the end-product applications broken down in the following way. About 60 percent of fabless company products on a revenue basis go into PC or computing-type applications. About just over 20 percent are programmable logic devices (PLDs), which of course can be used in a variety of applications. In the fabless sector, PLDs are such a large part of the product mix that we break this out separately. And in fact, many of those PLDs find their way into PC and computing applications, so that could actually raise that number. Just under 10 percent of fabless company products go into communications-, telecom-, and data communications-related applications. And then around 10 percent are in a category that we label as "shared and others." This includes many of the ASIC products. Because they are application specific, it is not always easy to tell which application they find their way into. But in terms of fabless company products, that represents only about 10 percent of the total. That 10 percent also includes some memory products, which again can be used across a variety of different applications. Again, this is only a segment of foundry demand, but I would characterize the demand driver in foundry to be like that of the rest of the industry—it is very PC dependent.

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Perspective

Semiconductor Contract Manufacturing Services Worldwide

Technology Analysis

The Challenges of Embedded DRAM in ASICs: A Manufacturing Economics Point of View

Abstract: *Recent trends and excitement in the semiconductor industry have centered on discussion of system-level integration in ASIC designs, most notably around the use of embedded DRAM. Although technically feasible, large hurdles exist in merging logic and DRAM process flows in the same wafer and making the proposition economically viable. This trend in the industry is under way and will succeed, but the pace of migration and the availability of competitive parts will likely be impeded by manufacturing economics.*
By Clark J. Fuhs

Definition of Embedded DRAM SLI from a Manufacturing Perspective

Application-specific IC (ASIC) devices employing system-level integration (SLI) have been in production for quite some time and have been lucrative because the fab process flow could be easily adapted from, and in most cases is the same as, the existing logic flow. The inclusion of DRAM embedded into the device introduces unique manufacturing challenges, however, that incur a higher cost per device than may be considered economically viable with relation to profitability and ultimate system-level cost savings.

Simply put, from a manufacturing perspective, embedded DRAM SLI means putting advanced logic and DRAM processes in the same fab and on the same wafer. Because of the striking differences in the two process flows today, one fact is evident—either the logic part or the DRAM part of the device will be optimized at the expense of the other. Which way the device is designed and constructed will be highly dependent upon how much DRAM is placed on the chip. Devices with large amounts of DRAM will benefit from optimizing the DRAM process, improving packing density and device

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performance. Devices with smaller amounts of DRAM will derive the most benefit from optimizing the logic part of the chip.

So What's the Big Deal about Putting These Together?

Actually, technically, it is not a big deal—just potentially very expensive. An analysis of the typical process flows drives this point home. Table 1 shows a comparison of the typical SLI implementation today, placing SRAM along with other logic in the device.

Table 1
0.35-Micron (Drawn) Process Flow Comparison of Logic and SRAM Processes

	Advanced Logic Flow	Fast SRAM Flow (4T/6T)	Pseudo-DRAM Flow (3T)	Merged SLI Flow
Number of Poly Levels	1-2	1-2	1-2	1-2
Number of Metal Levels	3-4	2	2	3-4
Number of Mask Levels	15-18	11-13	12-14	15-18
Storage Capacitor?	No	No	No	No
Gate Capacitor Thickness (nm)	6-7	6-7	6-7	6-7
Self-Aligned Silicide	Typical	Yes (6T)	No	Typical
CMP in Process Flow?	Yes	No	No	Yes
High-Density CVD or Etch Processes?	Both	Not typical	Not typical	Both
BiCMOS Designs Possible?	Yes	Yes	No	In some cases

Source: Dataquest (August 1997)

Both the fast SRAM and the "pseudo-DRAM" structures are actually subsets of the process flow for advanced logic, so designing and constructing SLI ASICs are a natural extension and do not really add much to the per-wafer cost of the process.

The origins of this date from the mid-1980s, when both Intel Corporation and Motorola Incorporated made strategic decisions to design their MPUs with SRAM cells instead of the conventional DRAM cell. From a manufacturing perspective, MPUs are nothing more than memory cells and wiring. When this migration occurred, with the 80386 Intel generation and the 68020 Motorola generation, the process technology road map for logic and DRAM diverged. This divergence has created a clear separation of the leadership, as well, with U.S. companies generally taking the lead in driving logic processes, and Asian companies driving DRAM technology.

The three-transistor (3T) pseudo DRAM design is actually an SRAM process flow with a design to simulate a DRAM in function. The advantage is that the cell size is substantially reduced when compared to a six-transistor (6T) design, but the device is a bit slower because of the exclusion of the self-aligned silicide local interconnect. In ASIC devices, the 3T design may incorporate a low-resistance local interconnect to regain speed. Because the 3T design does not employ a storage capacitor, it is not considered a true DRAM process flow relying on the gate capacitor for storage, like SRAM.

What are the differences for a one-transistor DRAM process flow? Table 2 shows a comparison of the typical logic and stacked DRAM processes. Stacked capacitor DRAMs represent more than 75 percent of production today and are therefore representative of the typical design.

Table 2
0.35-Micron (Drawn) Process Flow Comparison of Logic and Stacked DRAM

	Advanced Logic Flow	Stacked DRAM Flow	Merged SLI Flow
Number of Poly Levels	1-2	4	1-2
Number of Metal Levels	3-4	2	3-4
Number of Mask Levels	15-18	13-15	18-22
Storage Capacitor?	No	Yes	Yes
Gate Capacitor Thickness (nm)	6-7	10	?
Self-Aligned Silicide	Typical	No	??
CMP in Process Flow?	Yes	No	Yes
High-Density CVD or Etch?	Both	Poly etch	Both
BiCMOS Designs Possible?	Yes	No	With added masks/design

Source: Dataquest (August 1997)

Several points show the mismatch involved in combining these two processes. First, the storage capacitor is a construction unique to DRAM and therefore is a net addition in complexity to the standard advanced logic process flow. Stacked capacitor designs generally include four levels of polysilicon, with two of these plus several other special steps specifically required to construct the storage capacitor. This will inherently add mask levels and cost per wafer to the process.

Second, stacked capacitor DRAM processes do not employ a self-aligned silicide process, nor do they have a BiCMOS design capability option. Advanced logic elements, for the most part, still need to incorporate SRAM subelements to maintain speed performance. If the device is very advanced or requires high performance, the self-aligned silicide is required to meet that speed. Further, BiCMOS becomes an added complexity because the process cannot be implemented across the entire device.

Third, there are two processing features in the flow before metal one that involve trade-offs in DRAM and logic device performance. Both of these are reviewed in more detail in another Dataquest Perspective ("Embedded DRAM ASICs: Source of a Shakeout for the Japanese Semiconductor Market," SEMI-JA-DP-9706, July 28, 1997). Gate capacitor thickness is optimized at two different values for each of the advanced logic and DRAM flows. Plus, because of the need to construct the storage capacitor, the number of high-temperature processes is higher in the DRAM case, stressing the thermal budget of the standard logic process.

None of these issues is technically difficult, and they could be solved easily with a little engineering—they are simply expensive.

A small note is warranted here on the idea of using embedded flash memory instead of DRAM. Flash memory also has a storage capacitor, and the process flow typically has three levels of poly, so the same general issues exist and would apply at some reduced level. However, cell sizes are larger.

A Manufacturing View of the Concept of "Return on Investment"

New technology is developed constantly in semiconductor manufacturing. However, the transfer to high-volume production tends to occur more slowly than people initially believe. The reason for this tends to be economic, not technical, in nature, and technology migrations therefore occur only when they will be profitable.

Estimates for increase in cost per wafer to add embedded DRAM into logic run from a 25 to 40 percent. Embedded DRAM would also tend to increase chip size, so cost per chip could increase as much as 60 percent above a standard product without embedded DRAM. Although the standalone DRAM is eliminated, other system cost or performance advantages would have to be realized for this to gain acceptance.

What are the returns? Table 3 is a subset of Dataquest's basic model for measuring productivity in manufacturing in the semiconductor industry. It establishes ranges by product type and generation for the net revenue per square inch of silicon started.

Table 3
Revenue per Square Inch of Silicon (U.S. Dollars per Square Inch)

	Advanced	Mainstream	Lagging
Microprocessor	300-600	150-250	90-120
Logic, ASIC	100-140	80-90	50-60
DRAM (Average)	80-90	60-75	45-50
Microcontroller	-	60-70	50-55
Power/Discrete and Analog	30-50	25	<15

Source: Dataquest (August 1997)

Table 3 represents a general model for return from silicon processed by device type. The semiconductor industry average is currently at about $50, increasing by about 5 percent per year, on average, based on the mix change in the devices shipped. From year to year, the industry average can fluctuate because of DRAM prices. The basic grouping of advanced, mainstream, and lagging technologies is constant from year to year, but what constitutes "advanced" will change over time and by device type. Advanced analog is 0.7 micron, while advanced MPU is 0.3 micron today. New capacity additions in the semiconductor industry support a product set that averages about $75 to $80.

The group of fabless companies generally averages between $85 and $100, placing the group in the logic/ASIC category at the high end of mainstream. PLDs are at the high end of the range at about $120. The DRAM return is highly dependent on supply issues and can fluctuate at plus or minus 25 percent from the average levels noted. Those familiar with Micron Technology Inc. need to be warned—its returns are significantly above the average market, by 30 to 40 percent, because of the company's superior shrink designs.

Applying Return on Silicon to Embedded DRAM Design

Table 3 can also be used to conceptualize how new technology is generally employed. When a new processing technology is developed, it is generally successful if the revenue from the chip is above $120 net per square inch. At this level, margins tend to be high, and therefore a cost structure has a lot of flexibility.

Today, SLI ASICs generally return $100 or so per square inch of silicon started. What embedding DRAM into the device means is that a chip will be diluted with an element that has two-thirds the average return (if packaged individually) but has about a one-third higher cost. This is a daunting proposition. Put another way, to maintain an equivalent margin, the chip company is asking its customer for a 75 to 100 percent price premium to employ embedded DRAM.

This may be possible to sell, but the fact is—*in order to make embedded DRAM in SLI ASICs accepted in the market, there must be a proven system performance advantage or system costs are reduced by the lower count of chips to compensate.* This is the only way a purchaser can justify such a premium. In some applications in which standalone DRAM is used, the minimum configuration is more than the application can use, so there are possible efficiencies associated with optimizing DRAM size.

As another idea to illustrate, what if embedded DRAM were placed on a microcontroller (MCU)? The returns on silicon are about equivalent for DRAM and MCUs and, in some cases, could enhance the value of the MCU relative to the individual parts. Current mainstream MCUs generally do not have more than two levels of metal, nor do they generally have a need for self-aligned silicide, so a standard DRAM process flow could be adapted to include the MCU designs. In the near term, this design approach, while not as lucrative for the suppliers, might be a market to more quickly develop.

The concept of a "system on a chip" is appealing, but it will develop slowly, with supply leading demand in the near term. It is likely that the more popular uses of embedded DRAM will be in handheld or portable devices, where system-level cost savings can be greatest.

Are There Ways to Make Embedded DRAM More Economical?

Actually, there is a way to manufacture DRAMs in a way that is closer to the logic process flow, thereby reducing the cost increase noted in the previous section. The trench capacitor DRAM manufacturing method may actually hold a competitive cost advantage in embedded DRAM SLI devices.

Toshiba Corporation, among others, would argue that the trench capacitor DRAM has performance advantages in SLI relative to stacked capacitor designs. Dataquest will not evaluate the merits of this claim but instead concentrate on the manufacturing cost and integration issues of stacked versus trench capacitor DRAMs.

Table 4 compares the process flow of a conventional trench capacitor DRAM with the advanced logic process flow. In many respects, there is still something of a mismatch between these two processes, but the trench design melds much better to the logic flow than does the stacked design.

Table 4
0.35-Micron (Drawn) Process Flow Comparison of Logic and Trench DRAM

	Advanced Logic Flow	Trench DRAM Flow	Merged SLI Flow
Number of Poly Levels	1-2	2-3	2-3
Number of Metal Levels	3-4	2	3-4
Number of Mask Levels	15-18	13-15	16-20
Storage Capacitor?	No	Yes	Yes
Gate Capacitor Thickness (nm)	6-7	10	?
Self-Aligned Silicide	Typical	In most	Yes
CMP in Process Flow?	Yes	Some	Yes
High-Density CVD or Etch?	Both	Poly etch	Both
BiCMOS Designs Possible?	Yes	Yes, but not typical	Yes

Source: Dataquest (August 1997)

First, the storage capacitor is a construction still unique to DRAM, but the addition in complexity to the standard advanced logic process flow is limited to the construction of the trench capacitor itself and perhaps one added mask. Second, some trench capacitor DRAM processes do employ a self-aligned silicide process and are built on epitaxial wafers. These two issues make trench capacitor DRAM more friendly to a logic or BiCMOS design.

Third, the features in the process flow before metal one that involve trade-offs in DRAM and logic device performance still exist and need to be balanced, but as noted earlier, these issues are not technically difficult and could be solved easily with a little engineering.

The bottom line is that the trench capacitor DRAM design holds a competitive cost advantage because of the process flow similarities with advanced logic, holding the increased implementation cost to perhaps 10 to 20 percent per wafer over advanced logic processes. Further, the die size increase would be smaller, as well, because the trench capacitor DRAM has a fundamentally smaller cell size than the stacked capacitor.

Dataquest Perspective

The trend toward embedding DRAM in SLI ASICs has started, in part driven by suppliers offering the capability in a soft DRAM pricing environment. However, given the increased costs and uncertain returns on a per-wafer basis, this market will likely have either lower margins or slower acceptance than suppliers are currently hoping. However, embedded DRAM designs may enable logic suppliers to capture a higher percentage of semiconductor content. System-level cost savings, in some cases, could also preserve margins.

Suppliers that incorporate a trench capacitor design are expected to have a competitive cost advantage in the embedded DRAM SLI market. Because this technology is protected by patents, the number of companies that can offer this design is limited. There are only four DRAM companies that use trench capacitors: IBM, Siemens AG, Texas Instruments Inc., and Toshiba Corporation. These companies have a clear advantage in applying the design to SLI. Furthermore, several companies have technology agreements with these four and can hope to take advantage of this in the market. Those include Anam/Amkor, Winbond Electronics Corporation, Chartered Semiconductor Manufacturing Pte. Ltd., Motorola, and Hitachi Ltd.

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Perspective

Semiconductor Contract Manufacturing Services Worldwide

Market Analysis

Wafer Fab Equipment Market Forecast and Capacity Update

Abstract: *Investment in 0.25-micron technology and the attempted redirection of DRAM capacity to logic characterized the wafer fab equipment market performance in the first half of 1997. The wafer fab equipment market is essentially on track with Dataquest's higher forecast scenario stated six months ago, yet the overcapacity in the industry persists. Dataquest continues to believe the industry is still in a technology-buying mode. A sustainable growth recovery is not expected until later in 1998, meaning a pause in growth is likely later this year.*

By Clark J. Fuhs, Ronald Dornseif, James Hines, Takashi Ogawa, and Klaus Rinnen

Sustainable Recovery Still Far Off, Technology-Related Buying to Continue

The wafer fab equipment market is essentially on track with the forecast scenario Dataquest painted at the beginning of the year. There, Dataquest projected the first half of 1997 to show sequential strength from the second half of 1996 as chip companies initiated strategic investment plans in leading-edge technology. Indeed, the first-half strength came in slightly better than expected (at the top end of the forecast range), leading Dataquest to raise its 1997 wafer fab equipment forecast. A decline of slightly more than 9 percent when compared to calendar year 1996 is now expected.

The move to put 0.25-micron manufacturing capability in place, coupled with the retooling of fabs to migrate capacity away from DRAM to logic, has been the main focus of investment in equipment thus far in 1997. Equipment areas such as chemical mechanical polishing, factory automation, and epitaxial reactors have benefited. But deep-UV lithography is expected to be the real star, with a tripling of unit shipments in 1997 over 1996, and is now expected to account for about one-third of all steppers shipped this year.

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However, while optimism runs rampant throughout the industry, the fundamentals have not changed much in the last six months. Dataquest believes the industry has just completed the first year of a normal-length slow period and expects the next 12 to 15 months to be a period of sluggish growth characterized by stops and starts before a sustainable recovery is established. Dataquest is therefore continuing to call 1998 a high single-digit growth year, with technology investments continuing to be the focus (see Table 1). Even though a stronger 1997 could lead to weaker growth for 1998 than forecast, the accelerated commitment to build 300mm pilot lines should provide some underpinning strength to 1998, albeit a small contribution.

What Fundamentals Are Saying

At the beginning of the year, Dataquest pointed out three fundamental issues in the market that caused concern for 1997 and 1998 and needed to be reconciled before a sustainable upturn could occur. Here is a brief update of these issues, plus two new concerns.

Overcapacity in the DRAM Market Continues

Fundamental silicon consumption analysis in the sector still points to overcapacity until the end of 1998. Acceleration of the 64-Mb DRAM or an acceleration of shrinks in the 16-Mb part would only extend the period of overcapacity into 1999.

Dataquest does not believe the PC manufacturers will embrace the 64-Mb DRAM until the price per bit is competitive with the 16-Mb part and in a configuration that provides the PC manufacturer flexibility in offerings to the market. Currently, prices per bit for the 64-Mb DRAM are running at a 20 percent to 30 percent premium, which drives profitability of the new generation below the current one. From a manufacturing perspective, Dataquest does not see a crossover happening until late 1999 at the earliest, and more likely well into 2000.

Table 1
Wafer Fab Equipment Revenue Forecast, 1996-2002 (Millions of U.S. Dollars)

Regional Revenue and Growth	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1996-2002
Americas	5,825	6,277	7,234	8,945	11,761	13,116	14,295	16.1
Growth (%)	10.9	7.8	15.2	23.7	31.5	11.5	9.0	-
Japan	6,650	5,483	5,925	6,880	9,917	10,408	10,566	8.0
Growth (%)	5.2	-17.5	8.1	16.1	44.2	4.9	1.5	-
Europe	2,802	2,872	2,932	3,873	5,066	5,265	5,351	11.4
Growth (%)	18.9	2.5	2.1	32.1	30.8	3.9	1.6	-
Asia/Pacific	6,407	4,980	4,916	6,745	11,405	16,242	14,348	14.4
Growth (%)	23.3	-22.3	-1.3	37.2	69.1	42.4	-11.7	-
Total Wafer Fab Equipment	21,684	19,612	21,007	26,442	38,149	45,030	44,560	12.8
Total Growth (%)	13.4	-9.6	7.1	25.9	44.3	18.0	-1.0	-

Source: Dataquest (July 1997)

Capital Spending Ratio Still Too High

1997 will mark the third year in a row that the capital spending ratio as a percentage of semiconductor revenue will exceed 25 percent. The most recent years before 1995 to see these levels were 1984-1985. Dataquest believes the equilibrium level is closer to 22 percent, indicating the industry is still overspending. There are also a few more fabs starting up this year (50) compared to 1996 (48), well above the equilibrium level, which Dataquest believes is closer to 35-38.

Silicon Shipment Rates to Chip Producers Still below Peak of Q296

In the last six months of 1996, the silicon area shipment rate dropped by more than 20 percent. The wafer industry is on a recovery track, but the run rates are still some 5 percent to 10 percent below the peak last year, indicating unused chip capacity. This, along with the fact that Dataquest believes the industry added significant capacity in the last 12 months, leads Dataquest to conclude that factory utilization rates globally are still less than 80 percent. Dataquest estimates the industry will add about 9 percent to 11 percent net to the installed capacity base in 1997 in terms of square inches of silicon, while only a 4 percent to 5 percent increase is needed to meet production demand.

Where Are the Fabs?

In a recent visit to an equipment company, a marketing manager posed the above question rhetorically to express frustration in finding business for 1998. Taking this question seriously, Dataquest looked at its most recent fab database and noted that only 27 new fabs are planned for a 1998 start. At this time last year, there were 56 planned for 1997. This pattern of a decreasing number of new fabs in the second stage of a slow market is quite normal, as the pattern for new fabs generally lags the equipment slowdown by about a year. In the first slow years of the last cycle, 1990 and 1991, there were roughly 45 new fabs that came on line, versus 39 during 1989. Less than 30 fabs came on line in each of the years 1992 through 1994. Dataquest expects that both 1998 and 1999 will see new fab construction fall to below the 30 level once again.

This means that large orders will be harder to come by until the fundamentals of overcapacity are resolved.

The Foundry Industry Supply Is Ahead of Demand at 0.35-Micron

Dataquest has just completed an initial analysis of supply and demand of the foundry industry at 0.35-micron technology. While demand is strong, the supply base shows current plans about five months ahead of demand for the leading edge 0.35-micron technology through 1999. Evidence supporting this can be seen in the continued pricing pressure. There is really no room for new spending here.

Dataquest Perspective: Sluggish Growth and Technology Focus Continues

Dataquest believes that the wafer fab equipment market will be in for sluggish business conditions through at least the middle of 1998 before a sustainable bookings recovery can start. Fundamentals of capacity supply and demand balance simply do not support a major recovery occurring in 1997 or early 1998 for either memory or mainstream logic. Companies will continue to invest in technology, with shifting emphasis from 0.25-micron toward 300mm. Dataquest's quarterly forecast profile is shown in Table 2. It shows the weakness in the market in the second half of 1997 into 1998 before the recovery begins later in 1998.

Here are specific points to watch for:

- Dataquest expects the third quarter to be strong in the United States and Taiwan during Q397, but relatively weak in Korea and Japan. The addition of a seasonally weak booking pattern from Europe means basically a flat quarter. However, since U.S. and European equipment companies are better positioned in Taiwan and the United States, the market will "feel" stronger than it really is when looking at the SEMI North American book-to-bill figures and reports on the stock market.
- In a recent purchasing managers survey published by SEMI outlining the plans for 1997 spending, Q497 looks extremely weak. This survey, which excludes the Japanese companies but does survey more than 80 percent of the remaining market, indicates that orders will be down across all regions and collectively down more than 15 percent. Dataquest believes the Japanese companies will temper this and that some weakness may actually appear sooner, but these results are consistent with the capital spending survey of companies Dataquest just completed.
- During 1998, the industry will shift its focus to 300mm shipments in a big way. The majority of growth will come in the second half but does give some underpinning to stabilize the market in the first half. The vast majority of the growth placed into Dataquest's 1998 wafer fab equipment forecast comes from the investment in 300mm pilot lines. Dataquest expects capacity purchases will be relatively flat to 1997 levels but will accelerate with the Japanese companies, likely starting during Q498.

In the longer term, the pervasive strength of the semiconductor industry will drive the equipment industry to more than double by the year 2001.

Table 2
Wafer Fab Equipment Quarterly Revenue Forecast

	Q396	Q496	Q197	Q297	Q397	Q497	Q198	Q298	Q398	Q498
Wafer Fab Equipment (U.S.$B)	5.28	4.51	4.71	5.14	5.04	4.71	4.88	4.93	5.28	5.91
Sequential Quarterly Growth (%)	-14	-15	5	9	-2	-7	4	1	7	12

Source: Dataquest (July 1997)

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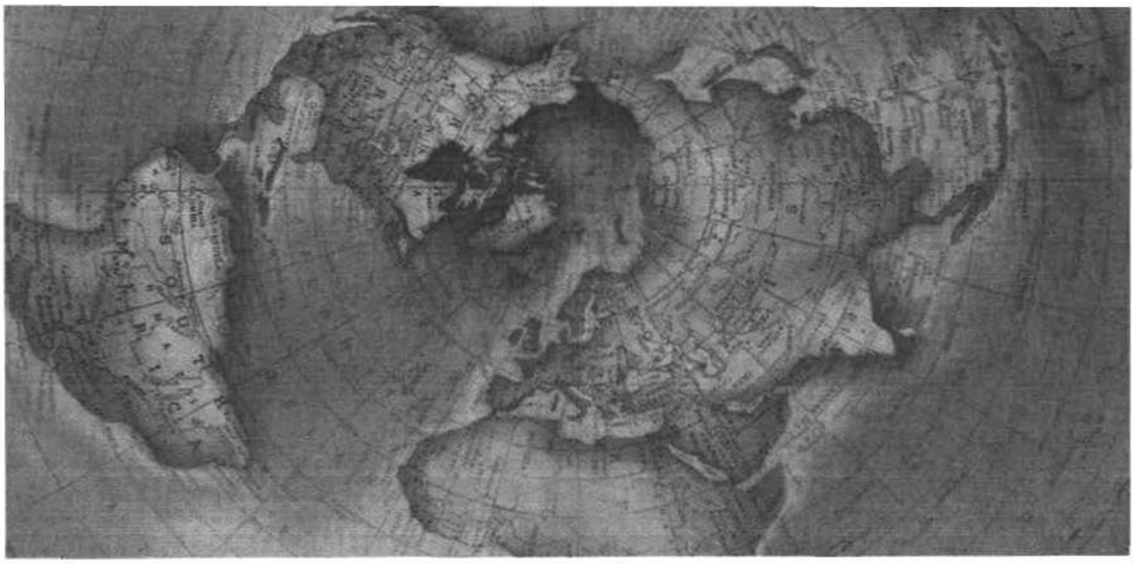

Semiconductor Contract Manufacturing Services Worldwide

Technology Analysis

System-Level Integration ASICs Add Embedded DRAM

Abstract: *In the early 1990s, the first steps toward system-level integration brought microprocessors and SRAM onto ASICs. Advanced silicon process techniques now allow one-transistor DRAM memory to join the other components on-chip in a giant step toward single-chip systems. This Perspective analyzes embedded DRAM technology and presents a forecast for this market through the year 2001.*
By Jordan Selburn

Single-Chip Systems in the Homestretch

There is a strong and accelerating trend in the ASIC industry toward system-level integration (SLI), that is, placing higher levels of the total system functionality on a single chip. Starting in the early 1990s, the widening availability of processor cores such as the ARM and MIPS microprocessors and the Oak DSP has made the first step to SLI a reality. Integration of mixed-signal capability, including digital-to-analog (D/A) and analog-to-digital (A/D) converters has reduced the system chip count further. The next candidate for widespread integration on an ASIC is single-transistor memory; with this embedded DRAM, the single-chip system becomes less of a dream and more of a soon-to-be realizable goal.

Dataquest forecasts that ASICs containing embedded DRAM will account for a significant percentage of the ASIC market by the year 2001. Especially significant is that this segment contains some of the highest added value, and hence the highest potential profit margin, designs, and these devices are going into some of the highest-growth markets, such as graphics controllers and digital video, among others.

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Embedded DRAM Technology

The conventional approach to system memory has placed small memory caches on the logic chips (usually ASICs), with the much larger main memory implemented in standalone DRAMs. The fundamental differences between a silicon process optimized for logic and one optimized for DRAM—primarily an emphasis on interconnect technology versus capacitor construction—have prevented significant integration until recently. Today we are beginning to see a merger of logic and memory in something known as embedded DRAM. This can be defined as a product that includes large amounts (more than 100,000 gates) of random logic and single-transistor (1T) DRAM on a single chip.

What Benefits Does Embedded DRAM Bring?

Most of the advantages to bringing system memory on-chip are quite straightforward. In brief, embedded DRAM allows the following:

- Few discrete components, hence less printed circuit board (PCB) area, higher reliability, and lower assembly costs
- Potentially lower parts cost, particularly if the logic design is I/O-limited (that is, there is some unused silicon area in the die core); note that the overall pin count also decreases by eliminating wide memory buses
- Higher performance through direct access to the DRAM instead of through I/O pairs and PCB traces
- Lower bit-usage requirement through the finer granularity of embedded memory
- Higher performance through system architecture optimization—for example, very wide memory buses such as 256 bits, 512 bits, or even 1,024 bits

Embedded DRAM Implementation

There are two approaches to embedding single-transistor DRAM into an ASIC. Starting with a logic-optimized process, vendors such as Samsung incorporate 1T DRAM through a quasi-merged logic/memory process. This attempts to preserve logic density and performance but does result in somewhat lower memory density. Conversely, most vendors start with a memory process to embed DRAM into logic. At present, there are two ways in which this can be accomplished, differing in the manner in which the charge-storage device is built: stacked capacitor or trench capacitor.

Most standalone DRAMs today are built with stacked capacitors. Layers of dielectric are sandwiched between polysilicon layers to build the capacitors. This technology is well-established and provides for integration of substantial amounts of memory on-chip. This has exacted a cost in logic density and performance from various trade-offs, such as interconnect for DRAM that has traditionally been limited to two layers and is not aggressively pitched, severely restricting logic density.

A more recent innovation is the trench capacitor, which places the dielectric in a trench etched into the substrate. This approach has several advantages over stacked capacitors, such as higher cell capacitance, a smaller impact on logic density, and higher maximum performance. Table 1 compares stacked and trenched capacitor implementations.

Table 1
One-Transistor DRAM Comparison

	Stacked Capacitor	Trench Capacitor
Maximum On-Chip Memory (0.25-Micron Generation)	64Mb	128Mb
Cell Capacitance	25fF	40fF
Maximum Performance	150 MHz	166 MHz

Source: Dataquest (April 1997)

Alternatives to Embedded DRAM

SRAM

Historically, ASICs have put small (relative to DRAM) amounts of memory on-chip with static RAM (SRAM). SRAM on an ASIC can be built of either logic gates (typically on a gate array) or out of dedicated six-transistor (6T) SRAM bit cells (typically for cell-based or embedded array designs). An SRAM memory block is much faster than an equivalent DRAM implementation but can be 10 times larger or more in area. For the 0.35-micron generation, a practical upper bound is about 1Mb of 6T SRAM on-chip. (All references to gate geometry refer to the drawn gate length of the transistor.)

Three-Transistor DRAM

A hybrid approach to large on-chip memory, the three-transistor (3T) DRAM is built with a pure logic-optimized process, allowing integration of significant amounts of memory (up to 16Mb) with no negative impact on logic density. Rather than building a standalone capacitor (that is, stacked or trench), the gate capacitance of one of the three transistors is used for charge storage. The result is a memory block about 40 percent smaller than a 6T SRAM implementation but one that is about 60 percent slower and has slightly higher power consumption. Also, the 3T DRAM needs refresh circuitry, which is unnecessary for SRAM. In the 0.35-micron generation, a practical upper bound is about 2Mb of 3T DRAM on-chip.

Standalone DRAM

The traditional approach to incorporating large blocks of memory in a system is standalone, standard-part DRAMs. As these are commodity parts, the cost is quite low per bit, assuming that all of the available memory on a chip is used; however, the amount of memory on a chip may not correspond well with the user's specific requirements because of the coarse granularity (1Mb, 4Mb, 16Mb, for example) of standard parts. A standalone DRAM solution also offers lower performance, higher power consumption, higher parts count, and more PCB area than an embedded DRAM solution.

There are some recent enhancements to standalone DRAM that can offer substantial improvements. Rambus DRAM, for example, at 500 MB/sec, has much higher performance than standalone DRAM and also reduces the ASIC's pin count, allowing a smaller die in some cases. These enhanced memories, however, generally come at a higher cost and usually do not reduce PCB area or power consumption.

Packaging Solutions

Multichip module (MCM) packages offer another approach to integrating memory with logic. By placing standalone DRAM and an ASIC on a high-performance substrate within a single package, it can look to the outside world as if the memory had been embedded on-chip. Performance and PCB area are usually enhanced in an MCM, although the cost is higher, primarily because of yield issues. At present, MCM remains a potential solution for the future.

Another innovative packaging solution is physically mounting a standalone DRAM directly on the ASIC. For now, however, this remains strictly a research project.

Table 2 shows the current state of the art for embedded DRAM, and represents the memory technology available in the 0.25-micron generation of ASICs. These ASIC products will begin prototype production in the latter half of 1997, with full production beginning to ramp in mid-1998. Figure 1 demonstrates the evolution of embedded memory technology through the 0.18-micron generation. These products will be introduced in 1998, with full production beginning in 1999; the 0.18-micron generation will become the mainstream ASIC technology starting in 2000 to 2001.

Embedded Memory Players

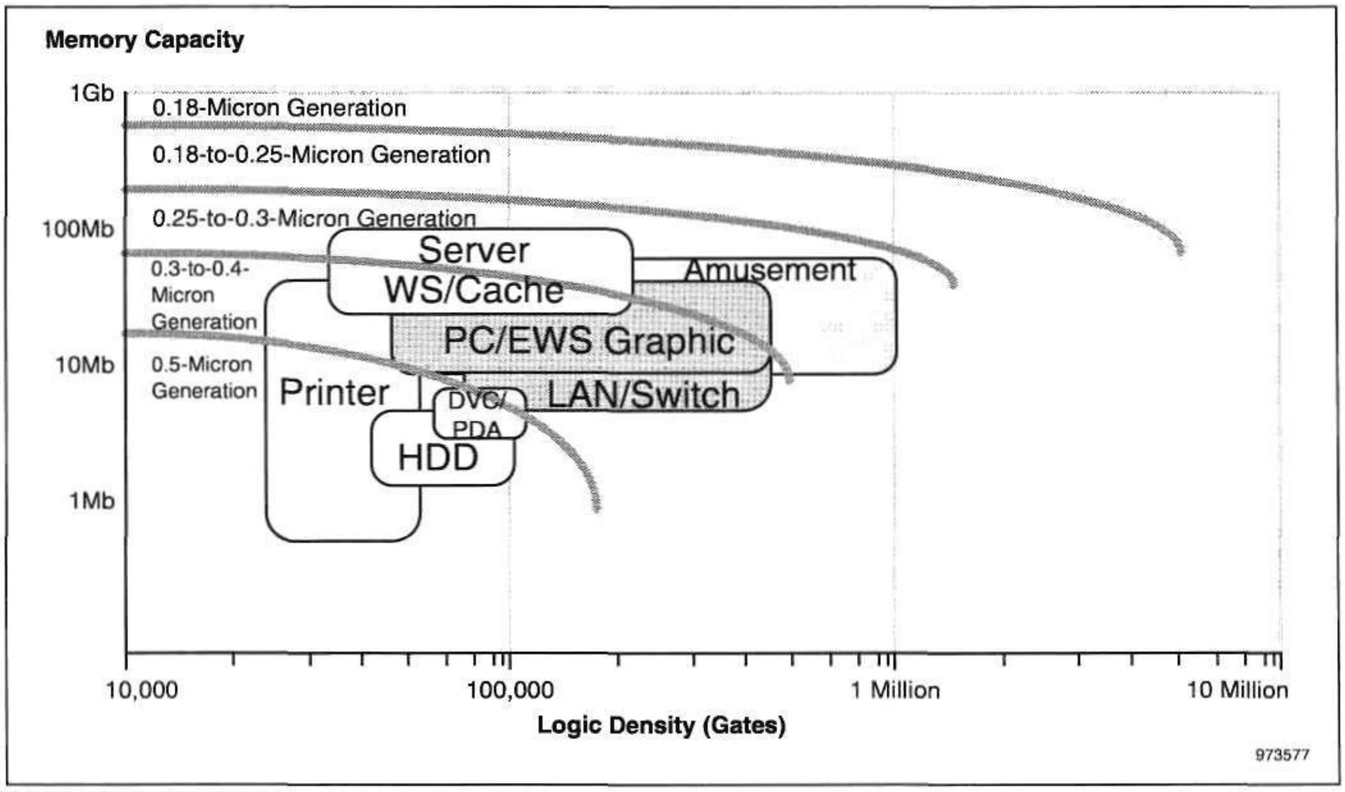
Table 3 shows a sample of ASIC supplier strategies for bringing system memory onto the logic chip. Virtually all of the leading ASIC vendors have either already announced support for embedded 1T DRAM or are exploring the concept and technology.

Table 2
Embedded Memory Comparison

	DRAM Process		Logic Process	
	Stacked Capacitor	Trench Capacitor	3T DRAM	6T SRAM
Maximum On-Chip Memory	+++	+++	+	-
Logic Density	++	++	+++	+++
Maximum Memory Performance	-	-	+	+++
Power Consumption	+	++	+	++
1Mb Approximate Area (0.25-Micron Generation)	2.5 mm^2	2.5 mm^2	16 mm^2	24 mm^2

Note: +++ shows best performance; - shows worst.
Source: Dataquest (April 1997)

Figure 1
Embedded DRAM Trends



Source: Dataquest (April 1997)

Table 3
Representative ASIC Vendors' Memory Offerings

	Stacked Capacitor	Trench Capacitor	3T DRAM	6T SRAM
NEC	X			X
LSI Logic			X	X
Fujitsu	X			X
Toshiba		X	X	X
Lucent Technologies				X
Texas Instruments	X			X
IBM				X
VLSI Technology			X	X
Samsung	X			X

Source: Dataquest (April 1997)

Embedded DRAM Applications

When to Merge Main Memory with Logic

Integrating system memory on-chip with logic and processors has the potential for significant benefits. Some applications require the higher performance attainable through the direct signal path to memory, some portable systems are driven to reduce parts count and board area, and all designs benefit from lower costs. Characteristics of designs that will see a greater degree of these benefits are summarized below:

- I/O-limited designs, where there is unused area within the core area of the die can have memory placed into this area at essentially no cost other than a somewhat lower yield. There is a further advantage in a reduction of the pin count through elimination of the off-chip memory interface. LAN switch chips are an example of this type of design.
- Designs with a performance bottleneck in the main memory interface can eliminate the I/O pairs and intervening printed circuit board wiring by bringing the memory on chip. Embedded memory can also be optimized for performance in that specific application, as opposed to generic standalone DRAM. 3-D graphics controllers fall into this category.
- Portable applications are driven to reduce size and extend battery life. Embedded DRAMs reduce chip count (hence PCB area) and reduce the system power consumption. Digital video camcorders and digital still cameras are typical for this type of design.

Leading designs that will incorporate embedded DRAM are:

- PC graphics controllers
- Workstation graphics controllers
- Digital video camcorders
- Digital still cameras
- LAN switches and hubs
- Hard disk drives
- Personal digital assistants (PDAs)
- Printer controllers

Selected applications, with specific memory requirements and forecasts, are discussed in more detail in the following sections.

When *Not* to Use Embedded DRAM

Despite its advantages, there are still many applications that do not benefit (and may even suffer) from using embedded DRAM. The converse of the characteristics in the above section are contraindications for bringing main memory on-chip. Core-limited designs housed in a desktop system that have large amounts of available PCB real estate and are powered from the wall socket are less likely candidates for embedded DRAM; for the foreseeable future, standalone DRAM will continue to offer a substantially lower price per bit than any embedded DRAM. Examples of this type of system include set-top boxes and desktop PC core logic, among others.

Specific Application Requirements

The following three examples from the computer (PC graphics controller), consumer (digital video camcorder), and communications (LAN/WAN switches and hubs) markets illustrate the spectrum of needs for and uses of embedded memory.

PC Graphics Controllers

Among the first applications to bring substantial amounts of memory onto the die are graphics controllers. The performance requirements as well as amount of memory used for graphics continue to increase as monitor resolutions improve and greater bit-depths (from 8- to 16- and ultimately 24-bit color) become common. As a consumer product, PCs also need to continue to bring these expanding capabilities to the market very cost-effectively. A typical mobile PC graphics system (shown in Figure 2) in 1997 has the following memory requirement:

- 1024 × 768 pixels at 16 bits/pixel: 1.6MB
- Multimedia and video clips: 0.2MB
- 3-D texture buffer: 0.2MB
- Total: 2.0MB

This amount could easily increase to 4MB by the year 2000.

Mobile PC systems, which are driven to reduce chip count and power consumption in addition to the performance and cost requirements mentioned, have already embraced embedded DRAM. The first product in this market, an application-specific standard product (ASSP) with 1.1MB of DRAM on-chip, began production in 1996.

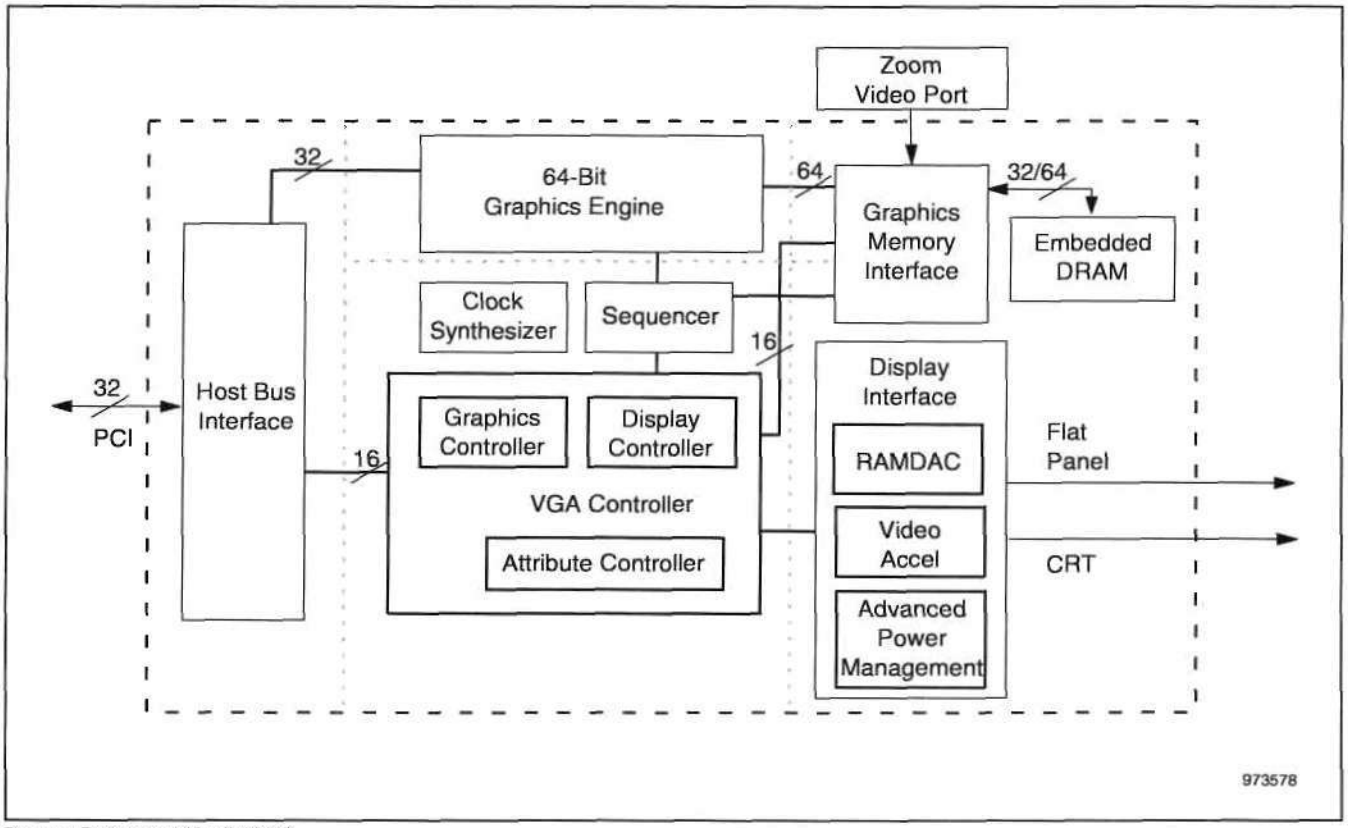
Desktop systems have even more demanding requirements than mobile PCs, with higher resolution, greater color depth, and additional multimedia. In 1997, an average new desktop PC has 2MB to 4MB of video memory, and this is expected to double by 2000. However, until the video performance requirements demand embedded DRAM (not until sometime after 2001), this market segment will continue to use the lower-cost standalone video RAM (VRAM) or synchronous graphics RAM (SGRAM) memory.

With the advent of digital television, there will be a new market for graphics controllers very similar to PC graphics. Like the desktop PC, this market is driven primarily by cost and will not move to embedded DRAM until performance needs require it; this, combined with a production ramp still several years off, makes digital TV only a very minor contributor to the embedded DRAM market until after 2001.

Digital Camcorders

Digital video camcorders (DVCs), introduced in the mid-1990s, have to balance performance, low power dissipation, small form factor, and cost. Second-generation camcorders, using 0.35-micron ASICs, have a system architecture shown in Figure 3. The total amount of DRAM in the system varies between 1MB and 2MB, depending on the specific camcorder, and is split about evenly between the error-correction and shuffling functions. The 1997 retail price for a DVC is about $2,000, which is over the spending limit of most consumers outside of the Japanese market. Integration of system memory is essential to make DVCs cost-effective enough to become a household item worldwide.

Figure 2
Graphics Controller Block Diagram

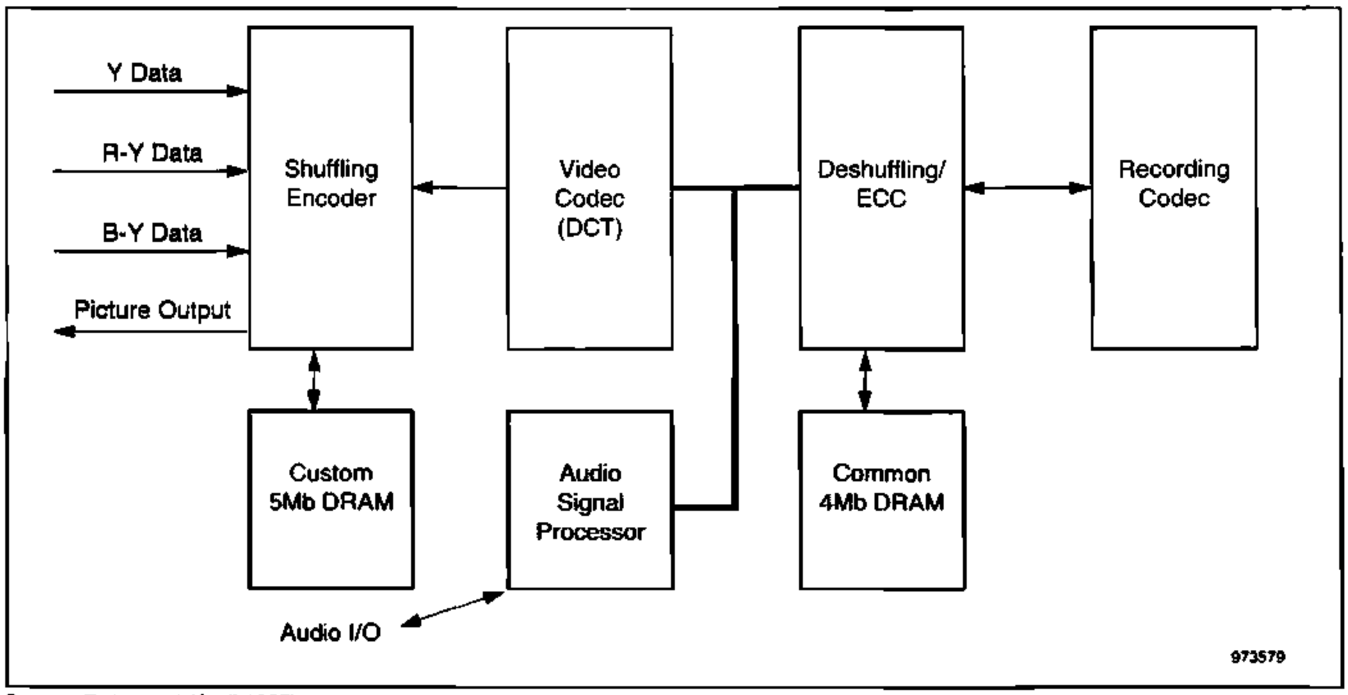


Source: Dataquest (April 1997)

Trends in the digital video camcorder market include MPEG encoding in the third generation of DVC (MPEG-1, with MPEG-2 in a following generation sometime after 2000), which will be introduced in 1998. This generation will be implemented in the 0.25-micron ASICs introduced in 1997, which becomes the mainstream ASIC technology in 1999 to 2000. Memory usage will increase to about 4MB to accommodate the needs of the MPEG encoder and the increased resolution of the third-generation DVC. SRAM is also used extensively in DVCs and, with the improved performance of embedded over standalone DRAM, could be replaced by embedded DRAM in a unified memory architecture for further die cost reductions.

Tabletop digital videocassette recorders (DVCRs) are unlikely to acquire any significant market penetration before the end of the decade; the prospect of recordable DVD may severely impact the possibility of any sizable DVCR market. As in the PC market, the lower cost of standalone DRAM will push the introduction of embedded memory into either of these products past 2001. The possibility exists, however, that some manufacturers may opt to use a common system for both portable and set-top products; this would accelerate the use of embedded DRAM in the DVCR and recordable DVD market somewhat.

Figure 3
Digital Video Camcorder Block Diagram



Source: Dataquest (April 1997)

LAN Switches and Hubs

The telecommunications market has the LAN and wide area network (WAN) market as its earliest adopter of embedded DRAM. Routers, which typically offer a small amount of base memory standard for data storage, with optional upgrades (through memory modules similar to PCs), are not a good candidate to bring main memory on-chip. In contrast, LAN hubs and switches use memory for program storage as well as buffering, and in this very competitive market are pushed to continually bring down the cost per port. As LANs move to 100 Mbps and eventually to Gigabit Ethernet, memory performance will become another factor accelerating the move to embed DRAM. Typical memory usage for LAN switches is 2MB for an eight-port switch; although the per-port memory requirement will remain about constant, the aggregate demand for ports is expanding rapidly. Dataquest predicts that the number of ports sold annually will increase by about two times from 1997 to 2001.

The WAN market, particularly remote access servers and data concentrators, also requires large amounts of memory and, like LANs, will begin to become a factor in the embedded memory market by the end of the decade. Home offices and telecommuting will drive substantial growth for WANs, and several million ports are expected to be sold in 2000. WANs use the memory for data buffering and program storage and have typically 4MB to 32MB per system.

Public switch networks, in contrast to LANs and WANs, typically have a very long life cycle. With systems in use for 10 to 20 years or more, this application segment will not be significant for embedded DRAM before the year 2001.

Embedded DRAM Forecast

Methodology and Assumptions

The following forecast was calculated in a demand-driven approach. For the years involved in the forecast (1997 to 2001), Dataquest analyzed the markets using embedded DRAM most intensively. The total logic and memory contents were forecast (based on application forecasts and semiconductor content analysis) for each application; then, a percentage of this total was forecast to be realized as embedded DRAM. It is important to note that this approach allows for the differing rates of embedded memory adoption for each application, taking into account application-specific factors such as design lifetime, advantages and disadvantages of different memory solutions, and technical requirements, among others.

For the baseline case (see below for a discussion of forecast variance), major assumptions included a predictable decrease in the price per bit of standalone memory and production availability of 0.25-micron drawn gate length ASICs beginning in 1998, becoming mainstream in 1999 to 2000.

1997-to-2001 Forecast

Table 4 and Figure 4 show the five-year forecast for embedded DRAM broken out by application. The expected year 2000 revenue of over $4 billion shows 40-times growth from 1997; while this is a very rapid ramp, this growth reflects the strength of the SLI trend, and the revenue still represents only negative 4 percent of the total standalone DRAM forecast.

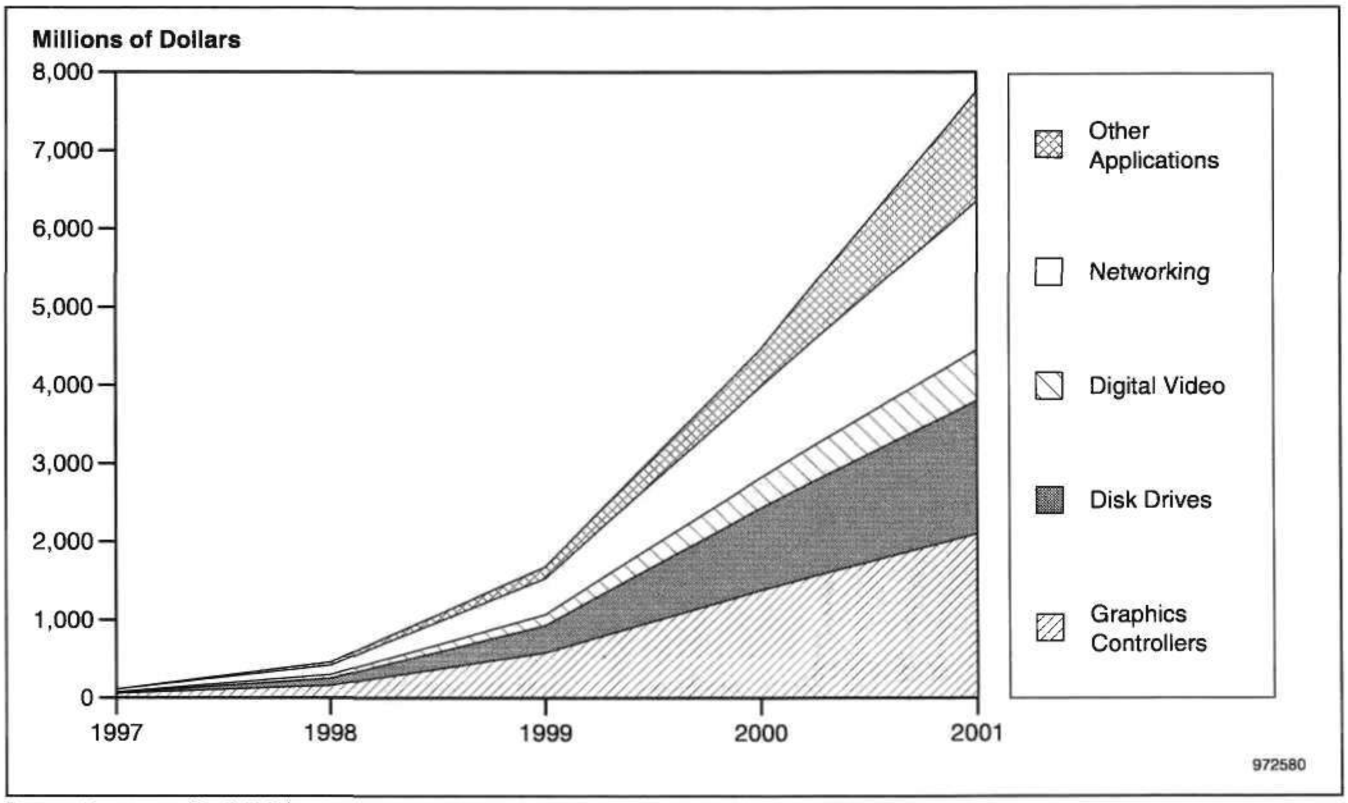
On an application basis, the growth in the embedded DRAM market is dominated by three applications: graphics controllers, disk drive controllers, and networking (LAN/WAN hubs and switches), which will account for almost 75 percent of the total in 2000.

Table 4
Worldwide Embedded DRAM Revenue Forecast by Application
(Millions of Dollars)

	1997	1998	1999	2000	2001
Graphics Controllers	60	160	580	1,380	2,100
Disk Drives	5	90	350	1,050	1,700
Digital Video	10	50	140	390	650
Networking	35	120	460	1,160	1,900
Other Applications	0	40	150	480	1,400
Total Embedded DRAM	110	460	1,680	4,460	7,750

Source: Dataquest (April 1997)

Figure 4
Embedded DRAM Forecast



Source: Dataquest (April 1997)

Forecast Variance

For each application, Dataquest also evaluated risk factors in the forecast (note that risk refers to upside as well as downside potential). These have been aggregated and result in the total embedded DRAM forecast distribution in Figure 5. Downside scenarios include:

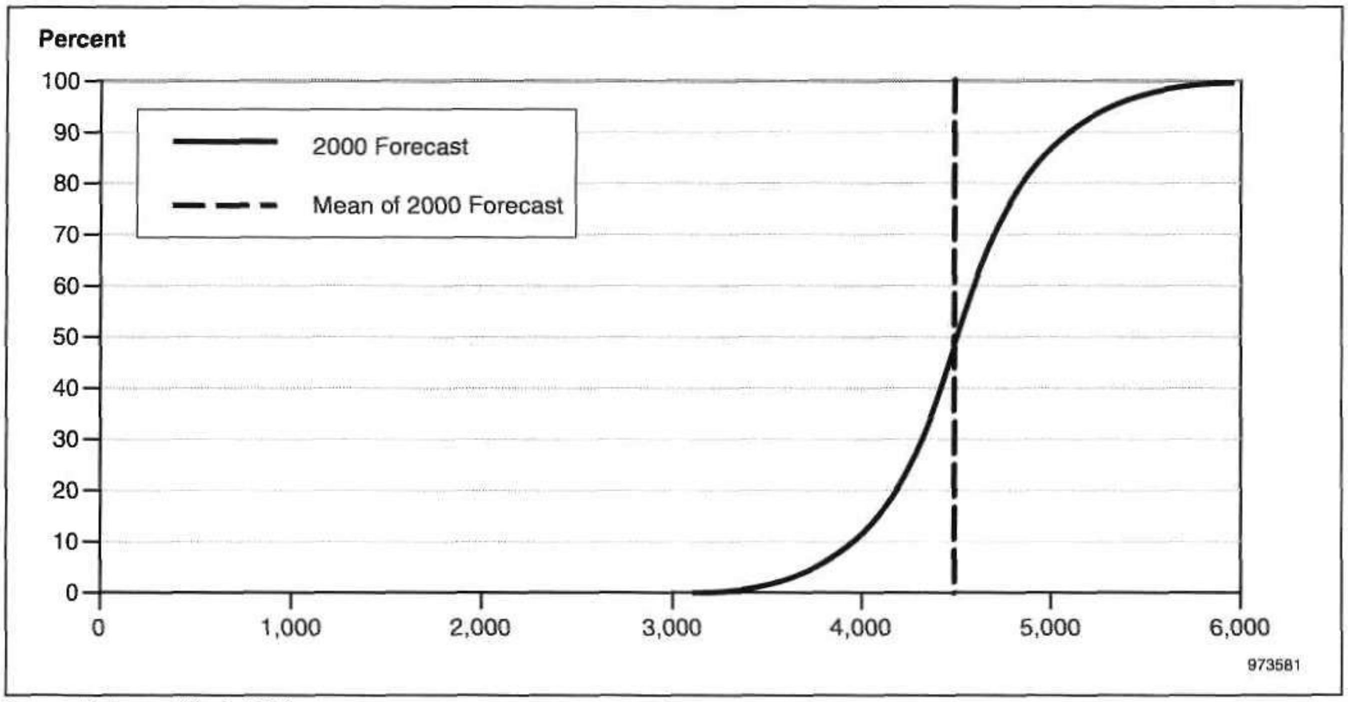
- A faster-than-expected decline in the price of standalone DRAMs, making embedded memory less cost-competitive in some markets
- Delays in the production ramp of 0.25-micron ASIC technology
- Mainstream, cost-effective production capability of alternate technologies such as MCMs

Conversely, upside scenarios to the baseline include:

- A lack of memory production capacity, leading to a price increase in standalone DRAMs
- Accelerated introduction of 0.18-micron ASIC technology, with even greater levels of embedded DRAM
- Increasing demand for memory-intensive, highly cost-sensitive consumer applications

Figure 5 shows the cumulative probability distribution of the embedded DRAM forecast for 2000; that is, based on the above factors, there is a 10 percent probability that the worldwide revenue will be below about $3,900 million and a similar probability that the revenue will exceed about $5,100 million. Equivalently, the 2000 forecast can be considered as normally distributed, with a mean of about $4,500 million and a standard deviation of about $450 million.

Figure 5
Embedded DRAM Revenue Forecast Cumulative Probability Distribution, 2000



Source: Dataquest (April 1997)

Dataquest Perspective

Just as embedded microprocessors represented a quantum leap in ASIC capability, embedded DRAM brings system-level integration one giant step closer to fulfillment. Although the technology enabling practical embedded DRAM is relatively recent and some technical trade-offs and questions remain, it is clear that this is a market poised for explosive growth. Many of the application areas with the highest growth potential, such as graphics controllers, require this technology to realize that growth. Within a few years, embedded DRAM will join processor cores as part of the technology portfolio required of an ASIC vendor in pursuit of high-end business.

The embedded DRAM scenario is somewhat similar to that of embedded 6T SRAM. SRAM was brought onto the ASIC in about 1990. Today, seven years later, a majority of ASICs (and virtually all of the SLI designs) contain some 6T SRAM. Embedded DRAM will see a ramp at least as fast as SRAM as the demand for memory bits continues to skyrocket. While embedded DRAM is clearly going to have a profound influence on the ASIC industry, the standalone DRAM industry should remain relatively untouched by this trend over the next five years.

Looking qualitatively beyond 2001, Dataquest sees continued strong growth for embedded DRAMs—to the point where a majority of SLI ASICs and ASSPs will contain some amount of embedded 1T memory. Even programmable logic is likely to embrace this technology at some point beyond 2001 in the form of large fixed memory blocks. This likelihood should serve as a warning flag to all industry participants that they must develop an embedded DRAM solution or risk relegation to a low-margin, commodity niche of the ASIC market.

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Perspective

Semiconductor Contract Manufacturing Services Worldwide

Market Analysis

1996 Fabless Semiconductor Review

Abstract: *Fabless semiconductor revenue growth slowed in 1996, reflecting general market conditions in the semiconductor industry, but fabless companies continued to outperform the industry as whole. Product diversification in nonmemory applications insulated the fabless companies to some extent from the severe price pressure that brought down the rest of the semiconductor market. Strong demand for advanced computer graphics, networking, and wireless communications products continues to provide a solid foundation for growth among fabless semiconductor companies.*
By James F. Hines

Fabless Companies Continue to Outperform the Semiconductor Market

The year 1996 was difficult for the semiconductor industry. Dramatic declines in DRAM prices heralded the end of yet another boom cycle. Against this rather gloomy backdrop, the fabless semiconductor companies provided a reason for optimism, with the segment showing positive growth in spite of the general industry downturn. Although the fortunes of individual fabless companies varied, the upward trend of the group lends credence to the notion that the fabless business model is successful and is here to stay.

Fabless semiconductor company revenue grew 8 percent in 1996 to $6.8 billion. Although this is a far cry from the 46 percent growth of the previous year, fabless companies did quite well relative to the rest of the semiconductor industry, which declined by 6.3 percent to $141.7 billion. Once again, fabless companies grew faster than the overall semiconductor market, advancing their collective share to 4.8 percent of the total, compared to 4.2 percent in 1995.

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Table 1 lists the top 50 fabless semiconductor companies and their reported revenue for 1995 and 1996. The fabless sector is very dynamic, with new start-ups being launched and older ones being absorbed through mergers and acquisitions. Brooktree, a pioneer of the fabless model, was acquired by Rockwell. Since Rockwell is not fabless, revenue from the sale of Brooktree products is no longer included in Dataquest's fabless total. Western Digital sold its semiconductor product lines to Philips, Adaptec, and Vixel; the $70 million reported for 1996 is for sales recognized before the transactions were completed. Several companies moved into the top 50 for which we do not have 1995 results, including Sun Microsystems, ATI Technologies, VIA Technologies, Zoran, Chip Express, and 3Dlabs.

Table 1
Top 50 Fabless Semiconductor Company Revenue, 1995 to 1996
(Millions of U.S. Dollars)

1995 Rank	1996 Rank	Company	1995	1996	Change (%)
1	1	Cirrus Logic	1,003	891	-11
2	2	Xilinx	520	566	9
3	3	Altera	402	497	24
4	4	S3	315	464	47
21	5	ESS Technology	106	227	114
17	6	Adaptec	124	214	73
8	7	Lattice	186	200	8
12	8	Sierra Semiconductor	143	188	31
13	9	Trident Microsystems	139	180	29
25	10	Oak Technology	84	172	104
NA	11	Sun Microsystems	-	170	NA
7	12	Cyrix	212	161	-24
18	13	Eupec	120	160	33
14	14	Chips & Technologies	138	151	9
16	15	C-Cube	125	150	20
20	16	Actel	109	149	37
NA	17	ATI Technologies	-	130	NA
15	18	Silicon Integrated Systems	127	127	0
9	19	OPTi	167	119	-29
27	20	Level One Communications	78	112	44
10	21	Integrated Silicon Solutions Inc.	158	111	-30
NA	22	VIA	-	110	NA
11	23	Exar	147	96	-35
39	24	Silicon Storage Technology	35	91	160
23	25	TCS	100	83	-17
24	26	Integrated Circuit Systems	97	79	-19
6	27	Alliance Semiconductor	220	76	-65
5	28	Western Digital	240	70	-71
28	29	Q Logic	61	68	11

Table 1 (Continued)
Top 50 Fabless Semiconductor Company Revenue, 1995 to 1996
(Millions of U.S. Dollars)

1995 Rank	1996 Rank	Company	1995	1996	Change (%)
30	30	DSP Group	60	67	12
33	31	Micro Linear	54	55	2
34	32	Catalyst	48	54	13
28	33	Quality Technologies	61	52	-15
36	34	Integrated Information Technology	44	51	16
26	35	Acer	80	50	-38
38	36	WaferScale Integration	36	48	33
35	37	Quality Semiconductor	46	46	0
37	38	ACC Microelectronics	40	45	12
31	39	Information Storage Devices	56	41	-26
40	40	Seeq Technology	27	32	19
NA	41	Zoran	-	29	NA
22	42	Tseng Labs	105	26	-75
42	43	QuickLogic	16	25	56
NA	44	Chip Express	-	24	NA
32	45	Paradigm	55	23	-58
44	46	Symphony Laboratories	15	17	11
45	47	G-Link USA	14	15	7
41	48	Logic Devices	17	14	-16
NA	49	3Dlabs	-	14	NA
42	50	International CMOS Technology	16	12	-25
18	NA	Brooktree	120	-	NA
		Other Fabless Companies	236	254	8
		Total Fabless Companies	6,302	6,806	8

NA = Not available
Source: Dataquest (May 1997)

Fabless Product Segmentation

Part of the reason that fabless companies fared so well is that they are less reliant on memory products, especially DRAM, and therefore they were not subject to the wild pricing swings characteristic of that market over the last year and a half. Table 2 presents a breakdown of fabless revenue by product type, and indeed memory is the only segment that declined in 1996. The 31 percent drop in revenue was probably a result of price pressures in the SRAM and DRAM markets, but because this segment represents less than 10 percent of the fabless total, its effect on the whole was minimal.

The fabless sector is dominated by microcomponents (microprocessors and specialty microperipherals, such as 3-D graphics controllers, audio controllers, and core logic chipsets), which represent over half of the fabless revenue. Fabless revenue in this important segment grew 13 percent in 1996, establishing the foundation on which the year's growth was built. Although the largest fabless company, Cirrus Logic, posted a decline of 11 percent, several other microcomponents suppliers had strong gains. Personal computer graphics companies such as S3, Trident Microsystems, and ATI Technologies saw their businesses grow. ESS Technology, a supplier of audio controller products, had an exceptional year, its 114 percent growth giving it the fifth-highest revenue of all fabless companies.

Table 2
Fabless Semiconductor Revenue by Product Type, 1995 to 1996 (Millions of U.S. Dollars)

Segment	1995	1996	Year-to-Year Change (%)
MPU/Microcontroller/Microperipheral	3,230	3,659	13
PLD	1,277	1,479	16
Memory	633	435	-31
Analog/Mixed Signal	753	772	3
Others	409	461	13
Total	6,302	6,806	8

Source: Dataquest (May 1997)

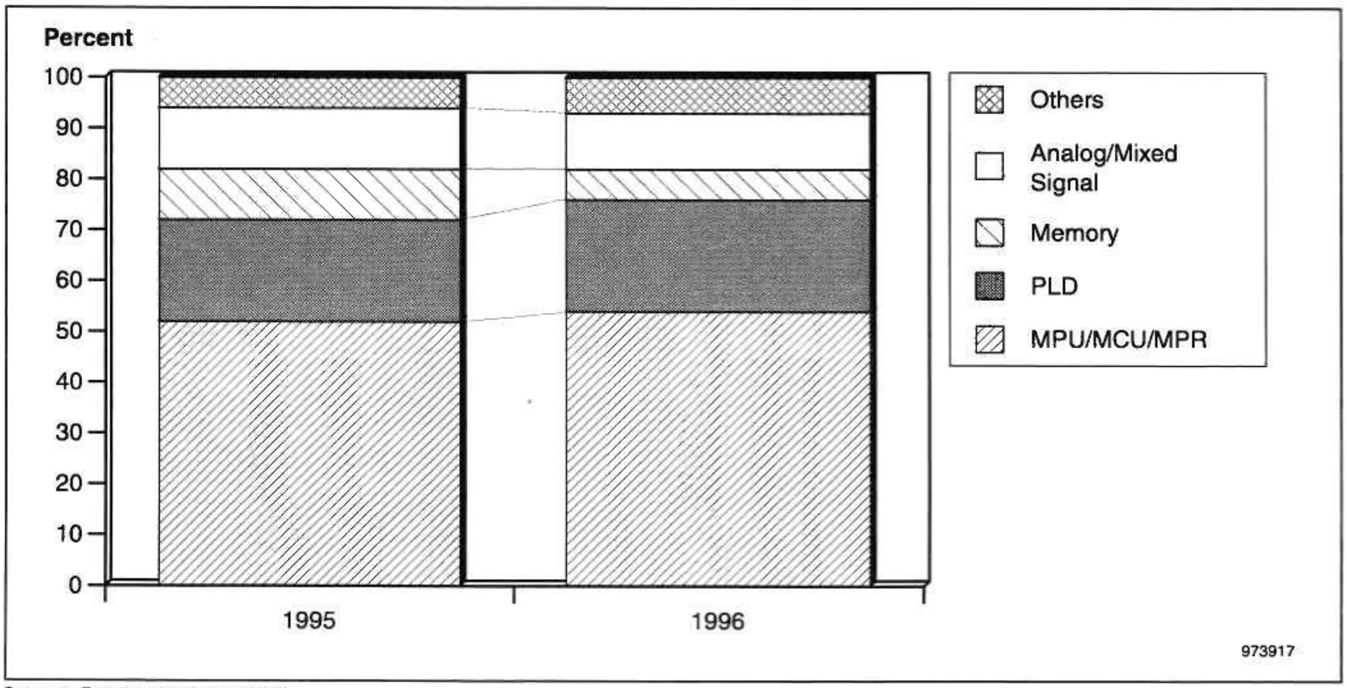
The programmable logic device (PLD) segment had the highest growth at 16 percent. Although there are relatively few fabless companies participating in this market, notably Xilinx, Altera, Lattice, and Actel, it represents the second-largest product segment for the fabless industry. PLDs contributed 22 percent of fabless revenue in 1996, up from 20 percent in 1995 (see Figure 1). By their very definition, PLDs are suited to a wide range of applications, providing a measure of insulation from the vagaries of the personal computer market. Also, with fewer players and significant barriers to entry, the PLD market is less subject to competitive pricing pressures than memory and other personal computer-related products.

Analog and mixed-signal products produced by fabless companies recorded a 3 percent gain in revenue for 1996. Sierra Semiconductor and Level One Communications both had a good year, with revenue growth of 31 percent and 44 percent, respectively. However, several of the other analog and mixed-signal suppliers, such as Exar, Microlinear, and Integrated Circuit Systems, had a flat or down year in 1996. Why did the fortunes of companies vary so much within this segment? Given the ready availability of wafers from foundry suppliers (even for these somewhat specialized process flows), the difference must be attributed to the product strategies being employed by these companies over the last year. Although the results were mixed this year, Dataquest expects this segment to grow rapidly in the coming years, fueled by increasing demand for high-speed data communications and wireless telecommunications products.

Fabless Company Growth Not Limited by Foundry Capacity

What a difference a year makes. When Dataquest published the "1995 Fabless Semiconductor Review" (SCMS-WW-DP-9601, May 20, 1996) at this time last year, a major topic of discussion was the capacity-constrained supply of foundry wafers and the limiting effect it was having on the growth of fabless companies. Although fabless revenue grew 46 percent in 1995, the consensus of the industry was that this number could have been higher had it not been for a shortage of wafers from semiconductor contract manufacturing (SCM) suppliers. Only when fabless semiconductor companies had access to an adequate supply of foundry-processed wafers, particularly with leading-edge process technology, would they realize their full potential.

Figure 1
Fabless Semiconductor Revenue by Product Type, 1995 to 1996



Source: Dataquest (May 1997)

Thanks to aggressive capacity expansion by foundry companies and the entry of major Korean integrated device manufacturers (IDMs) into the foundry business, the undersupply problem in the SCM market has been corrected. In fact, it could be accurately described as an overcorrection, and it happened even sooner than expected, with declining wafer prices appearing in the first half of 1996. When Dataquest surveyed SCM users and suppliers in March 1997, prices had declined rapidly, and even 0.35-micron wafer prices were being discounted, a clear indication that the entire SCM market, including the leading edge, had entered oversupply. (For a report of the March 1997 survey results and an analysis of foundry wafer pricing trends, see "Semiconductor Contract Manufacturing Wafer Pricing Trends," SCMS-WW-DP-9703, May 12, 1997.)

With an abundant supply of wafers available, why was fabless revenue growth lower in 1996 than in previous years? Of course, fabless companies were affected by the same dynamics that caused the overall semiconductor market to decline. It is also possible that lower wafer costs encouraged price competition among some fabless players, with the resulting lower average selling prices moderating revenue growth to some extent. This behavior would have been most evident in the memory segment, which is characterized by commodity products, but it was probably at work in the other segments as well, with varying degrees of competitive intensity. The PLD market would have been least susceptible, because of its relatively high barriers to entry, and indeed, the PLD segment had the strongest gains, as we have seen. With the SCM market projected to remain in oversupply through 1999, pricing pressures might be expected to continue in the fabless sector, and that may lead to some margin erosion among fabless companies.

Fabless Companies Positioned in High-Growth Applications

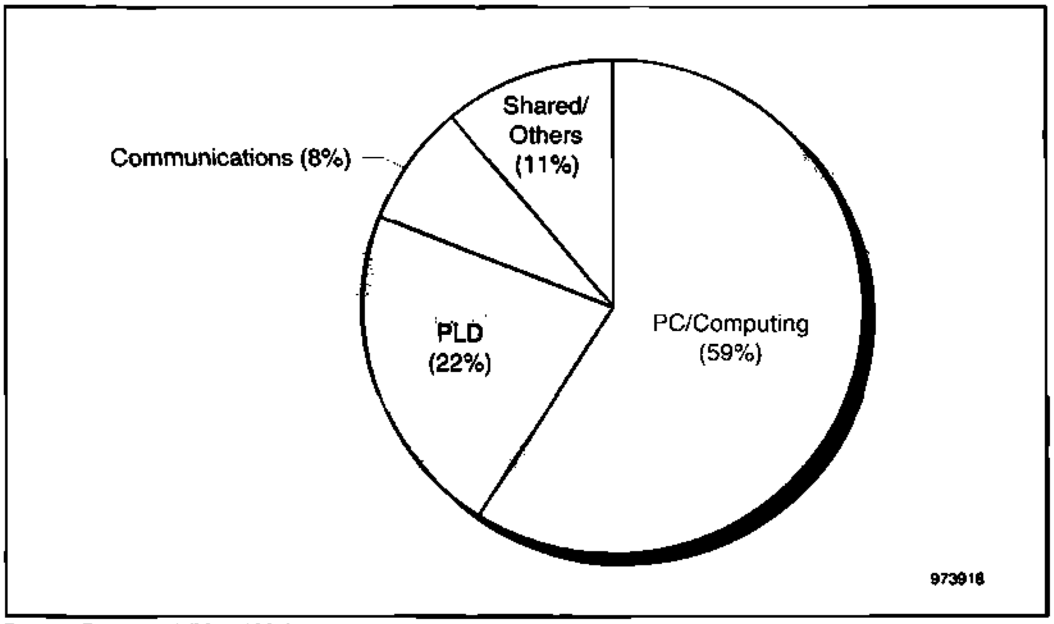
Regardless of competitive pricing pressures, the long-term prospects of fabless companies look very good indeed. Fabless companies are participating in some of the most exciting and fastest-growing semiconductor applications. This is not surprising, because the fabless model facilitates innovation and rapid product development, qualities necessary for success in the fast-changing markets created by these emerging applications.

Figure 2 presents a breakdown of 1996 fabless revenue by application. As expected, the majority of fabless products find their way into personal computers and other data processing or computing systems. This huge market provided 59 percent of fabless revenue in 1996. Many of the microcomponents (graphics and imaging controllers, audio processors, mass storage controllers, and core logic chipsets) and some of the memory (DRAM and SRAM) make up this application segment. The personal computer has long been the primary engine of semiconductor demand growth, and while other applications are gaining in importance, none can be expected to take its place anytime soon. With such a strong fabless presence in personal computer-related applications, this market will be the cornerstone of fabless sector growth.

Because they can be used in a wide variety of user-defined applications, PLDs are included as a standalone application segment. The PLD market appears to have become the unique province of a few fabless companies, as previously described. The relatively high level of differentiation in products and services offered by PLD suppliers creates a barrier to entry that will help these companies maintain their dominant position. Although this segment can be expected to show reasonable revenue growth, it may become a smaller part of the fabless total as other, faster-growing, applications consume a larger portion of the output of fabless companies.

The communications segment consists of both telecommunications and data communications applications. This is probably the fastest-growing application area, driven by rapidly accelerating worldwide demand for wireless communications and computer networking products. Again, fabless companies can take advantage of their agility to quickly develop new products that will address the special requirements of these applications as they emerge. Perhaps more than in any other segment, the fabless-foundry partnership will be crucial to ensure the availability of mixed-signal process technology to meet the needs of these applications. At 8 percent of 1996 revenue, communications-related applications are the smallest segment, but Dataquest expects this area to become an increasingly important part of the fabless picture in the future.

Figure 2
Fabless Semiconductor Product Applications, 1996



Source: Dataquest (May 1997)

The "shared/others" category includes those products that can be applied across a range of end-use markets or that simply do not fit into one of the previously defined application segments. Some of these include application-specific IC (ASIC) products, certain memory devices such as flash and EEPROM, and specialty integrated circuits. As parts of this group grow into larger and more definite application areas, they will be broken out and tracked separately.

Dataquest Perspective

In the context of the overall semiconductor market, 1996 has to be considered a good year for fabless companies. Most fabless companies saw their businesses grow at a time when many semiconductor manufacturers were experiencing the opposite trend. As a result, the fabless slice of the semiconductor pie is becoming ever larger, and the fabless model is now widely accepted as a permanent part of the industry infrastructure. Fabless companies are supplying products to the fastest-growing semiconductor applications, and now they have access to sufficient foundry manufacturing capacity to bring these products into volume production, so they can expect to capture an even greater share in the years to come. Fabless companies could make up over 6 percent of the semiconductor market by the year 2000.

The current oversupply in the foundry industry and its effect on pricing are reminders that, although fabless companies differ in significant ways from their IDM counterparts, they are subject to the same market dynamics and supply/demand fluctuations. Price competition brought on by increased foundry capacity and lower wafer costs could cause a shakeout among fabless companies in some of the more competitive markets, and fabless companies and foundries alike should not expect their businesses to be immune to the boom and bust cycles that are all too familiar to semiconductor industry veterans.

The foundry-fabless model works, and the performance of the fabless sector in 1996 is further evidence of that fact. Concentration of capital in the large fabs of foundry companies has dramatically lowered the cost of entry into the semiconductor market for dozens of fabless start-up companies. Division of R&D investment has given fabless companies a time-to-market advantage by allowing them to focus their efforts on product design and systems integration issues while the foundries take care of process technology development. Dataquest believes the fabless foundry model will continue to grow in importance, and it will dramatically change the complexion of semiconductor manufacturing in the future.

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Perspective

Semiconductor Contract Manufacturing Services Worldwide

Market Analysis

Semiconductor Contract Manufacturing Wafer Pricing Trends

Abstract: *This Perspective summarizes the results of Dataquest's March 1997 survey of semiconductor foundry wafer prices and compares current prices to those from previous surveys. Wafer pricing trends are analyzed in the context of current supply/demand dynamics in the wafer foundry industry. A comparison is made to recent developments in the DRAM market, and some conclusions are drawn relative to future trends in foundry wafer pricing.*
By James F. Hines

Dataquest conducted a worldwide semiconductor contract manufacturing (SCM) foundry wafer pricing study in March. A large number of SCM users and providers were surveyed and reported prices paid and charged in March 1997 for 150mm and 200mm foundry-processed CMOS wafers. The survey encompassed a variety of process technologies, categorized by minimum feature size and number of metal levels. Also, participants were asked to report prices for a number of special processing options, such as tungsten, chemical mechanical planarization (CMP), salicide, and epitaxial silicon. Finally, foundry users and suppliers were polled to obtain a consensus view on the expected change in wafer prices over the next six months.

Foundry wafer prices have continued to decline since Dataquest last surveyed the market in September 1996, reflecting the oversupply condition present in the SCM market. Prices dropped in all categories of process technology and wafer size except one. Not surprisingly, prices for special processing options have also gone down (compared to October 1995, the last time this element was surveyed). The consensus of survey respondents is that continued pricing pressure can be expected for at least the next six months.

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A Review of SCM Capacity Supply and Demand

Before discussing the details of the wafer pricing survey, a review of the dynamics of supply and demand currently operating in the SCM market may offer a useful perspective on the results. While demand for SCM capacity is expected to continue to grow at a steady pace through the end of the decade, there will be an even greater increase in the supply of SCM capacity. Much of the SCM capacity increase will be contributed by an abundance of new fab construction slated for the next few years. An analysis of the fab plans of dedicated foundry companies has shown that, over the next three years, new capacity will be put into place that is more than four times the total dedicated foundry output at the end of 1995. In addition to the dedicated foundries, there is a rising number of integrated device manufacturers (IDMs) offering foundry services. Most notable of these are the Korean IDMs, including Samsung and LG Semicon, which are offering ample leading-edge SCM capacity with very competitive wafer pricing.

This surge in SCM capacity supply caused Dataquest to revise our worldwide SCM capacity imbalance projection in December 1996. Dataquest assumes that a balanced supply-to-demand SCM market would require 5 percent to 10 percent higher supply than demand to account for the inevitable inefficiencies in matching customer requirements and supplier capability. We projected a 3 to 5 percent oversupply in overall SCM capacity in 1996, increasing to 8 to 12 percent in 1997, 20 to 23 percent in 1998, and peaking at 25 to 30 percent in 1999. The transition of the market from capacity constraint to oversupply began in the first half of 1996 and accelerated in the second half and into early 1997. The wafer prices reported in the surveys of September 1996 and March 1997 reflect this changing supply/demand picture, with generally accelerating price declines. Based on the projected oversupply, we can expect pricing pressure in the SCM market to persist for some time to come.

Because the SCM market is assumed to be price elastic, a continued downward trend in foundry wafer prices is likely to spur demand. Therefore, increased SCM capacity demand, ranging from 10 percent to 20 percent, has been built into the Dataquest SCM market forecast model. Price elasticity will, however, have only a modest ameliorating effect on the projected supply surplus. Dataquest believes the three years from 1997 through 1999, encompassing the 0.5-micron and 0.35-micron technology generations, will be a period of excess SCM capacity supply.

(For a more detailed discussion of this SCM capacity supply and demand analysis, please refer to the Market Trends report titled *Semiconductor Contract Manufacturing Wafer Pricing Trends*, (December 23, 1996, SCMS-WW-MT-9602.)

March 1997 SCM Wafer Pricing Update

Table 1 summarizes the results of the March 1997 foundry wafer pricing survey. Participants were asked to report prices paid for foundry processed wafers delivered during March 1997, assuming CMOS, unprobed wafers with 13 to 15 mask levels, single-level polysilicon, and no epitaxial silicon. The minimum volume requirement was set at 1,000 wafers per month.

Foundry service providers and users reported a relatively wide range of prices across all technology categories. This broad distribution of prices is characteristic of a dynamic pricing environment in which prices are changing rapidly, in this case, downward. Dataquest believes that most SCM suppliers now perceive the market as very competitive, and some aggressive players are offering low prices in an effort to capture, or just maintain, market share.

Table 1
March 1997 Foundry Wafer Prices (U.S. Dollars per Wafer)

	150mm Wafers		200mm Wafers	
Technology	Est. Average Price	Price Range	Est. Average Price	Price Range
1.0µm, 2-ML	505	320 to 650	NA	NA
1.0µm, 3-ML	542	360 to 650	NA	NA
0.8µm, 2-ML	573	400 to 750	1,116	NM
0.8µm, 3-ML	626	430 to 900	1,283	NM
0.6µm, 2-ML	641	470 to 950	1,305	1,000 to 1,625
0.6µm, 3-ML	696	500 to 1,100	1,453	1,100 to 1,875
0.5µm, 2-ML	760	570 to 1,175	1,547	1,300 to 1,975
0.5µm, 3-ML	793	600 to 1,050	1,693	1,400 to 2,200
0.35µm, 3-ML	NA	NA	2,347	1,850 to 3,000
0.35µm, 4-ML	NA	NA	2,514	2,000 to 3,450

NA = Not available
NM = Sample size too small to provide meaningful results
Note: ML refers to the number of layers of metal.
Source: Dataquest (April 1997)

Table 2 compares the estimated average wafer prices for the March 1997 survey to those of the survey completed in September 1996. With only one exception, prices for all process technologies declined, with average prices now 5 to 17 percent lower than six months ago. The exception is the price of 1.0µm, 2-ML, 150mm wafers, which actually increased by 8 percent. In general, lagging-edge technologies (0.8µm and greater for 150mm wafers and 0.6µm and greater for 200mm wafers) exhibited less pricing pressure than leading-edge technologies. Dataquest believes this difference in pricing behavior among the process technologies can be attributed to a developing oversupply condition in the leading edge of the market.

How Do the Perspectives of Buyers and Sellers Differ?

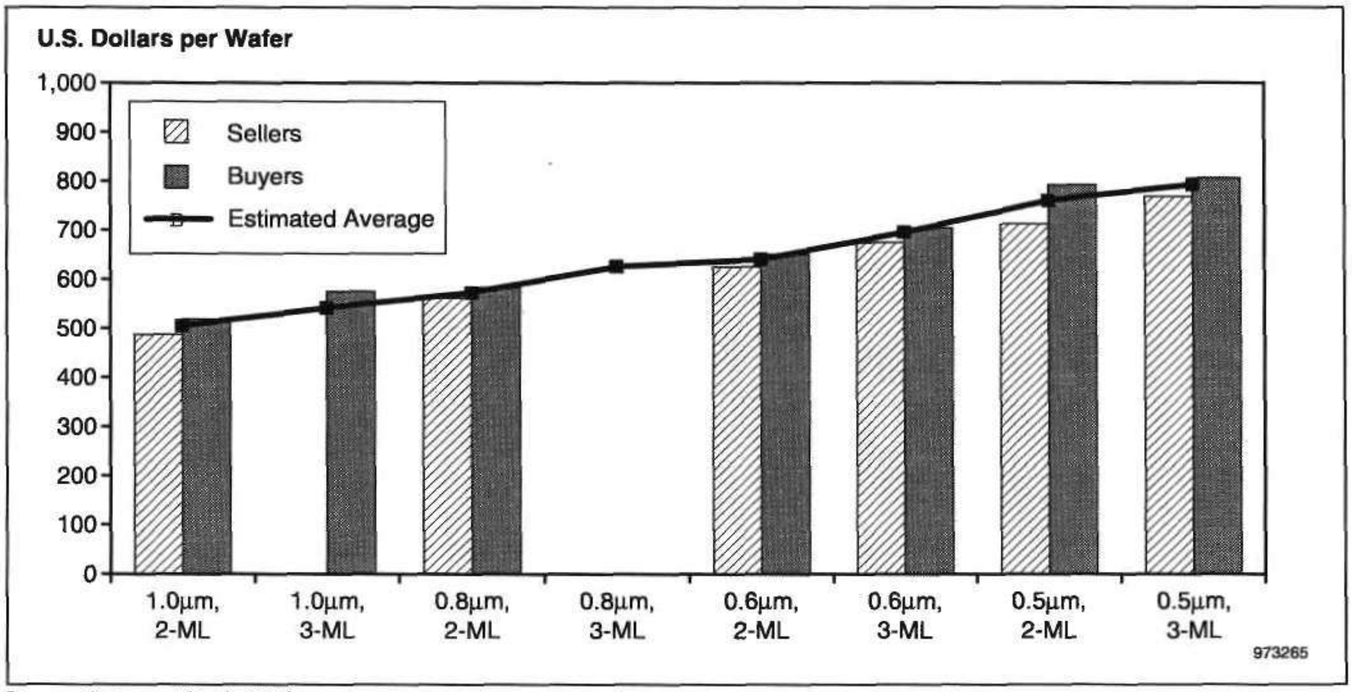
In comparison to the September 1996 survey results, the gap between responses of SCM service providers and users narrowed, with differences ranging from 10 percent to less than 1 percent. Figures 1 and 2 plot average prices reported by buyers and sellers, along with Dataquest's estimated average price, for 150mm and 200mm wafers, respectively. Note that prices for some of the categories are not shown because the sample size in those cases was not sufficient to provide a meaningful average value. At the time of the previous survey, the SCM market was making the transition to a buyer's market, and buyers were reporting prices significantly lower than those of sellers. The closer agreement of prices reported by buyers and sellers in the present survey could be an indication that the buyer's market is now widely recognized by buyers and sellers alike.

Table 2
Change in Average Foundry Wafer Prices—September 1996 to March 1997 (U.S. Dollars per Wafer)

	150mm Wafers			200mm Wafers		
Technology	Sept. 1996	Mar. 1997	Change (%)	Sept. 1996	Mar. 1997	Change (%)
1.0µm, 2-ML	466	505	8	NA	NA	NA
1.0µm, 3-ML	502	542	8	NA	NA	NA
0.8µm, 2-ML	613	573	-7	1,175	1,116	-5
0.8µm, 3-ML	673	626	-7	1,350	1,283	-5
0.6µm, 2-ML	738	641	-13	1,410	1,305	-7
0.6µm, 3-ML	799	696	-13	1,543	1,453	-6
0.5µm, 2-ML	850	760	-11	1,815	1,547	-15
0.5µm, 3-ML	912	793	-13	1,970	1,693	-14
0.35µm, 3-ML	NA	NA	NA	2,756	2,347	-15
0.35µm, 4-ML	NA	NA	NA	3,036	2,514	-17

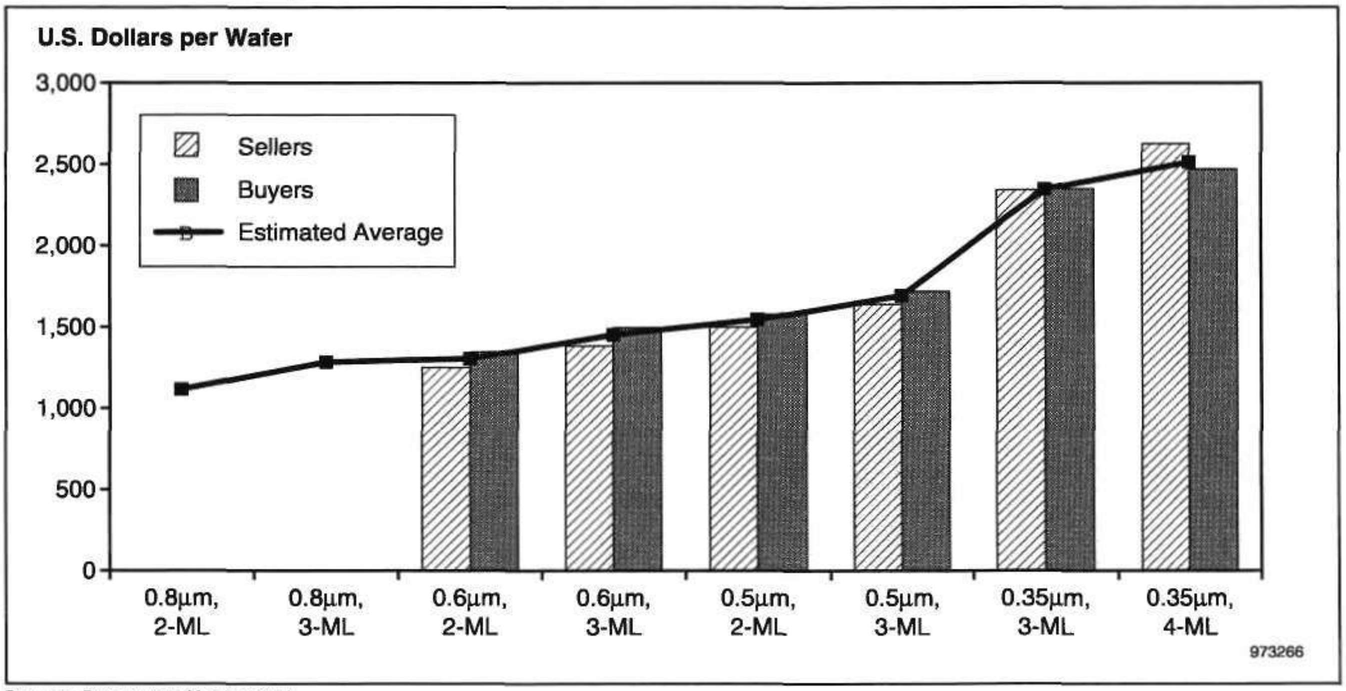
NA = Not available
Source: Dataquest (April 1997)

Figure 1
March 1997 Foundry Prices: 150mm Wafers



Source: Dataquest (April 1997)

Figure 2
March 1997 Foundry Prices: 200mm Wafers



Source: Dataquest (April 1997)

Some difference between the responses of buyers and sellers is normal in a survey of this type. What is interesting is the reversal of the relative bias of buyers versus sellers compared to the September 1996 survey. Six months ago, buyers reported lower prices than sellers across all process technology categories. This behavior was one of the elements contributing to the characterization of the SCM market as a buyer's market, with the buyers essentially driving prices. Now, sellers are reporting lower prices than buyers in all but one category. Does this mean the buyer's market has subsided? Probably not, since wafer prices have continued their rapid decline. However, it could indicate that SCM service suppliers have responded to the current competitive environment with a more aggressive pricing stance. It could also be a manifestation of the dynamics of rapidly falling prices in a changing market or simply that buyers are reporting contract prices that do not reflect recent pricing moves made by suppliers.

The exception to the buyer/seller bias reversal is 0.35µm, 4-ML, 200mm wafers, where buyers reported prices 6 percent lower than sellers, on average. Also, average prices reported by buyers and sellers at 0.35µm, 3-ML are almost identical. If we interpret this trend to mean that buyers are leading pricing in the 0.35 micron categories, then it is possible that the leading-edge segment of the SCM market is now making the transition to a buyer's market, and it can be expected to experience the greatest pricing pressure in the coming months. Indeed, another look at Figure 2 reveals that average prices for both of the 0.35 micron categories (3-ML and 4-ML) are noticeably higher than the trend line for the other categories, suggesting that they could be due for substantial downward price movement.

Advanced process technology has historically commanded a premium price. However, with 0.35 micron capacity now available from several sources, this segment of the market may be making the transition from an advanced "preproduction" phase to a more mature "production" phase, with its higher volumes and lower prices, accelerated, perhaps, by the developing oversupply condition at the leading edge of the market. In fact, although it is not reflected in the survey results, Dataquest is aware of at least one case of 0.35µm, 3-ML, 200mm wafers being quoted at less than the surveyed low of $1,850, which would place it right on the trend line mentioned earlier.

SCM Special Process Pricing

Table 3 shows prices reported for various special processing options. When Dataquest last surveyed prices for special processes in October 1995, all of the options listed involved some additional cost to the foundry customer. In other words, the low end of the price range was greater than zero. CMP was the most expensive process option for 200mm wafers and was not even available on 150mm wafers. Reviewing the ranges of prices reported in the March 1997 survey indicates that, in addition to generally lower prices, some suppliers are starting to include salicide, tungsten, and CMP processes in their basic wafer price. The standardization of these processes is most likely occurring at the 0.35-micron level. Tungsten plugs and CMP are already widely used in manufacturing, and they are becoming a necessity in multilevel interconnect structures with three, four, or more metal levels. Salicide is common in high-speed logic process flows, and it is probably in high demand by foundry users in the performance-oriented 0.35-micron segment. As foundries have gained experience with these process technologies, achieving more predictable and higher yields, it would be logical for SCM suppliers to begin offering them as standard processes, especially at the 0.35-micron level.

Table 3
March 1997 Foundry Wafer Process Option Pricing (U.S. Dollars per Wafer)

	150mm Wafers		200mm Wafers	
Process Option	Est. Average Price	Price Range	Est. Average Price	Price Range
Epitaxial Silicon	66	50 to 105	123	100 to 150
Salicide	60	0 to 150	77	0 to 180
Tungsten (per Level)	28	0 to 100	31	0 to 80
Polysilicon (above One Level)	74	40 to 105	120	60 to 180
CMP	44	0 to 75	49	0 to 150
Additional Mask Levels (above 15)	58	40 to 90	108	50 to 150

Source: Dataquest (April 1997)

Table 4 compares the estimated average prices of process options in the March 1997 survey to those reported in October 1995. Bear in mind that the price changes shown have occurred over an 18-month period, not six months as in our earlier discussion of basic wafer prices. Again, most prices have declined, but prices for epitaxial silicon and polysilicon on 150mm wafers increased by 14 percent and 7 percent, respectively. Incidentally, at 200mm, prices for these two process options declined the least. Foundry pricing for optional epitaxial silicon reflects the trend in underlying raw wafer pricing as epitaxial layers are typically done at the silicon supplier. The relative firmness in pricing of polysilicon levels may be an indication of increased focus on system-level integration (SLI)—putting DRAM on a logic chip. Formation of stacked capacitor structures requires complex polysilicon etch processes, contributing to higher costs for the additional polysilicon levels in SLI applications, which could be exerting upward pressure on average prices.

Table 4
Change in Average Foundry Wafer Process Option Prices—October 1995 to March 1997 (U.S. Dollars per Wafer)

	150mm Wafers			200mm Wafers		
Process Option	Oct. 1995	Mar. 1997	Change (%)	Oct. 1995	Mar. 1997	Change (%)
Epitaxial Silicon	58	66	14	144	123	-15
Salicide	109	60	-45	200	77	-62
Tungsten (per Level)	40	28	-30	90	31	-66
Polysilicon (above One Level)	69	74	7	140	120	-14
CMP	NA	44	NA	300	49	-84
Additional Mask Levels (above 15)	69	58	-16	170	108	-36

NA = Not available
Source: Dataquest (April 1997)

SCM Wafer Pricing Outlook

Dataquest asked SCM service providers and users to estimate how wafer prices would change over the next six months for 0.5- and 0.35-micron technologies. Table 5 shows the median responses for buyers and sellers and for the combined total. The group as a whole sees prices for 0.5-micron wafers dropping another 10 percent by September, with good agreement among buyers and sellers. However, buyers expect bigger declines in 0.35-micron wafer prices, dragging the median response of the group down to 13 percent for that category. The greater decline expected for 0.35-micron wafer prices is consistent with the increasing oversupply for this market segment discussed earlier. It is likely that pricing pressure will be strongest at 0.35 micron over the next six months.

Moderates and Extremists—Is There a Consensus?

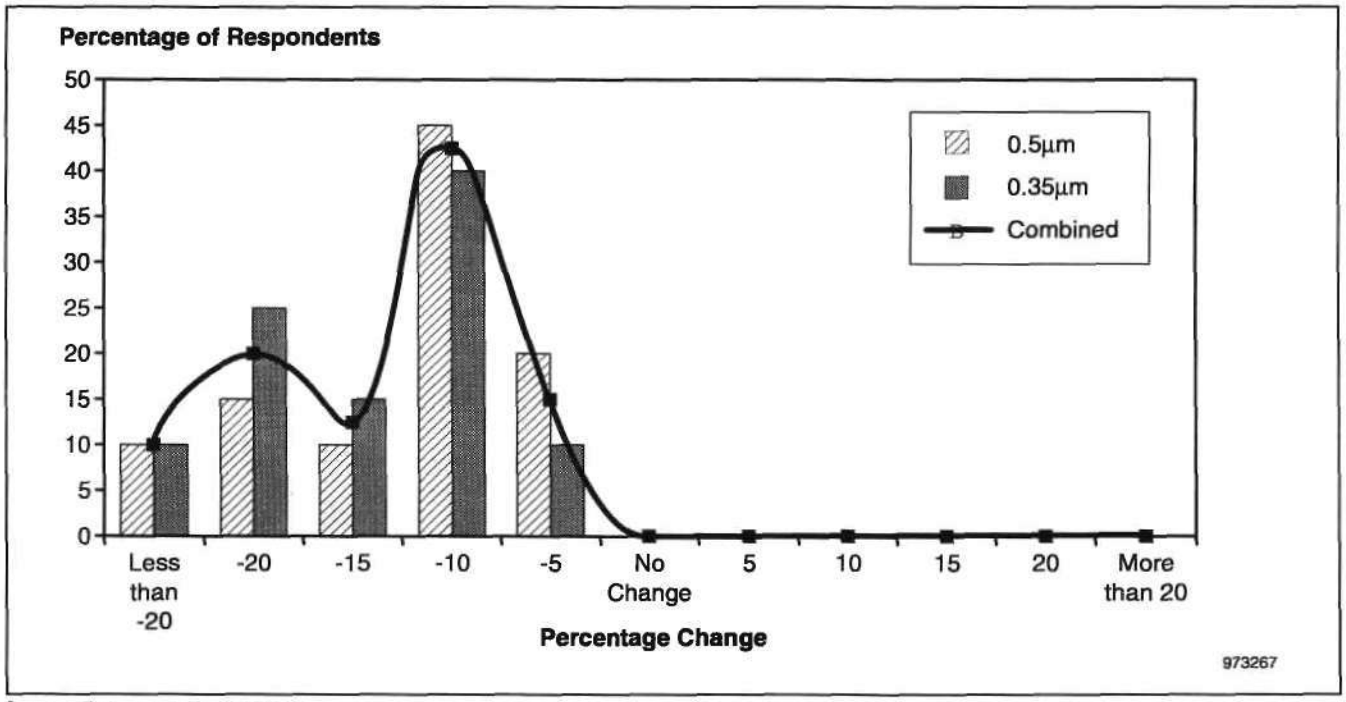
Figure 3 is a histogram of the responses for expected change in wafer prices, by 0.5- and 0.35-micron process technology, as well as the combined total. A bimodal distribution of responses is evident, suggesting that our survey respondents are split into two camps: the moderates and the extremists. The moderates are predicting price declines consistent with the trend of the past six months, about 10 percent on average. The extremists see a more precipitous drop ahead, expecting prices to plunge on the order of 20 percent over the next six months.

Table 5
Expected Change in Foundry Wafer Prices over Next Six Months

Median Response	0.5μm Wafers	0.35μm Wafers
Buyers	Down 10 percent	Down 15 percent
Sellers	Down 10 percent	Down 10 percent
Combined	Down 10 percent	Down 13 percent

Source: Dataquest (April 1997)

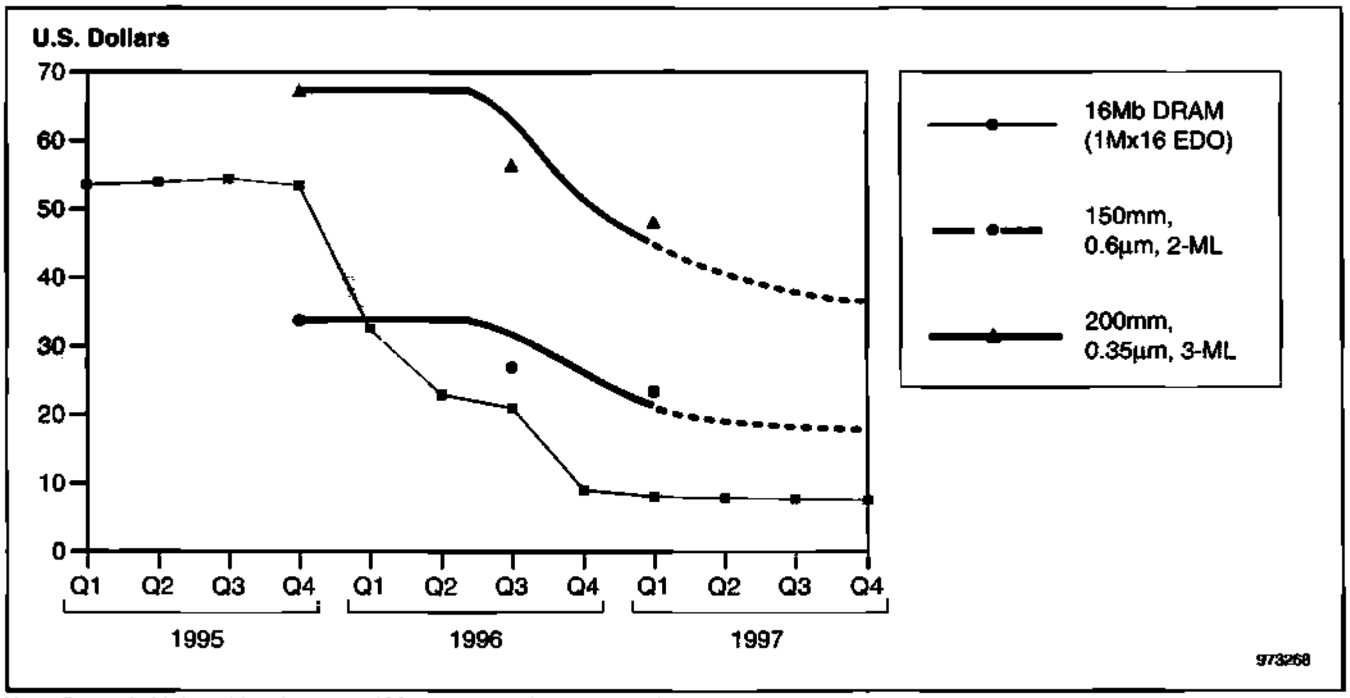
Figure 3
Histogram of Expected Change in Foundry Wafer Prices over Next Six Months



Source: Dataquest (April 1997)

Should we believe the moderates or the extremists? A brief examination of the recent behavior of DRAM price-per-bit trends may help us answer this question. Figure 4 shows a comparison of the trends in price per bit of 16Mb DRAMs and the price per square inch of 150mm, 0.6μm, 2-ML and 200mm, 0.35μm, 3-ML foundry-processed wafers from 1995 through 1997 (second, third, and fourth quarter 1997 prices are projections). Dramatic declines in price per bit began in the latter half of 1995, when the DRAM market went into oversupply, and continued through 1996, with some stability returning in early 1997 and small price declines projected for the remainder of the year. The price per bit dropped by more than 80 percent for both 4Mb and 16Mb DRAMs during this period.

Figure 4
Comparison of DRAM Price and Foundry Wafer Price-per-Square-Inch Trends



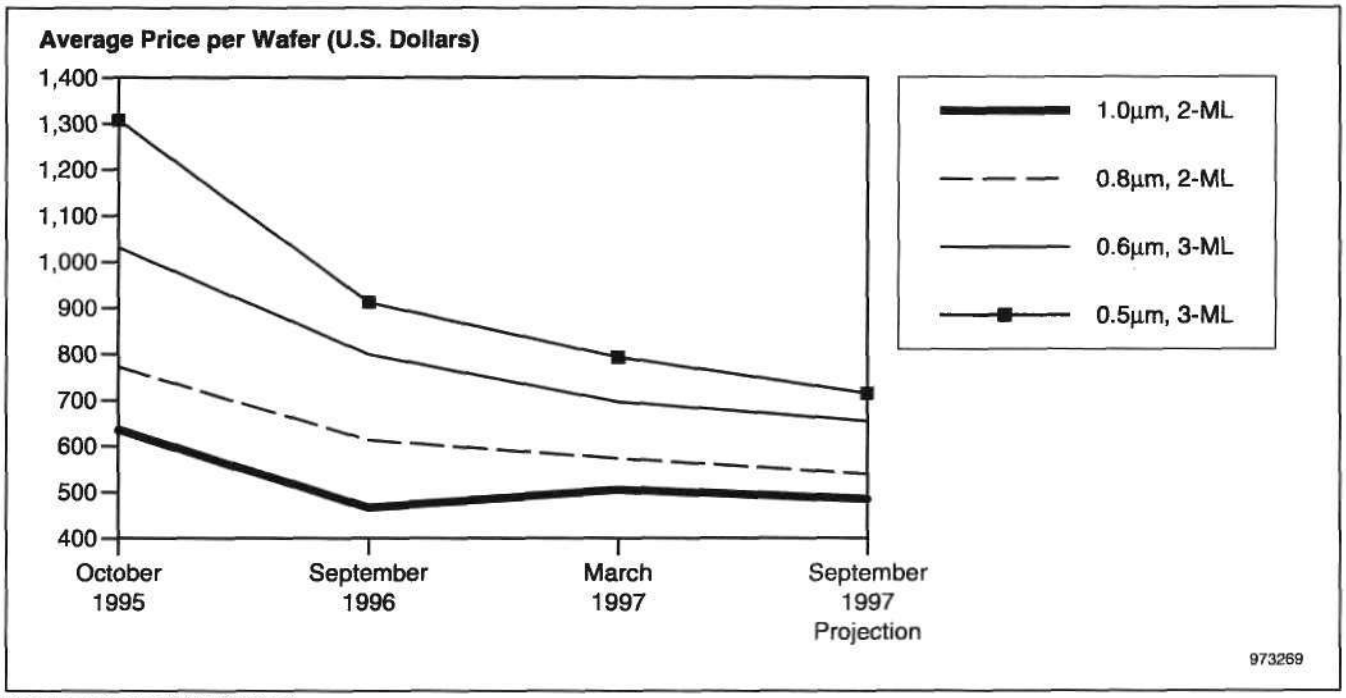
Note: Second, third, and fourth quarter 1997 prices are Dataquest projections.
Source: Dataquest (April 1997)

The transition of the SCM market to oversupply was evident around the middle of 1996, when prices began to drop. The SCM market is following the same trend as the DRAM market, but it appears to be lagging by nine to 12 months. If we were to assume that both markets are following the same periodic cycle, nine to 12 months out of phase, then we might be inclined to side with the extremists, arguing that foundry wafer prices still have a long way to drop before catching up with DRAM prices. Before accepting this conclusion, let us consider the fact that the 80 percent decline in DRAM prices we have just witnessed is the largest in the history of the DRAM market. While the cyclicity of the DRAM market is well known, the magnitude of the decline in price per bit during the down cycle has typically been much less, on the order of 40 to 60 percent. Dataquest expects the SCM market to follow the same cycle as the DRAM market, but we see no reason to believe it will experience the same magnitude of price decline. Figures 5 and 6 show historical and projected pricing trends for 150mm and 200mm wafers.

Dataquest Perspective

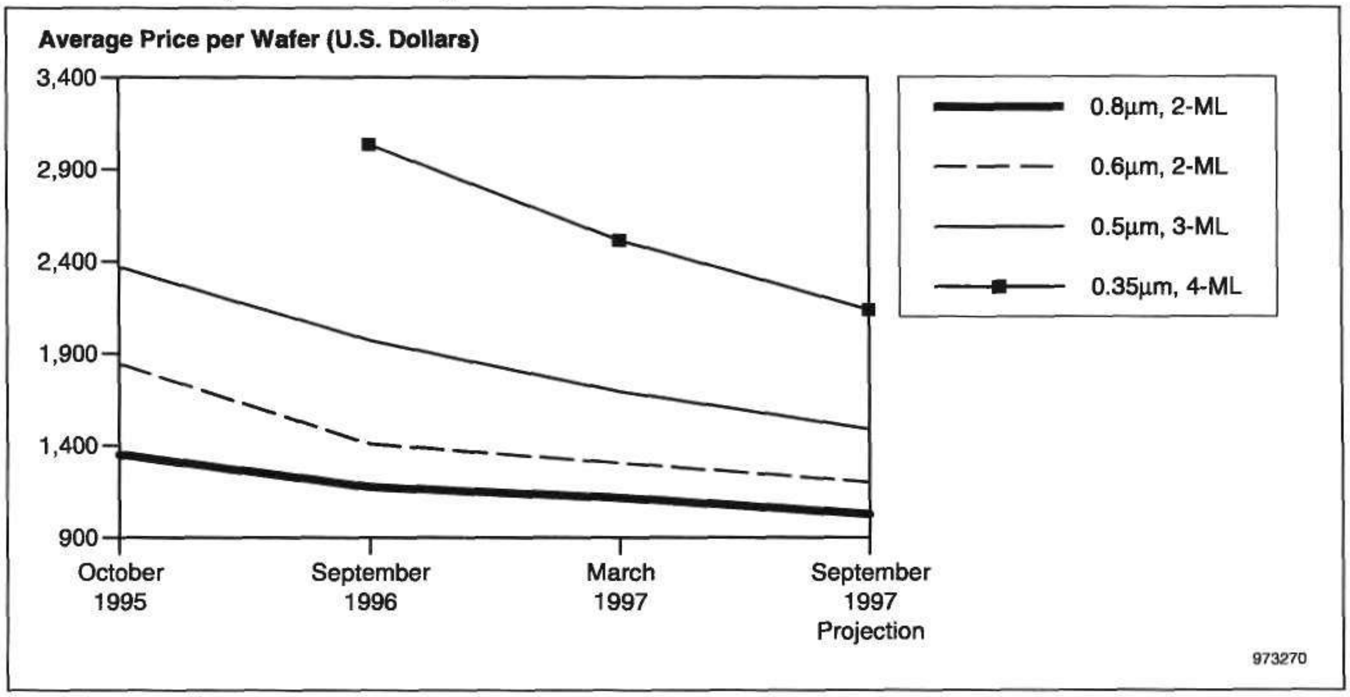
Foundry wafer prices have continued to decline since the last survey in September 1996, and this is consistent with the current oversupply in the SCM market. Leading-edge technologies, which had previously been selling at a substantial premium, led the decline in prices for this period. Prices for 0.35-micron wafers were hit particularly hard, and there is evidence that they have dropped further since the survey was conducted. These rapidly falling prices are a clear indication that the 0.35-micron segment is following the rest of the SCM market into oversupply.

Figure 5
150mm Foundry Wafer Pricing Trend



Source: Dataquest (April 1997)

Figure 6
200mm Foundry Wafer Pricing Trend



Source: Dataquest (April 1997)

SCM suppliers are aggressively expanding foundry capacity, based on current capital spending plans. The rapid expansion in SCM capacity will exacerbate the imbalance of supply and demand over the next year, creating an even stronger buyer's market and increasing downward pressure on prices. Although price elasticity in the SCM market will stimulate some incremental demand, it will not be sufficient to absorb the large surplus created by this aggressive expansion. Therefore, Dataquest expects foundry wafer prices to continue to weaken over the next six months, with the leading-edge technologies seeing the biggest declines.

Dataquest believes the SCM market is exhibiting the same supply/demand dynamics observed in the DRAM market of about one year ago. After a period of capacity constraint and stable prices, continued capacity expansion has moved the market into oversupply, causing a period of rapidly declining prices. With today's expansions in SCM capacity outstripping incremental demand, we must ask, is there a capital spending cut coming? We believe the health of the foundry industry would be well served by some restraint in this area.

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Perspective

Semiconductor Contract Manufacturing Services Worldwide

Event Summary

Telebriefing Summary: Is the Recovery Around the Corner in Wafer Fab Equipment? Or Will the Slowdown Extend into 1998?

Abstract: *Overcapacity in the DRAM market has now migrated to other parts of the semiconductor industry, most notably the foundry industry. While technology investment continues, there is a question about when a capacity-driven recovery in the wafer fab equipment market will occur. This Perspective is the complete transcript of the telebriefing held by Dataquest on January 3, 1997, with the release of the forecast update on capital spending and wafer fab equipment.*
By Clark J. Fuhs, Ronald Dornseif, Näder Pakdaman, and Calvin Chang

Opening Statement by Dataquest

Mr. Fuhs: Thank you. Welcome to Dataquest's telebriefing this morning. Our topic is from the Semiconductor Equipment, Manufacturing, and Materials (SEMM) group, and we track most aspects of the actual manufacturing of semiconductors worldwide. Today we will be discussing the outlook and forecast for wafer fab equipment and capital spending. We will also present our forecast for silicon wafers, supported by recent demand analysis tied to consumption patterns for semiconductor devices.

My name is Clark Fuhs, Director and Principal Analyst in the group and your host for the next hour. With me today are Näder Pakdaman, Calvin Chang, and Ron Dornseif, who are also analysts from the SEMM group. After a brief 15-to-20-minute review of our forecast, we will open up the session to your questions. You should have received a set of two tables and four figures, which visually describe some specific topics we will review.

Dataquest
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Filing: Perspective
(For Cross-Technology, file in the Semiconductor Regional Markets and Manufacturing binder)

Forecast Overview

Our group has just released its year-end semiconductor capital spending and equipment forecast. These are summarized in Tables 1 and 2 of your handout. Our forecast process has several cornerstones including semiconductor production by region, a worldwide database of existing and planned fabs, and independent comprehensive surveys of the equipment and semiconductor companies. We have just completed an update of the fab database, in which we have scrutinized planned fab activity worldwide.

Table 1
Capital Spending Forecast, 1995-2001 (Millions of U.S. Dollars)

	1995	1996	1997	1998	1999	2000	2001	CAGR (%) 1995-2001
Total Capital Spending	38,411	43,707	37,503	39,773	50,614	69,490	84,829	14.1
Percentage Growth	73.9	13.8	-14.2	6.1	27.3	37.3	22.1	
Americas	12,170	14,185	13,910	15,427	18,827	23,442	27,470	14.5
Percentage Growth	69.2	16.6	-1.9	10.9	21.4	25.2	17.2	
Japan	9,910	9,362	8,160	9,102	11,723	15,541	17,424	9.9
Percentage Growth	48.6	-5.5	-12.8	11.5	28.8	32.6	12.1	
Europe	4,137	4,756	4,228	4,209	5,563	7,195	8,308	12.3
Percentage Growth	65.2	15.0	-11.1	-0.4	32.2	29.3	15.5	
Asia/Pacific	12,194	15,405	11,205	11,035	14,599	23,312	31,627	17.2
Percentage Growth	113.2	26.3	-27.3	-1.5	32.3	59.7	35.7	

Source: Dataquest (January 1997)

Table 2
Wafer Fab Equipment Forecast, 1995-2001 (Millions of U.S. Dollars)

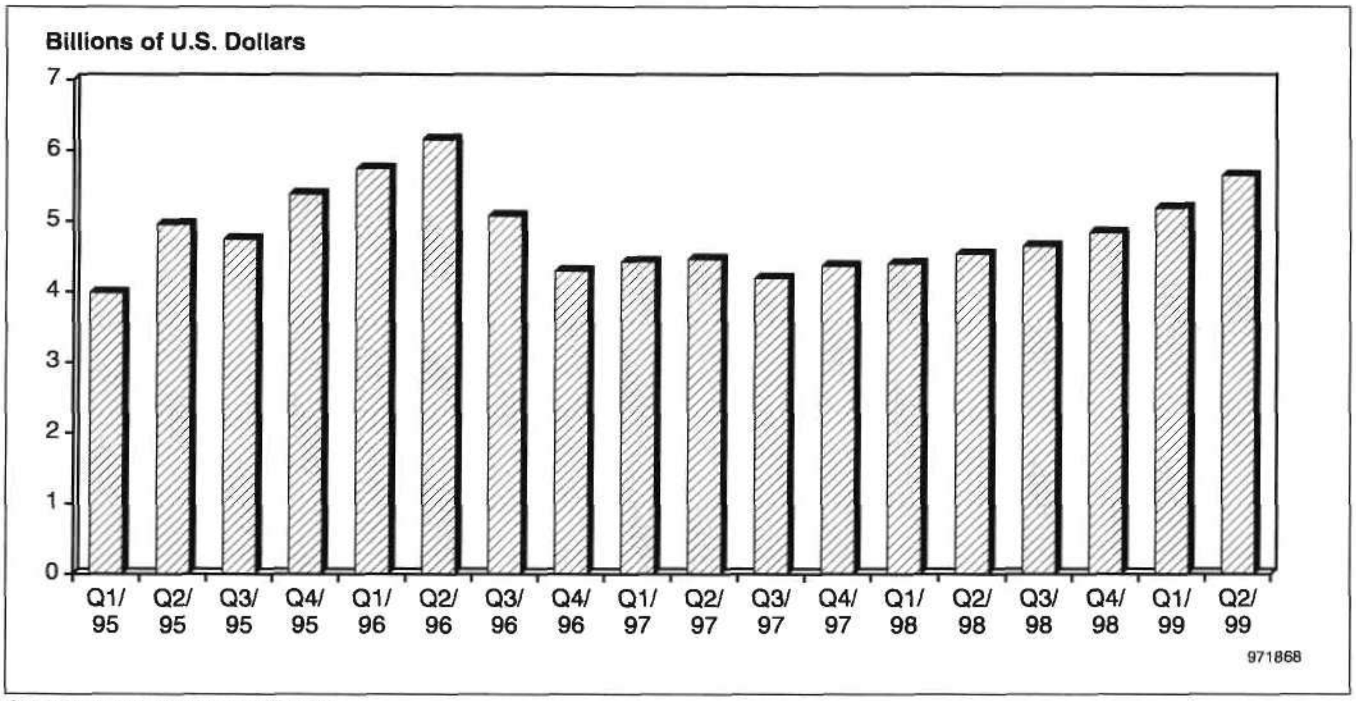
	1995	1996	1997	1998	1999	2000	2001	CAGR (%) 1995-2001
Total Wafer Fab Equipment	19,010	21,245	17,439	18,386	23,976	33,477	40,988	13.7
Percentage Growth	76.2	11.8	-17.9	5.4	30.4	39.6	22.4	
Americas	5,332	6,154	5,728	6,439	8,062	10,451	12,197	15.0
Percentage Growth	67.1	15.4	-6.9	12.4	25.2	29.6	16.7	
Japan	6,157	6,263	5,129	5,614	7,253	9,739	10,803	9.8
Percentage Growth	68.2	1.7	-18.1	9.5	29.2	34.3	10.9	
Europe	2,313	2,623	2,243	2,223	2,946	3,862	4,691	12.5
Percentage Growth	68.8	13.4	-14.5	-0.9	32.5	31.1	21.5	
Asia/Pacific	5,208	6,205	4,339	4,110	5,716	9,425	13,298	16.7
Percentage Growth	102.9	19.1	-30.1	-5.3	39.1	64.9	41.1	

Source: Dataquest (January 1997)

The survey results are one input into our several forecasting models, which include analysis of trends in semiconductor production, raw silicon consumption, spending ratios, investment cycles, new fab and expansion activity, stepper to DRAM price-per-bit analysis, and semiconductor revenue per square inch. Our forecast shows the following highlights:

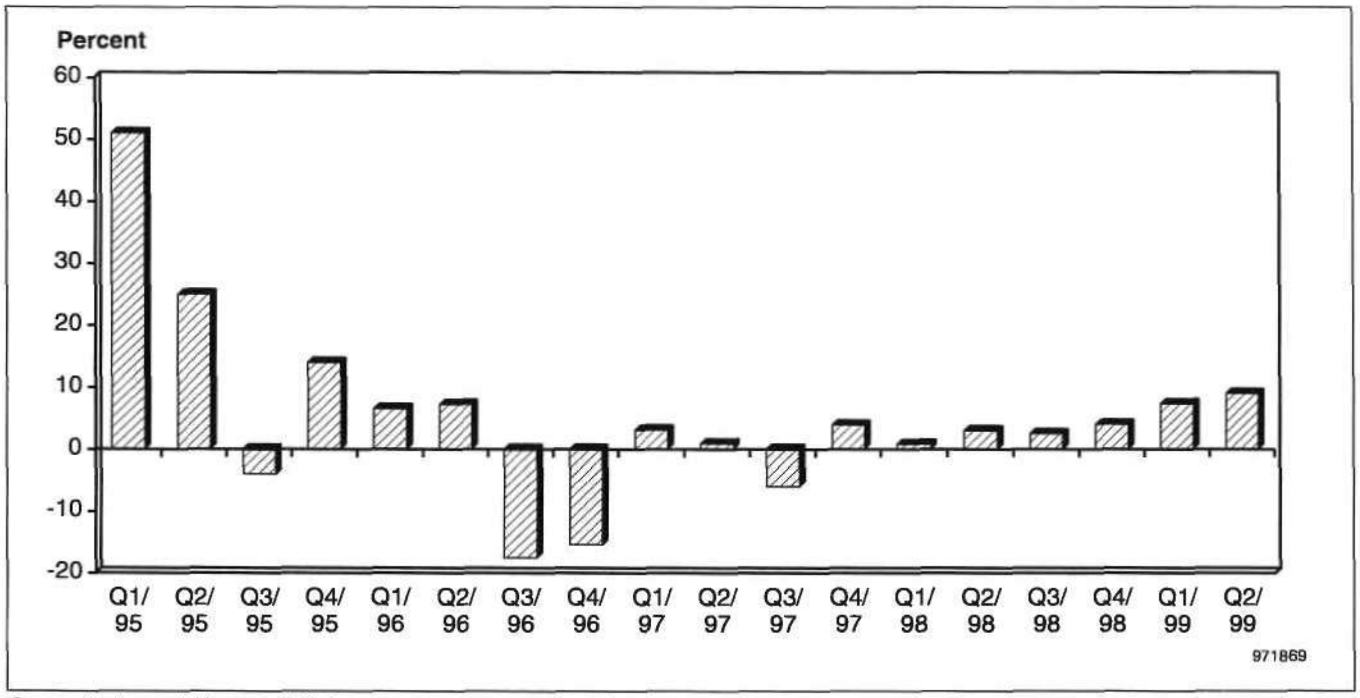
- The year 1996 was a year that turned from growth to decline, but the net growth was just under 12 percent in wafer fab equipment. We saw two distinctly different markets in the past year:
    - The first half was marked by many fab announcements, aggressive spending plans, and good bookings levels for equipment. The second half was the opposite: bookings collapsed, expansion delayed, and capital spending budgets cut.
- The only reason 1996 remains a double-digit growth year are that there were strong backlogs coming out of 1995. Our estimate was that the industry was at about a six-month backlog at the time, compared to a normal backlog of four months. The bookings decline has put pressure on backlog levels, and the industry has shipped down backlog now to more normal levels, with several companies below normal.
- Our top-line quarterly shipment forecast for wafer fab equipment is shown in your handouts in Figures 1 and 2. The second half of 1996 contained slightly more severe declines than we anticipated six months ago. If the fourth quarter 1996 run rate for wafer fab equipment shipments were to be held flat for all of 1997, the resulting decline would calculate to just over 15 percent for 1997.
- Our forecast for 1997 is for an 18 percent decline, which would suggest we believe we have not quite hit bottom yet, and indeed we are expecting bookings near the middle of 1997 to be disappointing.
- However, we anticipate that equipment companies, in the hope of improved bookings later in the year, to continue to ship down backlog in order to maintain a minimum financial performance, maintaining or increasing the run rates of fourth quarter 1996. We expect to reach a minimum three-month level backlog by the middle of 1997. At that time, with backlogs razor-thin, quarterly shipment rates are expected to be reduced to booking levels, leading to a sales dip in the third quarter of 1997.
- We do not expect sustainable bookings growth to support shipment growth until the middle of 1998, and shipment growth is expected to remain constrained until very late in the year. This quarterly outlook has produced the annual forecast of Table 2, showing 1998 as a single-digit growth year.
- We would expect supply/demand dynamics to be fully corrected by early 1999, driving a robust resumption of growth with the wafer fab equipment market growing to over $33 billion in the year 2000, from the just under $19 billion in 1998.

Figure 1
Wafer Fab Equipment Quarterly Revenue Forecast



Source: Dataquest (January 1997)

Figure 2
Wafer Fab Equipment Quarter-to-Quarter Sequential Growth Rates



Source: Dataquest (January 1997)

Even in the face of strengthening semiconductor demand currently under way today and strong end-use electronic equipment and PC markets, Dataquest has a relatively conservative view of the recovery in wafer fab equipment. Why? The answer is that the fundamentals of the overcapacity situation we are in today simply do not allow a large volume spending recovery to occur before mid-1998, even in the mainstream logic sector, which has traditionally been the part of the market less affected by the cycle.

Six months ago, we believed that the logic sector would be in a position to drive a capacity recovery late in 1997. Developments in the second half of 1996 in Asian company strategies and a deeper look into trends in silicon consumption have led us to change this belief.

We do not see a stoppage in advanced technology investments, indicating the continued belief in the customer base of a strong end-user market for semiconductors. In some respects, it is this and other "strategic" investments that are pushing out the timing of the recovery in our mind.

What do we mean by "strategic" investment? It is very normal in a downturn to get a pocket of companies that will stay and continue to invest in the infrastructure in order to position themselves for the next cycle. In 1997 and early 1998, several companies are expected to continue to make strategic investments. Examples of this are:

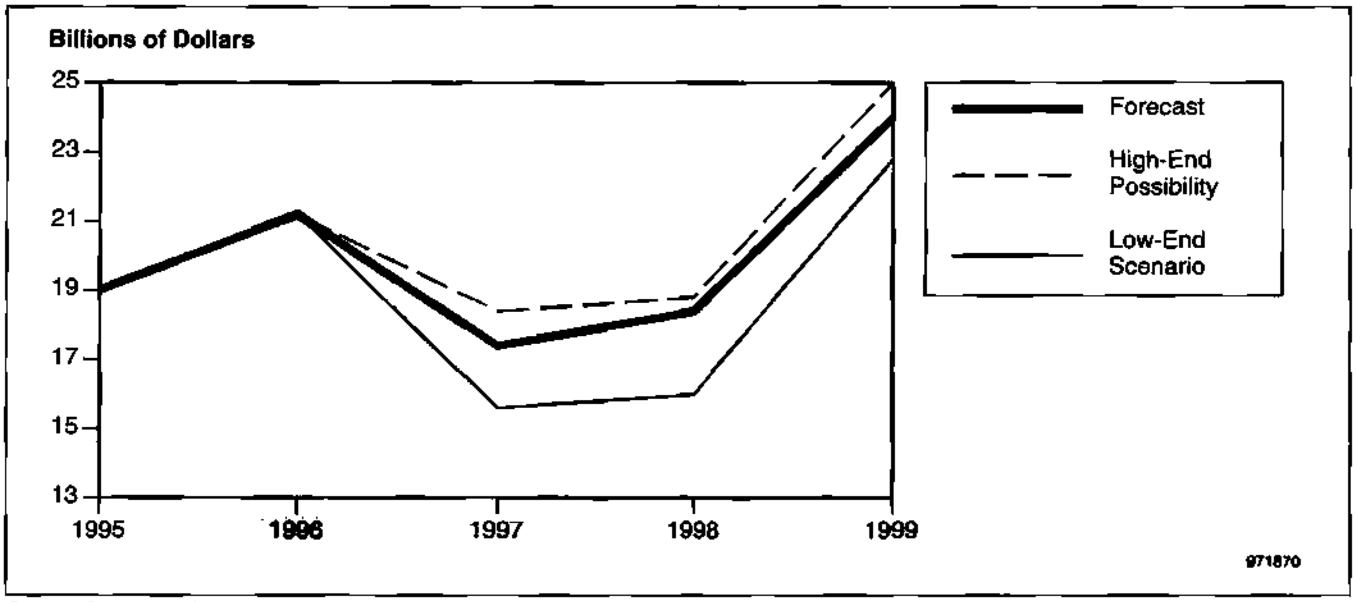
- The U.S. fabs being built by TSMC, Samsung, and Hyundai
- The U.K. fabs being built by Siemens, LG Semicon, and Hyundai
- Japanese continuing to build facilities to position for quick ramp-up when needed during the next cycle
- Initial shipments of 300mm pilot equipment
- The array of initial joint venture fabs such as IBM/Toshiba, TwinStar, and Motorola/Siemens in the United States; Winbond, PowerChip, and Macronix in Taiwan whose activities are tied to Japanese companies; and Texas Instruments' ventures in Thailand and Korea (with Anam)

The key word in this last set of fabs is initial, where there are factors that are more important than the capacity being added, such as a strategic development or supply relationship. Location of production can also be a reason to invest in initial capacity. Let's now burrow into some of the dynamics and detail issues that cause us to remain cautious for prospects near term.

Issues for the Industry to Reconcile in 1997 and 1998

Overcapacity in the DRAM market has now trickled to most areas in semiconductor manufacturing. We have also uncovered a number of facts that give us concern and issues that need to be reconciled during 1997 and 1998. These issues provide the basis for our belief that there is more downside risk than upside potential to our forecast in the next two years, even in the face of a strong end-use demand for semiconductor devices. This forecast window is shown in Figure 3.

Figure 3
Wafer Fab Equipment Forecast Window—Downside Risk



Source: Dataquest (January 1997)

The key is the industry needs a capacity driving force to resume sustainable growth prospects. Our concerns are three:

- The number of fabs and spending ratio currently factored into in our forecast for 1997
- The consumption of silicon into the DRAM sector declining in the face of increasing bit demand
- Existing excess capacity, which we have now roughly quantified, being upgraded and redirected

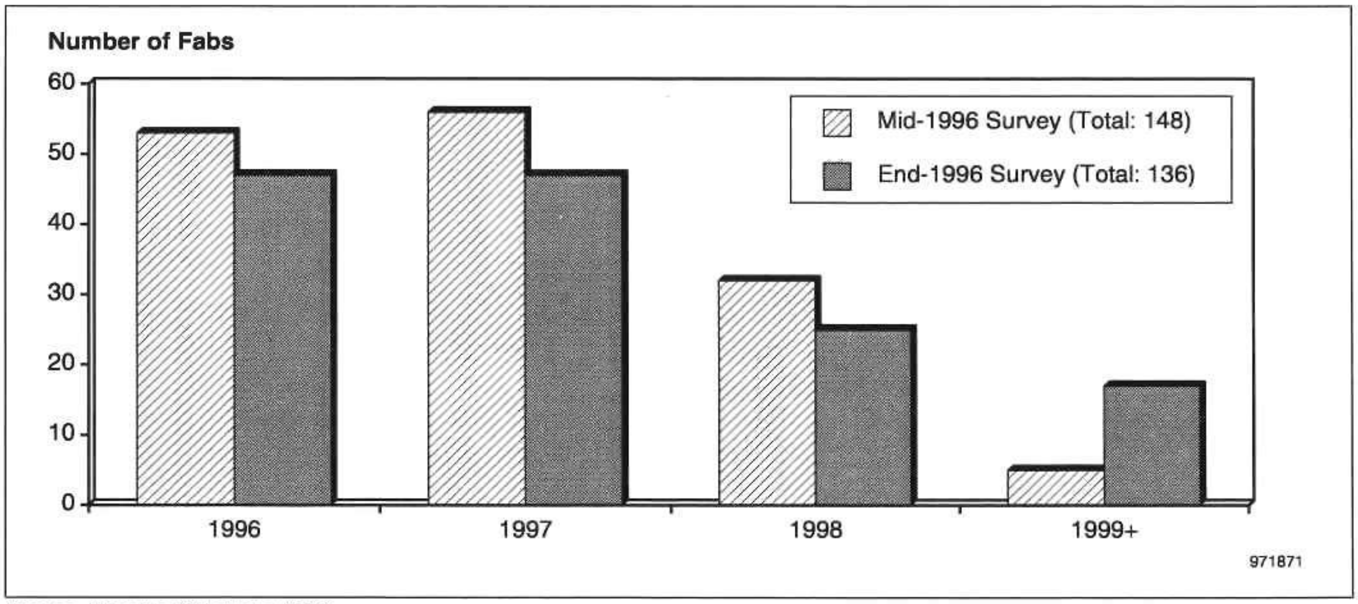
Let's take these issues one at a time.

Too Many Fabs Starting and Spending Ratio Too High in 1997

With all the "strategic" investment happening in the world, 1997 is simply turning out to be looking "too good," if there is such a thing is this environment.

In all, there are still just under 50 fabs that have been announced to come on line in 1997. While this is significantly lower than a spot check of plans six months ago (refer to Figure 4 of the handout), this is the same number as started in 1996 and higher than the 40 or so in 1995. Even though the facilities will likely be equipped with a minimum equipment set and have slower ramp rates, the capacity coming on line in 1997 exceeds incremental demand.

Figure 4
Planned Fabs—Recent Activity



Source: Dataquest (January 1997)

Capital spending as a percentage of semiconductor revenue, which is a significant figure of merit, is also high—at 24 percent in 1997. We believe that to support long-term growth in the chip industry about 35 to 38 fabs per year and a spending ratio of 22 percent is an equilibrium level. This means that 1998 and 1999 are likely to be years under these equilibrium levels, and our current forecast supports this. We would also expect that fab delays and outright cancellations will continue throughout 1997.

Silicon Consumption in DRAM Sector: Overcapacity into 1998

Second, as we mentioned in our last telebriefing and have illustrated in publications, the industry migration from 4Mb to 16Mb DRAMs would cause overcapacity even in the face a high bit demand growth. Die size relationships mean that the average 16Mb DRAM has two to three times more bits per square inch than the 4Mb generation.

This means that wafer starts should actually decline for a period of two to three quarters as a result of this silicon efficiency. Indeed, we have performed a quarterly analysis of the square inch consumed by the DRAM market and have calculated that 14 percent less silicon is required in the third quarter of 1996 compared to the fourth quarter of 1995 to support higher DRAM bit demand. We are not expected to return to fourth quarter 1995 silicon demand levels until the second quarter of 1997, yet in those six quarters a lot of capacity will have been added.

Current factory utilization rates for DRAM fabs are running about 70 percent, and we would expect utilization to continue falling in 1997, perhaps to the low 60s. According to this fundamental analysis, capacity spending in DRAM is not expected to return until late in 1998.

Equivalent of 40 Idle Fabs Created in Asia and Japan

Third, and probably the largest, concern is that we believe this is not just a DRAM thing anymore. A startling fact became evident during our forecast process in the silicon market.

When we look at the actual consumption of 150mm wafers in Asia/Pacific and Japan together in 1995 (about 37 million wafers), and compare it to our forecast for 1997 (about 27.5 million wafers), we see that in these regions fabs are consuming 9.5 million wafers less in 1997. This means about 800,000 wafers a month capacity has been idled, or about the equivalent of 40 fabs!

This was so surprising that we were convinced our model for silicon consumption needed confirmation. Upon further investigation, we found that fourth quarter 1996 run rates for 150mm wafers were at about 2 million a month for the industry, and that run rates would have to increase by about 11 to 14 percent to achieve our 1997 forecast. Our rough analysis indicates that about 14 of these "equivalent fabs" are in Korea, with the balance likely in Japan. Let's look at the makeup of these idle fabs, most of which are a result of the shut-off of 4Mb DRAM production.

In Korea, these fabs have been almost entirely redirected to the foundry market, and the result has been a 25 percent reduction in prices during the middle of 1996. Both LG Semicon and Samsung have become very aggressive players in this market, and it is very likely that these companies will invest some to upgrade the fabs to 0.5-micron technology. Our analysis of the foundry market without these extra fabs shows a market in oversupply in 1997 through 1999 by 15 to 25 percent.

Foundry capacity supply and demand can be used as a proxy for mainstream logic capacity investment. This picture shows no fundamental driving force for renewed capital spending growth.

The fabs in Japan (equivalent of 26) fall into two areas. Japanese companies initially processed 16Mb DRAMs on 150mm wafers, and we estimate that perhaps 10 fabs worth of capacity is now available to be upgraded to run 200mm wafers. As this will effectively double that square inch capacity of this block at a relatively low cost, the DRAM-driven recovery could be pushed back a bit.

The other block of 16 equivalent fabs in Japan cannot be upgraded to run 16Mb DRAMs, so these will migrate to lagging processes such as those for microcontrollers, telecommunications chips, mixed signal, and analog ICs.

Wafer Fab Equipment Summary

These three issues together represent a possible different scenario. One can think of the next two years as being one of two possible types of markets. Semiconductor companies could continue to invest strategically, keeping spending levels for 1997 high enough to not fully correct the excesses. This puts a drag on growth prospects for 1998. If the chip industry were to fully correct for the excesses of 1995 and 1996, the 1997 market could be significantly worse—perhaps down 25 to 30 percent, and recovery could be significant sequential growth in the second half of 1998. The first scenario represents our forecast scenario. The second, more dramatic, scenario represents the downside risk given the facts of the day.

In summary, Dataquest believes that the wafer fab equipment market will be in for sluggish business conditions through the middle of 1998, before a sustainable bookings recovery can start coming initially from DRAM capacity spending. Fundamentals of capacity supply and demand balance simply do not support a recovery occurring in 1997 for either memory or mainstream logic. The next 18 months are expected to be dominated by strategic investment by IC manufacturers, which include production location positioning and investment in new technology.

Equipment areas such as chemical mechanical polishing, epitaxial reactors, and HDP-CVD will benefit from higher penetration of the technology, and RTP system suppliers will benefit from the much higher interest for this process in 300mm lines. Design starts are increasing; coupled with undersupply in the mask shop, it means mask-making equipment continues to show good growth. Both deep-UV lithography and high-voltage implant are expected to benefit from increased penetration of the technology as well; however, suppliers of steppers and implanters will also be impacted from a dramatic falloff in their capacity-oriented businesses, namely i-line steppers and volume DRAM purchases.

The key message here is batten down the hatches through early 1998. The equipment industry must now rely on the fundamental demand in PCs and telecommunications to catch up to the supply.

Update on the Silicon Wafer Forecast

I would like to touch briefly on our silicon forecast, on which we will be releasing an Alert next week. We had anticipated that the second half of 1996 would be weaker in silicon demand based on the migration from 4Mb to 16Mb DRAMs mentioned earlier. However, starting about August, the silicon market collapsed, with current run rates about 20 percent below just six months before. Silicon area growth for 1996 will end up at about 7 percent in terms of million square inches (MSI).

While our forecast for equipment could be characterized as conservative compared to others, our forecast for silicon consumption in 1997 is actually a little more optimistic than others we have seen.

These dynamics can mostly be explained by the activities in the DRAM market and a discussion of inventories. We mentioned earlier that we have performed a quarterly analysis of silicon consumption into the DRAM market. Not taking inventories into consideration, wafer starts would have declined into the DRAM sector during the first quarter of 1996.

Of course, this did not happen. Optimism about demand and fear of a silicon shortage led to DRAM manufacturers' continued production in the first half of 1996, expanding DRAM chip and wafer bank inventories, as well as keeping inventories of raw silicon wafers high. This corrected with one big ax during the third quarter of 1996. Theoretically, silicon consumption into the DRAM sector should be recovering now. However, actual shipments from wafer manufacturers will lag by four to six months as inventories are worked down. We do expect recovery in silicon MSI shipments in the second half of the year. Our quarterly model into the DRAM sector suggests run rates by fourth quarter 1997 should be 20 to 30 percent higher than current depressed levels.

Our MSI growth forecast overall (including test wafers) for 1997 is just over 7 percent, expanding to over 13 percent growth in 1998.

That concludes our prepared comments. We would now like to open this briefing to your questions.

Question-and-Answer Period

Operator: Thank you. If you would like to ask a question, please press one on your touch-tone phone. I'll take your questions in the order that they are received. #70, you may ask your question.

Caller #70: Thank you. Clark, based on the latest update of the semiconductor consumption, you are still holding the worldwide forecast at about $290 billion in the year 2000. I am wondering how the reduced number of 136 fabs reconciles and supports the forecast consumption?

Mr. Fuhs: The reduced number of fabs at 136 is simply a database of the announced fabs for which companies have firm plans. As you can see from Figure 4, the number of planned fabs coming on in 1999 and beyond is still at a very low level of 17. This database simply does not have the visibility past 1998, with a two-year horizon. We would anticipate that as the industry starts to recover in late 1998 and 1999, we would get more new fab announcements. The number of about 35 fabs per year is an equilibrium level we use in the long term, so over any five-year period, you would expect to see somewhere in the neighborhood of 170 to 180 fabs being built.

Mr. Pakdaman: This is Näder Pakdaman. I would like to add a comment to that. Also, we are seeing quite a few advanced fabs that were announced and came on line in 1994 and 1995. They have plans to continue equipping themselves with advanced equipment and increasing capacity. So that planned fab figure Clark mentioned is one that fluctuates, but an average of somewhere between 34 to 35 fabs seems reasonable. A figure we look at is the incremental semiconductor revenue per square inch and the corresponding silicon consumption required as to where capacity is needed and revenue is being generated for the industry.

Mr. Fuhs: Next question.

Operator: At this time, #64, you may ask your question.

Caller #64: Yes, I would be interested in knowing if you have any figures on how much investment there is in the 300mm wafer fab equipment at the moment, and when you would expect to see that equipment actually start being used in production.

Mr. Fuhs: In our model, we see a small amount of investment in new equipment for 300mm in 1997. A lot of the equipment shipments that will be made in 1997 will be into the R&D feasibility programs, such as I300I and Selete, which are nonrevenue, nonproduction machines. There will be more equipment being shipped in 1998 and 1999 for pilot production fabs. In our model, we build what I call here a "300mm bubble," which assumes that we would expect two nonproducing pilot lines to come on line by 1999. In that model, we spread out that $2 billion of equipment investment over the three years 1997 through 1999. Right now we have 10 percent going into 1997, the bulk of 50 percent in 1998, and the other 40 percent in 1999. Then, as these pilot lines come on line in 1999, and people are getting familiar with production, some additional fabs will be announced and will come on line producing product. Our silicon consumption in the year 2001 for 300mm wafers is about 3 percent of the market in terms of square inches, and I have a unit number here that I can refer to as well. The bottom line is equipment will start to ship in bulk for revenue during 1998.

Operator: Thank you. #59, you may ask your question.

Caller #59: I wondered if you could comment on what you expect in your capacity model as far as accelerated conversion to 0.25 micron, with mix-and-match lithography and existing 0.35-micron fabs. Could you also comment on the timing of the 64Mb DRAM coming on line, and what that will do to the capacity situation?

Mr. Pakdaman: That is a very good question. Let me start with the second part. We have done some analysis and have developed a hypothesis on the relationship of price per bit in DRAM to equipment production efficiency and shipments. If you look at stepper unit shipments and price-per-bit growth rates and compared the two, there is a very strong correlation. If you look at the this relationship, it shows how capacity and technology have interplayed and how technology has migrated into capacity over time and has enabled semiconductor manufacturers to increase bit output in a step function fashion and therefore change the balance in supply and demand and reduce price per bit. So every time price per bit goes down, it means that silicon efficiency has increased tremendously. We see it in every transition even going back to 4Kb all the way to 1Mb, 4Mb, and then the current transition to 16Mb.

We believe that mix and match and implementation of advanced lithography equipment will continue. Actually, if you look at the DRAM market, a lot of big capacity increase is achieved by shrink and product transition. Our current forecast from our memory group has a transition to the 64Mb DRAM happening in the later part of the decade, the 1999 time frame. However, we believe that below-0.3-micron DRAM capacity should be coming on line before then in 1998, with development happening during 1997. It will have an impact on bit supply and increasing bits per square inch. That, in a sense, will have again a negative effect on unit growth for steppers because the silicon efficiency is increased. Eventually, the bit demand should catch up to this increased supply, and we would see then the stepper market recover. Our current forecast for 1997 is about 850 units, and we keep it essentially flat for 1998. This is down from over 1,300 units in 1996. Then we see an increase in 1999 and 2000, accelerating again well above 1,000 units. During this time, we see deep-UV very strong, and we see mix-and-match strategies as being very prevalent. We think mix and match is going to make a place for scanning i-line during the 1999 time frame.

Mr. Fuhs: One additional comment on the 16Mb-to-64Mb conversion. Just this morning, there was an announcement from a Japanese company that it would be increasing its production tenfold for the 64Mb DRAM. We already have accounted for that in our model for silicon consumption in our quarterly forecast. The 64Mb DRAM is about a 3.7 million unit market in the fourth quarter of 1996, and will reach 30 million by fourth quarter 1997. Compare that to 16Mb shipment level of 444 million units in fourth quarter 1997, and you quickly get a picture that we are still going to be primarily driven in terms of capacity by the 16Mb DRAM. During the next few years, there will be more shrinks of the 16Mb, making it much more cost-effective. We expect profitability to return to the 16Mb chip by late 1997 and into 1998. That will put pressure on the 64Mb to ramp up to even higher yields in order to be more profitable. The net of all of this is that we do not expect the 16Mb-to-64Mb crossover to occur until 1999 or 2000.

Operator: Thank you. #53, you may ask your question.

Caller #53: Yes, I am wondering if you would expand a little bit on your distinction between new technology and raw capacity. Would yield management equipment, for instance, fall into the new technology category? How about cluster tools and others?

Mr. Fuhs: Why don't we start with cluster tools. I am not sure that I have a pat answer for the cluster tool question. There are generally two types of cluster tools, so to speak. The first is where there are multiple chambers of the same kind of reactor on a platform to increase the throughput, and obviously that is a capacity-driven application for cluster tools. The second would be integrated processing, where you are taking layered depositions or etch and putting it together on one system. This application is more driven by technology, thin-film interface control issues, and device performance. The market size of the first relative to the second—in other words, the capacity relative to the technology—is pretty large. The capacity-oriented one makes up perhaps two-thirds of the market, and the technology-driven application the other one-third. The majority of the technology, or the integrated processing one, is in the sputtering systems. And to some extent, sputtering systems are going to be suffering over the course of the next year from a capacity-driven issue. So I would say that the cluster tool market in general is only 15 to 20 percent driven by technology.

Caller #53: How about the yield management?

Mr. Pakdaman: Let's start the yield management discussion from patterned inspection, and then perhaps we can speak about other process control segments. Our study of patterned inspection shows that in the past two years this market has matured to a position where actually it is now not in an emerging ramp-up mode, but it actually is expected to follow the general trends within the equipment market. That means, for instance, on patterned inspection we have almost the same average growth rate, perhaps slightly above, from 1995 to 2001 that we have for the equipment market—about 14 percent. In patterned inspection, the maturity is obviously there and is a definite ingredient in ramping up new fabs. It is not an afterthought anymore, and definitely all of the new fabs will be bringing in yield management equipment, in particular patterned inspection.

There is a segment of process control where the implementation has not yet matured—the defect review market—especially with new technologies like scanning electron microscopes and focused ion beam (FIB) for review, inspection, and processing monitoring. We expect that market to grow actually at a very stunning average growth rate between now and 2001 to about the tune of above 20 percent and will be placed in the fab as a complement to patterned inspection. We believe that is especially true in the technology investments that are needed to ramp up for the next generation to go below 0.3 micron. These two equipment segments, particularly the defect review, are going to play an important role.

Caller #53: Thank you.

Operator: Thank you. #54, you may ask your question.

Caller #54: Hi, I have an additional follow-up question to the previous question. In FIB and specifically with this 20 percent growth that you guys might see through the year 2000, is that in the failure analysis labs, or is that in line process monitoring?

Mr. Pakdaman: This is primarily in line process monitoring. With FIB, I am not sure how much of it is going to be in line because of the gallium source issue, but it is definitely part of process monitoring. It is not going to be like defect review tools of SEM-based or optical-based systems where the wafers will go back in line. So it obviously will see less wafers. But we do see it as a growing piece of the defect review market. Especially in advanced logic, there will be a need for the new films and the new processes to be understood, and FIB is going to play a very important role there.

Caller #54: So for your forecast of 20 percent, if for some reason progress could be made in the source technology, that would only be additive to your estimates?

Mr. Pakdaman: Yes, but I still see FIB as definitely a complement to this SEM- and optical-based systems.

Caller #54: So in other words it is an enabling technology?

Mr. Pakdaman: Well, you are putting words in my mouth. If you want me to say it is enabling technology, I think that it is. I think it still needs to be incorporated into the fab and into the fab culture. Gallium is a safety issue that needs to be accepted in the fabs. FIB systems are being used currently, and actually 1996 saw tremendous growth. But again, we see it as a complement to the SEM-based systems and in process monitoring. Again, they will see less wafers than the patterned inspection and the other parts of the defect review market.

Caller #54: Thank you.

Operator: Thank you. #59, you may ask your question.

Caller #59: Yes, I had a follow-up question about the mask-making business. I believe that you made a comment in passing about the capacity situation and the expected growth rate in the mask-making arena, could you elaborate on that, please?

Mr. Fuhs: Let me get the notes out in particular to mask-making equipment. We cover the mask inspection and the lithography segments, the E-beam, and the direct-write optical systems. The mask-making lithography market did really explode in 1996. We have got the market growth in the neighborhood of 120 percent or so and have the compound annual growth rate from 1995 to 2001 of just over 30 percent. It is one of the few segments that we do see growing modestly in 1997 and 1998. There has been a lot of capacity-driven buys, and this is the first time that we have seen this in the photomask industry for many years. The risk here is that there are a lot of captive lines that are coming back on board. We may see the capacity issue begin to become more balanced by the end of 1997 or 1998 as a result. We are currently embarking on a new study, which will look at that in a much more deep manner, trying to link mask production to design starts. We expect to start that project in the first half of this year.

Mr. Pakdaman: The mask-making equipment industry depends on two factors: both design starts and the installed base of steppers. The overall depression that we are seeing in the next two years for stepper shipments, where the numbers are almost cut down by 50 percent in unit terms for 1997 and 1998 from the 1996 level is a reason for conservative estimates for mask-making equipment.

Caller #59: Do you have any comments on the mask market itself as opposed to the equipment side?

Mr. Fuhs: We have not covered the mask business itself recently. We hope that the study that we start in the first half will help us quantify that.

Caller #59: When you look at the equipment demand, I presume that you have factored in things like the more time-intensive manufacturing such as optical proximity correction and phase shift masks in your compound annual growth rate of 30 percent over 1995 to 2001?

Mr. Pakdaman: That is correct. One additional comment. We have broken the mask-making lithography market into both E-beam and optical. Growth rates for the optical systems both in terms of units and revenue are much higher than the E-beam systems. The E-beam systems obviously are going to be dedicated to the more advanced linewidth devices. The optical systems seem to have not only caught up, but actually fill in the volume demand that is there. We think that the dynamics between those two segments within mask making plays an important role in addressing the capacity needs.

Caller #59: OK, great. Thank you.

Operator: Thank you. At this time, sir, I am showing no further questions.

Mr. Fuhs: While we are waiting for somebody else to ask a question, we still do have about 10 minutes here left, I would like to follow up on an earlier question. I looked up the number for our wafer consumption forecast for 300mm wafers, and the level is about 150,000 wafers a month in the year 2001. The majority of those will be test wafers, but there will be some production capacity by that time. One of the things that you can use as a proxy is looking at the ramp rate of 200mm wafers. I believe R&D began in 1985 when the first 200mm wafers were processed in a piece of equipment. The first production of a 200mm wafer from start to finish through a line was in 1989, and production really started ramping up in 1992 and 1993. If you simply added 11 years to that time line, it would be very close to our expectations for the 300mm wafer size in our mind.

Mr. Dornseif: This is Ron Dornseif, and I would like to add a comment to the 300mm equipment market. It is obviously under way in terms of companies all over the world producing 300mm prototype units. The 300mm equipment market is expected to be a classical double hump type of consumption pattern. That is, there will be a hump in the R&D and pilot line phase, and then it will go quiet before the production ramps start up, which will occur after the turn of the century.

Mr. Fuhs: One other comment about the 300mm equipment issue. This is going to be slower than we think a lot of people want. The reason has to do with the fact that there are a lot of issues that need to be dealt with and a lot of development issues that need to be handled. A case in point, I had an etch manufacturer come up to me and complain that he could not get useful 300mm wafers for him to do any development work because there was not really a stepper out there that could image an advanced linewidth on 300mm wafers. There are imaging steppers out there that can process 300mm wafers, but they are basically modifications of flat panel display systems and are limited to the larger linewidth. These unfortunately do not provide much usefulness for an etch equipment manufacturer trying to fine-tune a process for microprocessors at 0.25 or 0.18 micron. So there is some work that needs to be coordinated among the different classification of equipment in order for the entire picture and the entire fab to be put together. This is going to happen a lot slower than people want. The latest information we have is that the first true 300mm advanced stepper will not be available until the end of 1998.

Mr. Fuhs: Are there any further questions?

Operator: At this time, #33, you may ask your question.

Caller #33: Yes, could you just go over one more time on Figure 3? Why is there more downside risk than upside in your forecast?

Mr. Fuhs: In today's overcapacity situation, what we are basically talking about here is the mindset of the customer. Is the mindset of the customer going to be: (a) am I going to continue to strategically invest because I believe in the long-term prospects of the market, or (b) am I bleeding so bad from a profitability perspective in this overcapacity that I am just going to cut my capital spending. We think that the first case is going to be more likely than the second. But there is not really a third and stronger, more optimistic case than continuing to strategically invest. So that is why we were saying that there was more downside risk than upside potential. In order to have recovery in the second half of 1997, the chip market would have to probably grow by 30 percent in 1997. Our current forecast for the chip market in 1997 is 13 percent growth, and that is on the optimistic side of consensus.

Caller #33: OK. Thanks.

Mr. Dornseif: Could I add a comment to this upside potential/downside risk? You look at those scenarios—they are distinctly different scenarios. Our forecast has some high-end possibility, but it is a matter of degree of probability. If you look at the downside scenario, it is a different scenario. That is, people start to back off on the strategic investments, and they start to make other decisions. So it is a different scenario as opposed to just a change in the probability of numbers.

Mr. Chang: This is Calvin Chang. Again touching on the overcapacity issue. I think that in summary there are two major parts that make up that overcapacity, and we talked about that in length. I just want to capture that here. First of all, there is that 4Mb-to-16Mb transition, probably the most significant impact and contributing factor to overcapacity. Second, there is this tremendous build-up in foundry capacity, and not all just from dedicated foundries that are now building, in total, 15 to 18 new fabs. Also, there is the redirection of the DRAM capacity that can be upgraded to do foundry. So together, those two issues—the 4 Mb-to-16Mb transition and the overcapacity in foundry—really make up the cornerstone of the overcapacity scenario that we see for the next couple of years. That is going to really put pressure on the capacity-driven buys for the near term.

Mr. Fuhs: Now there is one segment of the market that is in undercapacity—microprocessors. So if you are a supplier like Intel, you are probably going to be pretty happy over the next year or so. There are only two companies in the top 20 expected to increase capital spending in 1997, and they both make microprocessors. By the way, the only reason AMD is really going to increase capital spending is because it is getting a subsidy from the German government. One additional data point is that both Intel and AMD had less capital spending in 1996 than they did in 1995. So they are actually counter trending the overall market in this case. So if you are a supplier to an advanced microprocessor company, then you are going to probably weather the storm a little bit better.

Operator: Thank you. #53, you may ask your question.

Caller #53: Yes, I am wondering if you could list a few more categories of new technology as distinct from raw capacity?

Mr. Dornseif: This is Ron Dornseif, I can add a few to that. In the CVD area, particularly in metal CVD, there should be some high activity in the barrier films, such as Ti/TiN, and the combination of CVD and sputtering. There will be some technology buys that are going to continue in the integrated polycide. I think that you are going to see a lot of activity in very low-k dielectrics as well as high-k dielectrics. Then there will be the activity associated with trying to bring on line the damascene process flow with different metallization schemes. All of that will have R&D-level activity, which I think will start to heat up in 1997.

Caller #53: Great. Thanks.

Mr. Pakdaman: Add deep-UV and i-line scanners in lithography. CMP is obviously another candidate.

Mr. Fuhs: Also, high-voltage implant in terms of a lateral isolation scheme, which I think Genus is promoting. I think that is going to get more widespread acceptance into the logic and flash area. We are currently in the midst of putting together a study on the demand prospects for epitaxial silicon. It is being implemented particularly into flash and logic devices, with a little in the DRAM area today. The penetration is a lot higher into flash these days, and as flash is a growing market in 1997, that is going to be an area of higher demand. There is some debate as to how it is going to be implemented to DRAM and at what level, at the shrink 64Mb level or later.

SOI (silicon on insulator) is going to be a technology that will expand in coming years as well. Some of the low-voltage portable applications are going to actually drive substrate SOI demand. That is another area where we will see some technology investment going on.

OK, do we have any further questions?

Operator: At this time, Mr. Fuhs, I show no more questions.

Mr. Fuhs: It is one hour, and I thank you for joining us this morning. We will be presenting more details for our forecast at the ISS Conference at Pebble Beach next Tuesday, so hopefully we will see some of you down there. Thank you very much for participating, and good bye.

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Dataquest
A Gartner Group Company

Perspective

Semiconductor Contract Manufacturing Worldwide

Dataquest Predicts

Dataquest Predicts: Semiconductor Contract Manufacturing in 1997

Abstract: *This Perspective presents Dataquest's outlook for the semiconductor contract manufacturing industry in 1997. Predictions of the industry's probable major developments, such as technology and wafer pricing trends, are described.*
By Calvin Chang

With a Plethora of Process Options, 0.35 Micron Hits the Big Time

Dataquest does not expect any earth-shattering developments to erupt in 1997, but vendors should monitor the following trends that will impact the semiconductor contract manufacturing (SCM) industry as the new year unfolds:

- The 0.35-micron technology will enter the mainstream of foundry processes in 1997.
- There will be a continual but gradual decline in foundry wafer prices.
- Armed with excess capacity, Korean foundries will be the wild card in setting market supply and demand dynamics and wafer prices.

The year 1997 will be the year in which 0.35-micron processes will be available in volume at all major foundries. In addition to baseline SRAM and logic processes, a large selection of process options will be offered at the 0.35-micron level. These include dual-voltage logic, mixed-mode, and dual-voltage mixed-mode on the logic side. In memory offerings, DRAM and even embedded DRAM processes will be widely available. Nonvolatile memory technologies will see ROM processes comfortably at 0.35 micron, while erasable programmable read-only memory (EPROM), electrically

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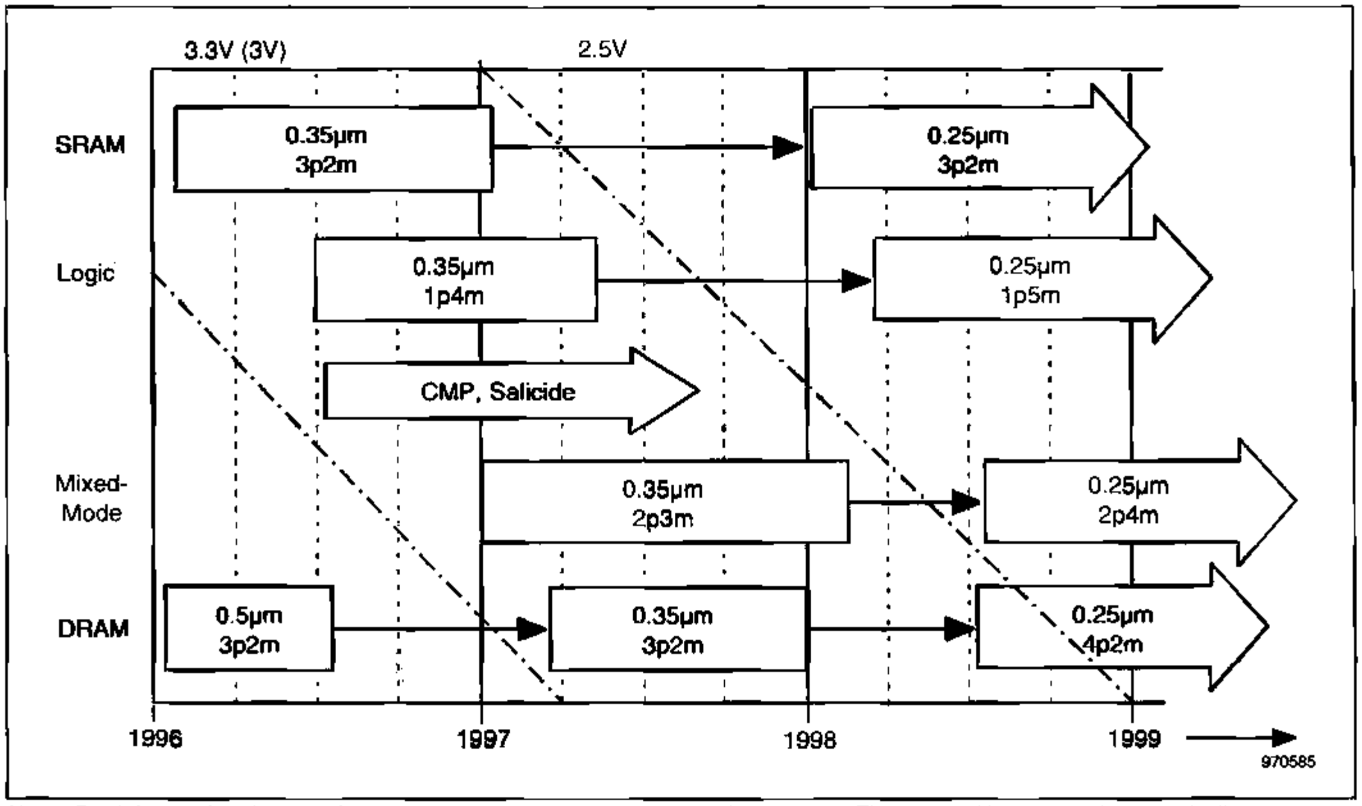
erasable programmable read-only memory (EEPROM), and flash will reach the 0.5-micron level.

Figure 1 presents the process technology road map projection for 1997 through 1999 in semiconductor contract manufacturing. This technology projection represents the composite of the technology road maps of the major foundries, such as Taiwan Semiconductor Mfg. Co., Chartered Semiconductor, and United Microelectronics Corporation. As shown in the figure, 0.35-micron technology, first introduced in 1996 as principally an SRAM process, will be widely available in all process families, logic, mixed-mode, and DRAM. Critical to fabrication of multilevel interconnects in sub-0.5-micron logic devices, chemical mechanical polishing (CMP) will be a standard option for global planarization, available from all major foundries. The salicide process for improved transistor performance will also be a standard adder.

Meanwhile, 0.25-micron processes are not expected to enter the foundry scene until 1998, with volume production, initially in SRAM and logic processes, slated to begin in the fourth quarter of 1998.

Figure 1
Semiconductor Contract Manufacturing Technology Road Map Projection

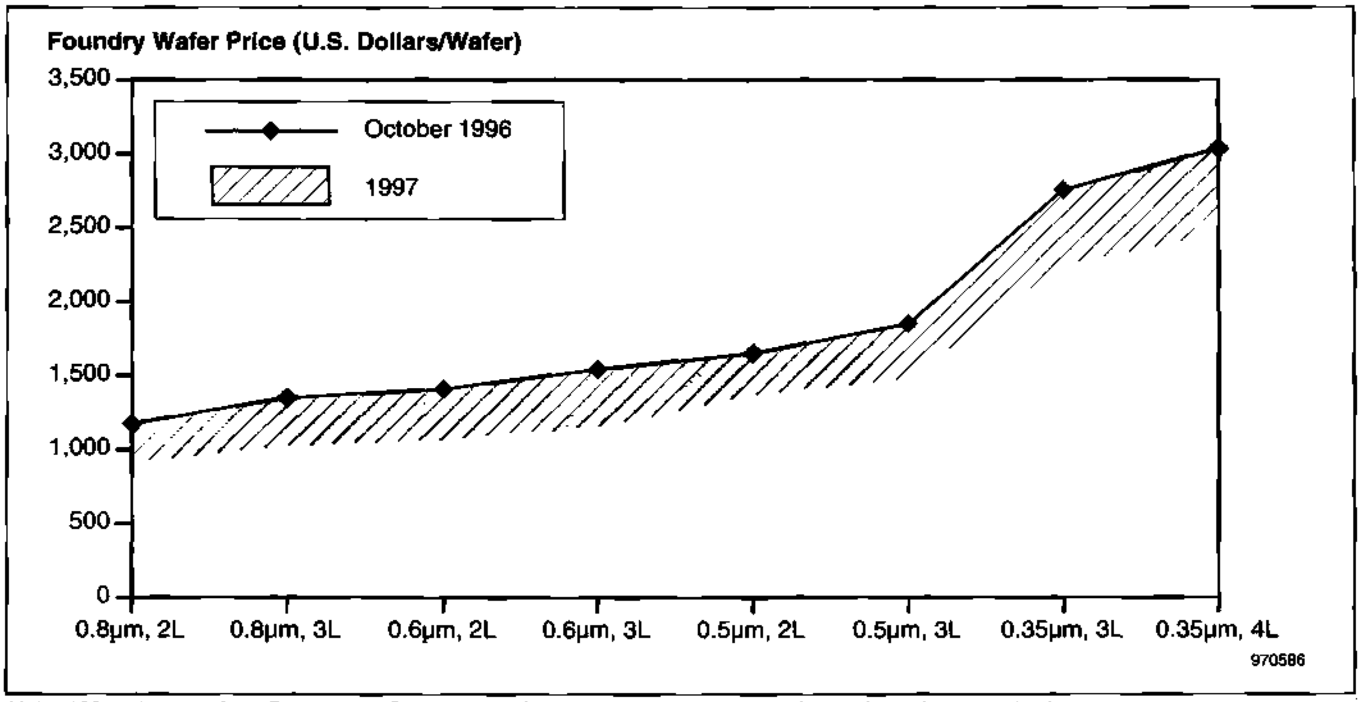


Notes: The left end of the box signifies early technology adopters and technology leaders. The right end indicates volume production.
Source: Dataquest (January 1997)

Prices Are Heading Lower, but Gradually

SCM capacity in 1997 will continue to be abundant, with continued pressure on wafer prices. Compared with 1996, foundry wafer prices in 1997 will see a much more gradual and stable price decline. Dataquest expects 200mm SCM wafer prices to fall by an average of 10 percent during 1997. The most significant decline, shown in the 200mm foundry wafer price projection in Figure 2, is expected in the 0.35-micron processes. As a continual stream of new 0.35-micron foundry capacity enters into production during 1997, prices for 0.35-micron, four-layer metal processes are expected to challenge the U.S.$2,500-per-wafer level by the end of the new year. The 0.5-micron processes, on the other hand, should hover within the range of U.S.$1,500 to U.S.$1,800 a wafer.

Figure 2
200mm Foundry Wafer Price Projection for 1997 Compared with 1996



Note: 1996 prices are from Dataquest's October 1996 foundry wafer pricing survey. Prices for 1997 are projections.
Source: Dataquest (January 1997)

Korean Foundries Are the Wild Card

Dataquest believes that the Korean IC giants, including Samsung, LG Semicon, and Hyundai, represent the most important wild card in the SCM industry in 1997. Seeking to become less dependent on memory products, the Korean IC manufacturers are looking for ways to diversify their vast IC manufacturing. One possible area is clearly the foundry market, whose traditional logic focus plays well with the Korean companies' aim to diversify into the logic/ASIC device market. Also, there is a large idle capacity in Korea that is looking for manufacturing opportunities. The 4Mb-to-16Mb DRAM transition that began in late 1995 has resulted in substantial excess memory capacity throughout the IC industry. This capacity excess consists of older, typically 150mm wafer fabs that cannot be economically upgraded or converted to the production of the new generation of DRAMs (16Mb and shrink). Much of the obsolescent DRAM capacity is quantified by the dramatic decline in the consumption of 150mm silicon wafers projected during 1995 and 1997. Figure 3 shows the 150mm wafer consumption decline, contrasted with growth in 200mm consumption, from 1995 to 1997 in Asia/Pacific and Japan, which together account for more than three-quarters of the world's DRAM production. Within two years from the 1995 production peak, a decline of 27 percent, or 270 million square inches, in 150mm consumption is expected to emerge. This is equivalent to the idling of 40 150mm fabs in two years!

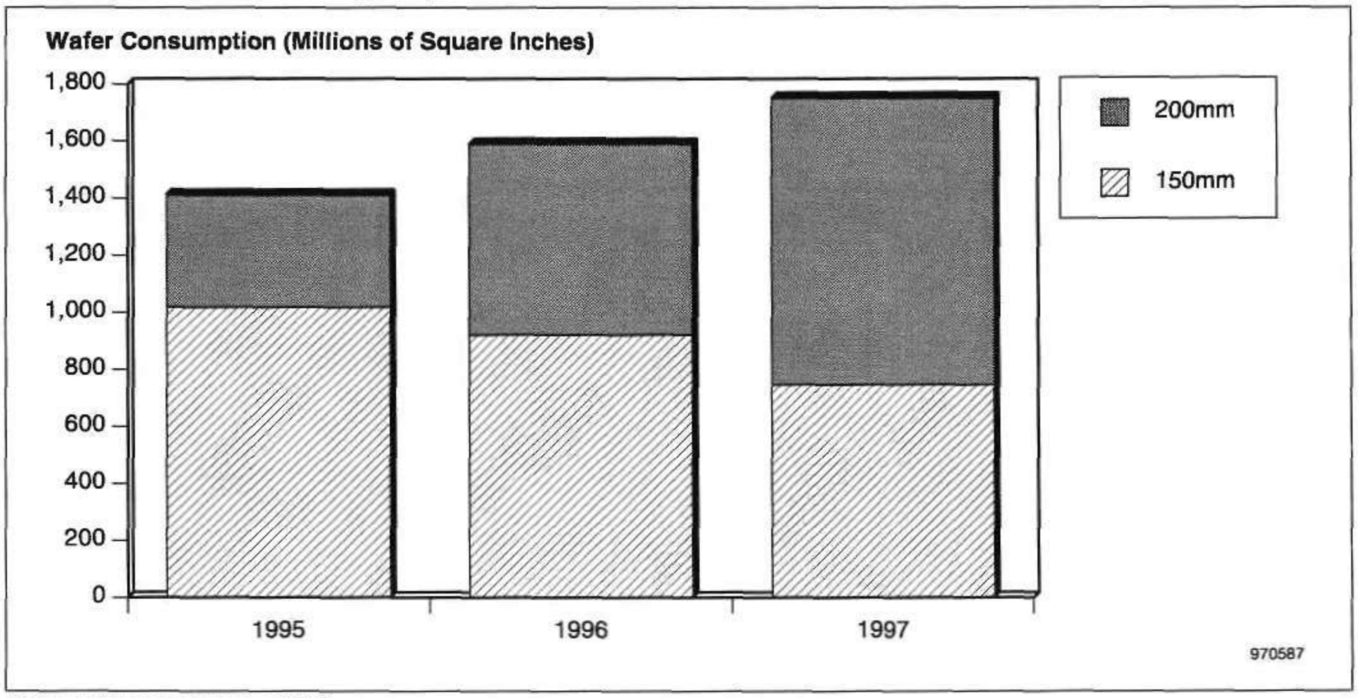
Of these 40 150mm idling "equivalent" fabs, 26 are in Japan and 14 are in Korea. Of the 26 Japanese fabs, about 10 fabs are capable of 16Mb production, with some having been upgraded to 200mm wafers processing. The balance of Japan's excess fabs will likely migrate to analog and microcontroller (MCU) production, where 0.6-micron-and-higher technologies are more than sufficient.

The 14 "equivalent" fabs in Korea, on the other hand, could well be redirected in large measure to foundry production at the 0.6-micron level and higher. Also, some fabs could expect to be upgraded to enable 0.5-micron and even sub-0.5-micron process technologies. One key area in which the Korean companies, specifically Samsung, have already made a major impact in the foundry market is in the embedded DRAM technologies. Leveraging from its expertise in DRAM design and manufacturing, Samsung has successfully developed an embedded DRAM technology that produces logic chips with substantial (4Mb to 16Mb) memory blocks. Fabless graphics chip vendors and foundry customers, such as Chips & Technologies and Trident, have already signed up with Samsung's embedded DRAM process. In the absence of other major foundries with competitive embedded DRAM offerings, Dataquest expects Samsung to continue to gain business in this area.

Further, the Korean IC manufacturers have developed a reputation for being competitive price setters. Armed with large depreciated capacity, the Korean IC manufacturers have a very competitive production cost structure that allows them to provide competitive pricing on foundry wafers.

With an abundance of low-cost capacity, established IC manufacturing expertise, and an objective of migrating into nonmemory markets, the Korean IC makers are poised to become a force to be reckoned with in the SCM market. Dataquest believes that 1997 will be the year in which the Korean wild card will be dealt, producing long-lasting impact on the worldwide SCM market.

Figure 3
Wafer Consumption in Asia/Pacific and Japan: Idling Nonconvertible DRAM Capacity Means Declining 150mm Wafer Consumption while 200mm Wafer Capacity Continues to Grow



Source: Dataquest (January 1997)

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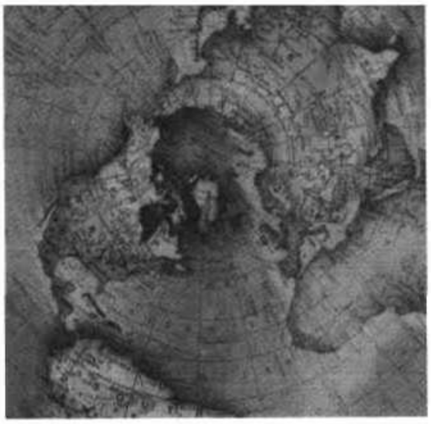

9/16

Dataquest

Midyear 1997 Forecast: Semiconductor Contract Manufacturing

Market Trends

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Midyear 1997 Forecast: Semiconductor Contract Manufacturing

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Table of Contents

List of Figures

List of Tables

Chapter 1
Executive Summary

The semiconductor contract manufacturing (SCM) market is poised for sustained long-term growth. The foundry and fabless models simply work too well. The escalating cost of a new fab makes concentration of capital in the foundry fabs a necessity, and division of labor in R&D allows the fabless company to concentrate on product design and marketing instead of process technology development. Hundreds of fabless companies owe their existence to the semiconductor foundry industry, and hundreds more fabless companies yet to be launched will help fuel its growth into the next century.

Fabless companies are not the only ones to benefit from the use of SCM services. Integrated device manufacturers (IDMs) today represent over two-thirds of the demand for foundry-processed wafers. Why would an IDM pay a foundry to process its wafers when it has invested so much capital in its own fabs? Outsourcing wafer fabrication can be an important element of an IDM's manufacturing strategy. In some cases, the IDM may find that the costs of outsourcing are less than the internal costs of manufacturing a particular product. Supplementing internal capacity with external SCM capacity can also be an effective risk management technique whereby the IDM seeks the most efficient balance between internal and external capacity loading, allowing the internal fabs to be operated at higher utilization rates. Finally, an IDM may use SCM as a means to gain access to leading-edge technology that may not be available internally. For these reasons, Dataquest expects the IDMs to continue to be a major source of demand for SCM services.

SCM Market to Reach $15.5 Billion in 2001

With strong demand growth from both the fabless and IDM segments, Dataquest is forecasting the market for SCM services to grow from $6.5 billion in 1996 to $15.5 billion in 2001, representing a compound annual growth rate (CAGR) of 18.9 percent. The Americas and Asia/Pacific regions will lead growth in demand for foundry services because of the active use of SCM among North American IDMs and the explosive growth of fabless companies in the United States and Taiwan. Although IDMs will continue to play an important role in the growth of the SCM market, fabless companies are expected to be the fastest-growing segment, accounting for 40 percent of foundry demand by 2001.

It appears that SCM revenue in 1997 will be essentially flat when compared to 1996. Even though millions of square inches (MSI) demand will grow by about 14 percent, this growth will be offset by lower prices across all technology categories. The average price per square inch for foundry wafers can be expected to increase slightly as the technology mix shifts toward the premium-priced, leading-edge technologies. The higher prices and steadily increasing demand on an MSI basis enable the resumption of positive growth in 1998, which is forecast to continue through 2001.

Project Analyst: James Hines, Principal Analyst

Plenty of Foundry Wafers to Go Around

The overall SCM industry moved into overcapacity in the second half of 1996, and the overcapacity is forecast to continue through 2001. The SCM industry is expected to reach a peak of 15 percent overcapacity in 1998 before beginning a gradual trend toward balanced supply. The bulk of the overcapacity is believed to be in the 0.5- to 0.8-micron range of technology, and much of it is the result of the recent entry of IDMs into the SCM market. It is possible that tightening industry capacity could cause some of these IDMs to retreat from the market. Such a movement, if large enough, could put the SCM market into shortage as early as late 1999.

0.35-Micron Capacity Ahead of Demand

Demand for 0.35-micron foundry wafers is ramping up quickly, but so is capacity as several dedicated foundry fabs become ready for real production volumes. Dataquest sees capacity leading demand by about five months at present, and this trend is expected to continue through 1999. New 0.35-micron fabs are filling up quickly, but additional capacity keeps coming on line to satisfy the rapidly increasing demand. The result is a very fast-growing market for 0.35-micron foundry services that is characterized by relatively high fab utilization rates and a soft pricing environment.

Dataquest Perspective

The semiconductor contract manufacturing (SCM), or foundry, industry is coming of age. When semiconductor foundries first emerged in the late 1980s, the idea was viewed with skepticism. At best, it was an opportunistic way to use excess fab capacity. All that has changed now, and the foundry has become an integral part of the semiconductor manufacturing infrastructure. The success of the foundry business model, and its complement, the fabless model, have positioned the SCM market for above-industry-average growth rates in the years to come.

The transition of the SCM market from capacity-constraint to overcapacity and the ensuing decline in foundry wafer prices, which occurred in the wake of a crashing DRAM market, illustrate the interconnectedness of the foundry and overall semiconductor markets. As the rest of the chip industry goes, so goes foundry. The aggressive movement of major IDMs into the SCM business transferred much of the industry's excess capacity directly into the foundry market at a time when dedicated foundries were already building capacity. As a result, SCM suppliers experienced a DRAM-like drop in foundry wafer prices, indicating that the foundry market does indeed follow the general industry trend, lagging by about nine months, in this case.

Dataquest believes the SCM market will continue to follow the semiconductor industry, but it will represent an ever-larger share in the coming years. As the foundry industry grows, it will move from the periphery to the center of the semiconductor manufacturing infrastructure. In fact, it is already well on its way.

Chapter 2
Semiconductor Contract Manufacturing Forecast

Highlights

Highlights of the SCM forecast are:

- Dataquest forecasts the market for SCM services to grow from $6.5 billion in 1996 to $15.5 billion in 2001, representing a compound annual growth rate (CAGR) of 18.9 percent.
- North America and Asia/Pacific will lead the growth in demand for SCM services, largely because of the proliferation of fabless semiconductor design companies in those regions.
- SCM revenue is forecast to be flat in 1997, despite a 14 percent growth in MSI demand, because of lower average selling prices.
- Foundry wafer prices declined dramatically in 1996 and 1997. Moderate increases in average price per square inch for foundry wafers are expected as the result of a shift to leading-edge technologies.
- The technology sweet spot of the foundry market is believed to be at 0.5 micron at present, as IDMs off-load production of 0.6 and 0.8 micron and the fabless companies begin to ramp up production of products based on 0.35-micron design rules.
- IDMs today represent about two-thirds of the demand for foundry services, but fabless companies are growing at a faster rate. Fabless companies are expected to account for 40 percent of worldwide demand for SCM services by 2001.

Forecast Methodology

Dataquest forecasts the market for SCM services by projecting supply- and demand-side trends separately, then reconciling them into a cohesive market forecast. This fundamental analysis is performed on a silicon area basis, where the units are millions of square inches of silicon. By measuring silicon area instead of number of wafers, differences in wafer size are automatically accounted for. (To convert MSI to millions of 6-inch-wafer equivalents, divide by 27.4 square inches per 6-inch wafer.) SCM wafer pricing trends for various technology categories are estimated, again on a silicon area basis, in terms of U.S. dollars per square inch and applied to the MSI forecast to arrive at a forecast for SCM revenue.

On the supply side, SCM capacity is projected for dedicated foundries and IDMs, based on current and anticipated capacity expansion plans. The primary source for this information is Dataquest's fab database, which tracks all existing and planned semiconductor fabrication facilities worldwide. The database input comes from an annual survey of semiconductor manufacturing companies, with quarterly updates to include announcements of new fabs and changes to plans. For the IDMs, the portion of capacity allocated to SCM services is estimated based on prior survey results and expected market conditions. The capacity projections are compared to Dataquest's silicon consumption forecast to ensure consistent results.

Demand for SCM services comes from fabless semiconductor design houses, IDMs, and system OEMs. Dataquest has been closely following the emergence of the fabless sector, and many of these companies are now included in the annual semiconductor market share survey. This data provides a historical perspective on the penetration of fabless companies in the various semiconductor application markets from which projections of future market share trends can be drawn. When combined with Dataquest's forecast of semiconductor application markets, an estimate of the growth of the fabless sector as a whole is obtained that provides the basis for forecasting fabless company demand for SCM services. For the IDMs and system OEMs, SCM demand is projected on a company-by-company basis, using prior survey results as a starting point and taking into account prevailing market conditions. (For an analysis of fabless companies' application markets, see the Dataquest Perspective, *1996 Fabless Semiconductor Review*, SCMS-WW-DP-9704, June 9, 1997.)

Reconciliation of the supply- and demand-side forecasts will depend on the supply/demand dynamics of the market. When in undersupply, market growth is constrained by the shortage of available capacity in the near term, and the market is characterized by price firmness and long lead times. Suppliers will respond to these conditions by adding capacity, which will become available 18 to 24 months after the decision is made. Thus the size of the market is determined by the supply-side, or capacity, projection in the first one to two years, with a transition to the demand-side projection occurring in the second and third years, and demand dominating the long-term forecast. In a balanced or oversupplied market, demand determines the size of the market in both the near- and long-term. However, if overcapacity persists, the effect of price elasticity must be accounted for because lower prices are likely to stimulate additional demand.

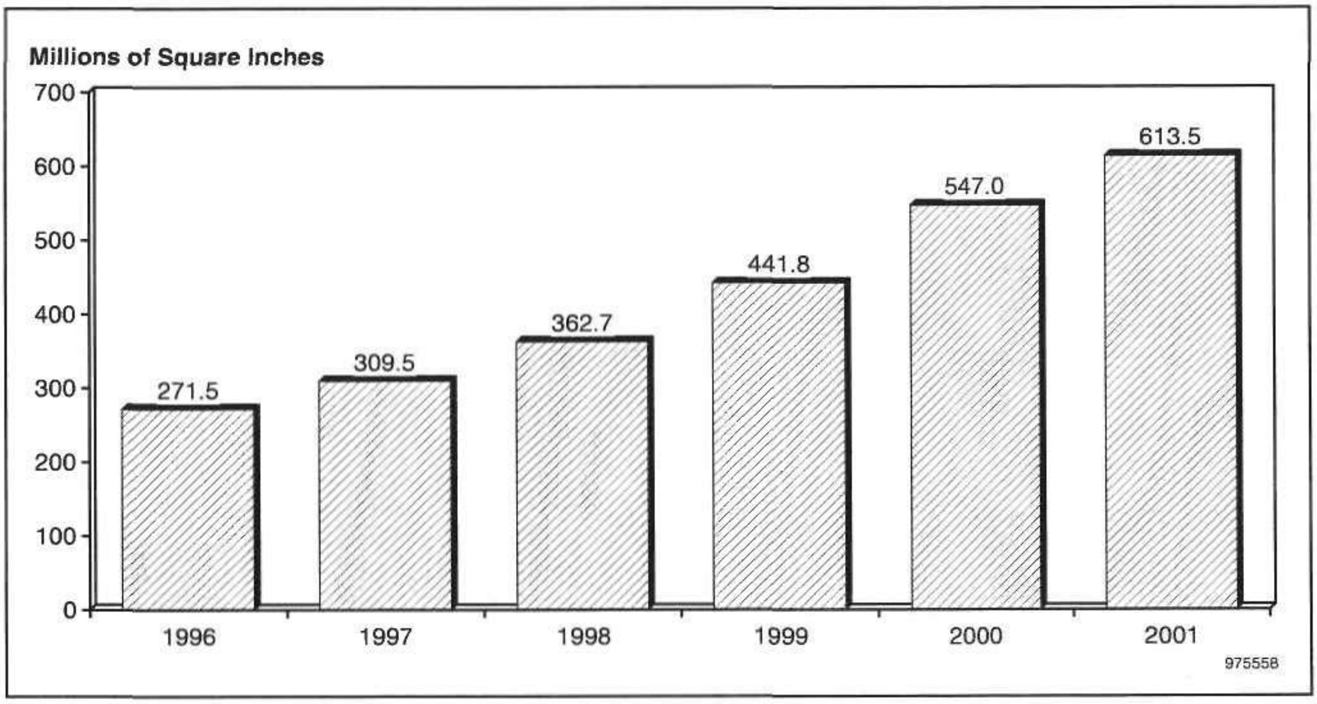
SCM Demand Forecast

Figure 2-1 shows forecast worldwide demand for SCM services in millions of square inches of silicon. Dataquest expects semiconductor foundry demand to grow steadily through 2001, fueled by the rapid growth in the number of fabless semiconductor design companies and the transition of many smaller IDMs to the fabless business model. With the escalating cost of a new semiconductor fab, economies of scale favor the concentration of capital in the large fabs of the dedicated foundries and larger IDMs. This trend is reflected in the forecast growth in demand for foundry services shown here.

SCM Pricing Trends

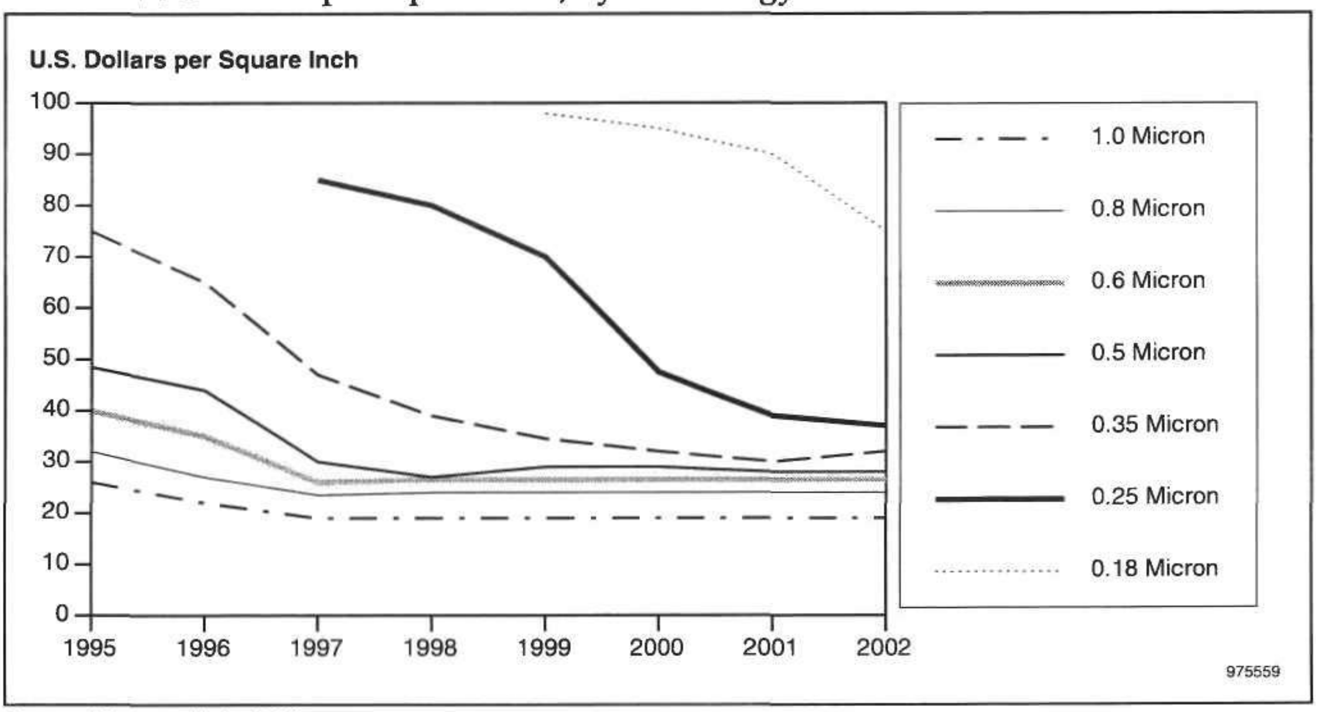
In order to obtain a forecast of revenue for the SCM market, an estimate of pricing trends is required. In Figure 2-2, the price per square inch for various technology segments is projected over the forecast period. Note the characteristic shape of the pricing curves. At the time of its introduction, a new technology will command a premium price, and pricing will remain relatively stable for a period of time while it is in the "preproduction" phase. As more capacity comes on line and the technology begins its move into mainstream production, prices begin to decline, reflecting the increased competition for market share among suppliers. Eventually, the price reaches a minimum and then rebounds slightly as the market matures and supply and demand dynamics stabilize.

Figure 2-1
Worldwide SCM Market Forecast, 1996 to 2001



Source: Dataquest (July 1997)

Figure 2-2
Trends in SCM Price per Square Inch, by Technology



Source: Dataquest (July 1997)

Since these pricing estimates were formulated, Dataquest has received input from some participants in the SCM market that indicate certain of these prices may have been overestimated. In particular, 0.35-micron prices appear to be under considerable pressure, continuing their rapid decline. Also, introductory prices of 0.25-micron wafers are lower than expected. (Results of the next foundry wafer pricing survey will be published in the fall.)

In the pricing chart, a compression of the technology generations can be seen in the trailing-edge technology segments. Traditionally, semiconductor manufacturing technology nodes have been separated by about three years. Since its introduction in the late 1980s, the semiconductor foundry industry has been on a steep learning curve as it catches up with the rest of the semiconductor industry. Initially, process technology available from foundry suppliers lagged that of the leading semiconductor manufacturers by one to two generations. Now, 0.25-micron processes are coming onto the foundry market at about the same time that the world's leading semiconductor companies are announcing their 0.25-micron products. The foundries have caught up, and from now on they can be expected to follow the more traditional three-year technology cycle.

Technology Mix

As leading-edge foundry process capability becomes available, demand will increase as customers find ways to take advantage of the improved performance in their product designs. The fabless design companies and system OEMs are the first to adopt the new technology as a means to more competitive product offerings. Most IDMs are still investing significantly in process technology development, and they are likely to use this internal capacity to meet their early production needs. As the technology matures and SCM prices decline from their initially high levels, the IDMs can be expected to supplement their internal capacity by off-loading a portion of their production to SCM providers.

The fabless companies now make up the majority of demand for 0.35-micron wafers, as they will for 0.25 micron when it becomes available later this year. This conclusion is supported by the results of the Fabless Semiconductor Association's *1997 Wafer Demand Survey,* which covers about 60 percent of fabless SCM demand. The fabless companies are the primary driver of growth in demand for SCM services, especially at the leading edge, and this is causing a steep ramping of demand for 0.35-micron wafers.

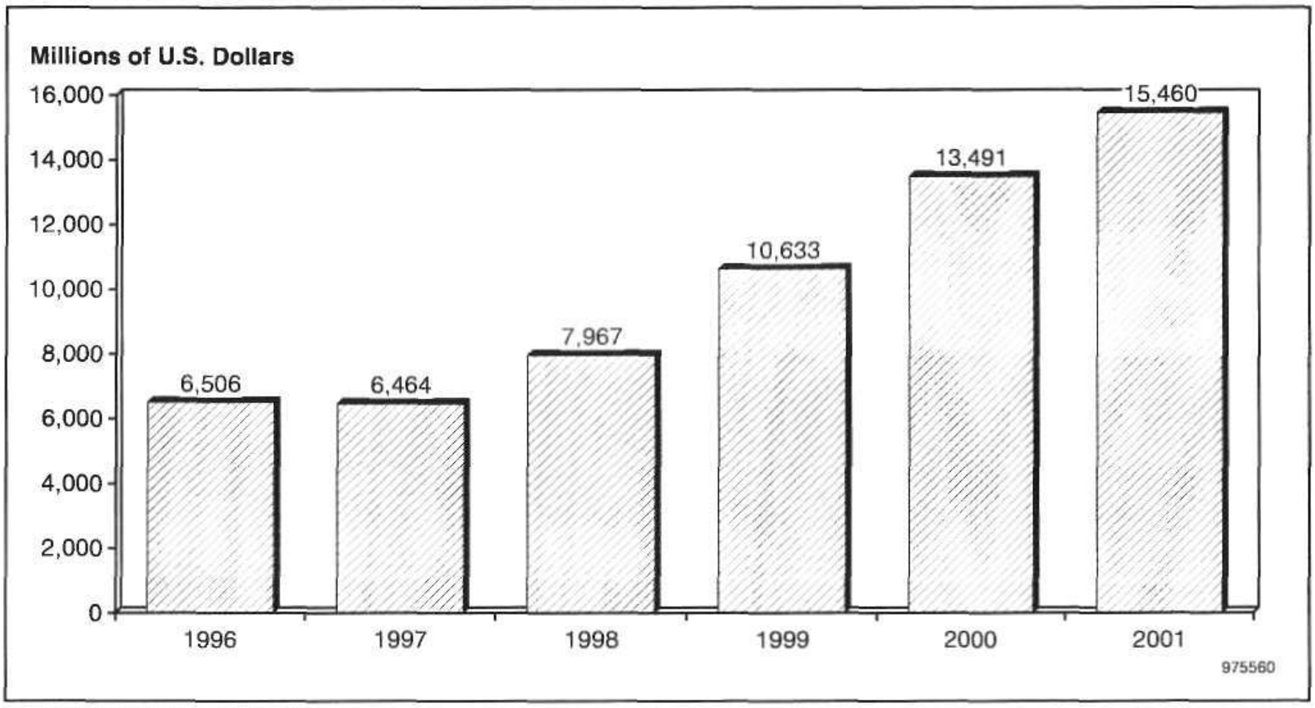
Many of the IDMs are off-loading production of 0.6- and 0.8-micron technology, and there is some evidence of moderate firming of prices in this area because of increased demand. This concentration of IDM demand, combined with rapidly increasing demand for 0.35-micron processes among the fabless companies, puts the sweet spot of the market around 0.5 micron at present. The sweet spot will gradually move through successive technology generations as the fabless design houses and system OEMs aggressively pursue leading-edge technology while the IDMs continue to supplement their internal capacity for mainstream and lagging-edge technologies. One result of this shift of the technology sweet spot over time is an increase in the average price per square inch for SCM services.

SCM Revenue Forecast

The average price per square inch, based on the changing technology mix, combined with the MSI forecast presented earlier, gives the forecast of SCM revenue shown in Figure 2-3. Dataquest forecasts essentially flat SCM revenue in 1997, despite healthy MSI growth of 14 percent, because of lower wafer prices. Revenue growth resumes in 1998, reaching U.S.$15.5 billion in 2001, which represents a compound annual growth rate of 18.9 percent.

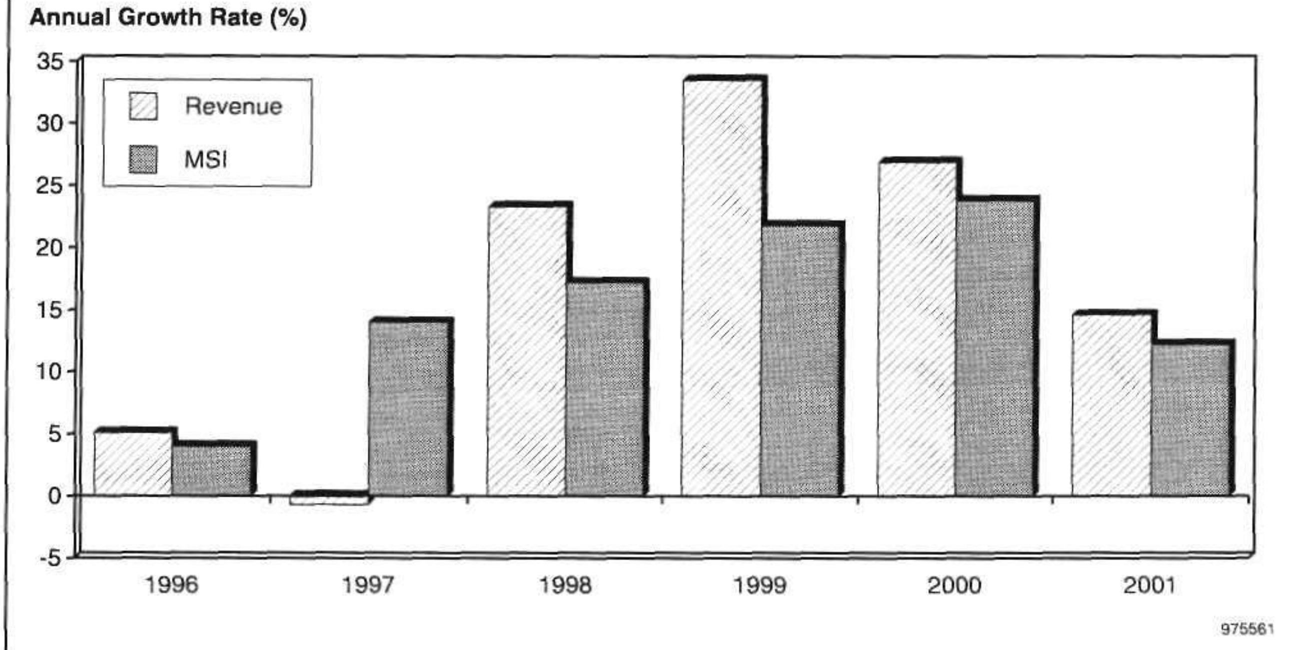
In Figure 2-4, the sequential annual growth rates of MSI and revenue are compared for the forecast period. In MSI terms, the SCM market is expected to grow at an increasing rate throught the year 2000. Slowing expansion is forecast for 2001 as the industry begins its transition to the next down cycle. The effect of pricing can be clearly seen in the year-over-year growth in SCM revenue. As previously discussed, dramatically lower prices for foundry wafers will result in flat revenue for 1997, despite positive MSI growth. SCM revenue will experience a growth spurt in the years 1998 and 1999. The higher growth rates in these years are the result of an increasing average price per square inch for foundry wafers, which is driven by the shift in technology mix toward the leading edge. As 0.35- and 0.25-micron wafers make up a larger portion of the SCM market, their premium prices move the average price per square inch higher.

Figure 2-3
Worldwide SCM Market Forecast, 1996 to 2001



Source: Dataquest (July 1997)

Figure 2-4
Year-over-Year Growth in the Worldwide SCM Market, 1996 to 2001



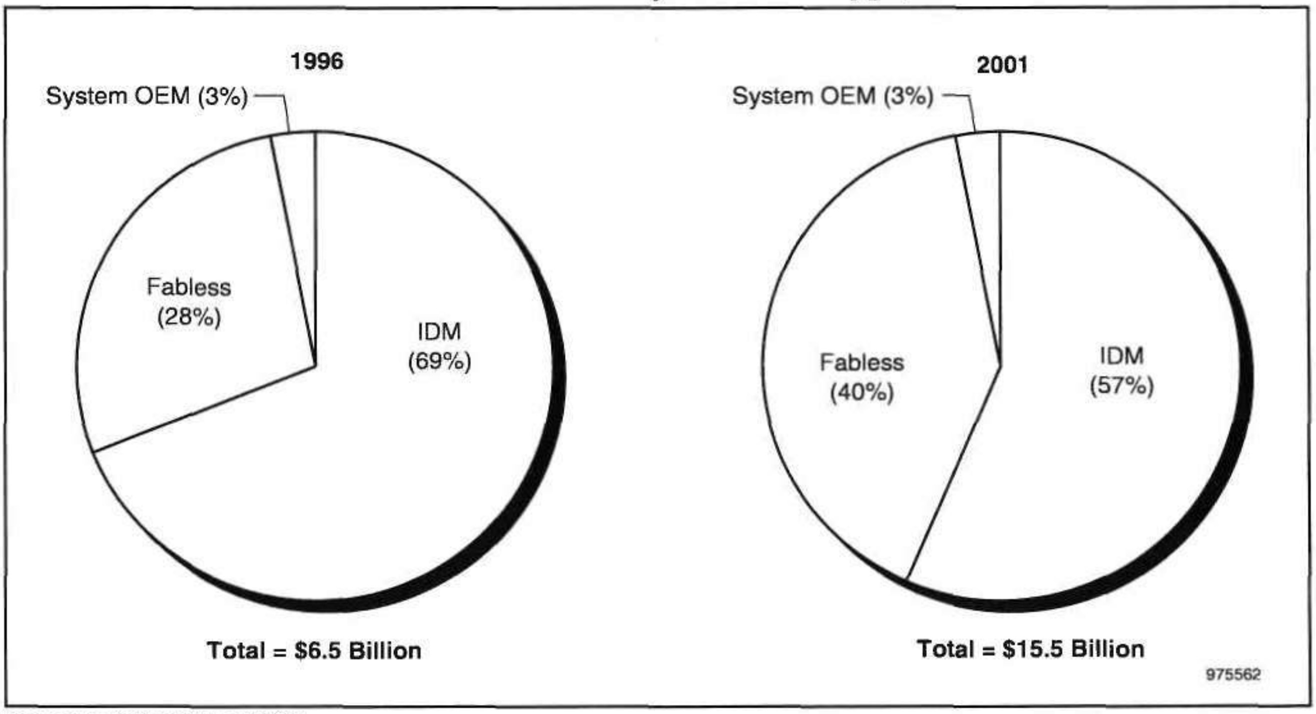
Source: Dataquest (July 1997)

Customer Types

Customers for SCM services include fabless semiconductor design companies, integrated device manufacturers, and system OEMs. IDMs are companies that design, manufacture, and market their own semiconductor products. Many IDMs supplement their internal manufacturing by purchasing additional foundry capacity, often for older technologies that are no longer the focus of the company's manufacturing operation. Fabless companies and most system OEMs are almost completely dependent on foundry providers for their wafer processing. (The FSA defines a fabless company as one that relies on outside sources for greater than 75 percent of its semiconductor manufacturing capacity.)

The dedicated foundry and the fabless design house are complementary business models that emerged at the same time, so the fabless companies are often thought of as the primary customer for foundry services. It may come as a surprise to some that IDMs made up over two-thirds of the demand for SCM services in 1996 (see Figure 2-5). Even though they have their own fabs, IDMs are outsourcing a significant portion of their production volume to foundries. The use of foundries has become an important element in the manufacturing strategy of many IDMs. The foundry becomes an extension of their own manufacturing operation, offering greater flexibility in capacity loading and perhaps a broader range of process technologies. Also, an IDM can achieve a finer granularity in capacity additions by using a foundry to gradually step up production levels until a new fab is needed. For these reasons, the IDM customer can be expected to play an important role in the SCM market of the future and, in fact, is forecast to represent over half the demand for foundry services in 2001.

Figure 2-5
Distribution of Worldwide SCM Demand by Customer Type, 1996 and 2001



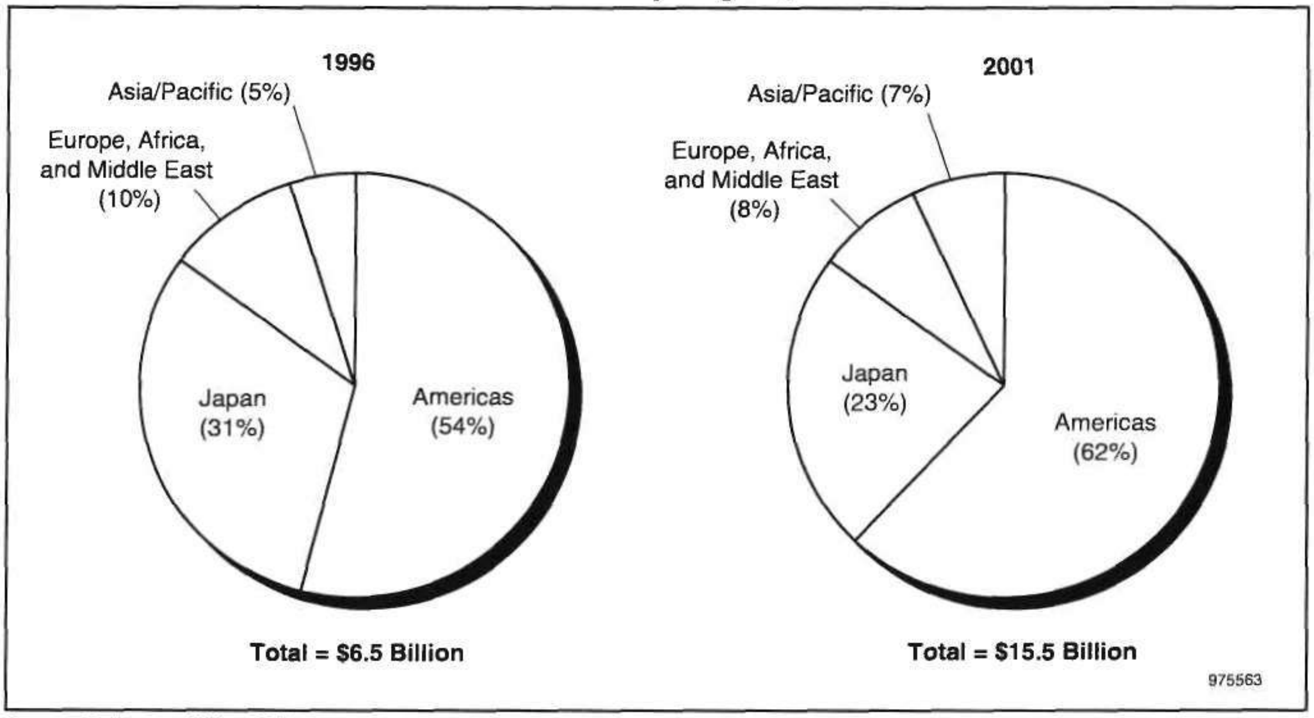
Source: Dataquest (July 1997)

Of course, the fabless companies will play an equally important role in the development of the SCM market. Because these companies are participating in some of the fastest-growing semiconductor application markets, growth of fabless revenue is forecast to outpace the greater semiconductor market. As a result, fabless companies will represent a larger portion of the demand for SCM services, increasing from 28 percent in 1996 to 40 percent in 2001.

Regional Distribution

Figure 2-6 shows the distribution of demand for SCM services by geographical area. North America is the largest consumer of foundry services, driven largely by the proliferation of fabless companies in the region. Japan has a well-developed foundry industry supporting an internal market. Looking to 2001, the fastest growth is expected to occur in the Americas and Asia/Pacific regions. Once again, fabless companies are at the root of this expected surge in demand. The fabless community in the United States is already large and well known, but there is an emerging fabless semiconductor industry in Taiwan that is expected to contribute to growth in Asia/Pacific demand for SCM services.

Figure 2-6
Distribution of Worldwide SCM Demand by Region, 1996 and 2001



Source: Dataquest (July 1997)

The SCM demand picture in North America is dominated by the fabless IC design sector, which has until recently been a uniquely American phenomenon. The well-publicized early successes of the fabless business model have inspired literally hundreds of fabless start-ups in the United States, offering a broad range of semiconductor products, from PC graphics accelerators to communications controllers and programmable logic devices (PLDs). Concentration of capital in the large fabs of the foundries and division of R&D investment (foundries develop process technology while fabless companies focus on product design) have dramatically lowered the cost of entry for fabless companies wishing to participate in the semiconductor market.

Chapter 3
Semiconductor Contract Manufacturing Capacity and Demand

Highlights

Highlights of SCM manufacturing capacity and demand are:

- The year 1996 marked the transition of the worldwide SCM market from capacity constraint to overcapacity. This move was accompanied by dramatic declines in foundry wafer prices, starting in the middle of the year and continuing into 1997.
- SCM overcapacity is expected to continue throughout 1997, reaching a peak of 15 percent in 1998 before starting a gradual decline to a minimum of 8 percent in the year 2000. The trend toward excess capacity resumes in 2001 as the semiconductor industry enters another down cycle.
- An analysis of 0.35-micron capacity and demand reveals neither overcapacity nor shortage. Capacity is leading demand by about five months with both on a very steep ramp-up. This market is close to ideal, with ample capacity and a competitive pricing environment.
- The bulk of overcapacity in the SCM market appears to be concentrated in the 0.5- to 0.8-micron technology range, the result of an influx of unused capacity from IDMs.
- A tightening of capacity in the greater semiconductor industry could cause some opportunistic IDMs to retreat from the SCM market. If this happens, the market could be pushed into shortage as early as late 1999.

Methodology

As discussed in the previous chapter, Dataquest obtains supply- and demand-side information from a variety of sources in order to forecast the market for SCM services. The "supply" of SCM services is the aggregate of semiconductor wafer processing capacity allocated to SCM, or foundry, services. In the case of a dedicated foundry such as Taiwan Semiconductor Mfg. Co. or Chartered Semiconductor Manufacturing Pte. Ltd., 100 percent of usable fab capacity is made available to the SCM market. An IDM, such as IBM or LG Semicon Co. Ltd., will allocate a certain percentage of its capacity to SCM services. Dataquest measures these amounts in millions of square inches of silicon and sums them to obtain the total SCM capacity.

The internal Japanese "captive" SCM market has been excluded from this capacity/demand analysis. Japan has a large foundry market in which both supply and demand sources lie completely within its borders. It is a unique arrangement in which semiconductor manufacturers can concentrate production of trailing-edge process technologies in a few older fabs, thus maintaining acceptable utilization levels. Since the under- or overcapacity of this internal market is not relevant to the greater worldwide SCM market, it is not included here. It should be noted, however, that several

Japanese companies export foundry services to the worldwide market, and these have been counted in Dataquest's capacity projection.

The projected SCM capacity is compared with the previously forecast demand for SCM services to give an indication of relative under- or over-capacity at a particular time. The foundry market is not perfectly efficient; it takes some time to match suppliers' capabilities with customers' specific needs as process development issues are worked out, qualification cycles are completed, and production is ramped. This means that foundry capacity must be available typically about four months ahead of actual customer demand. The capacity values have been shifted by four months to account for this delay.

Looking at the Leading Edge

The 0.35-micron SCM market has been heating up, and Dataquest wanted to see what was happening here from a capacity/demand perspective, also. At 0.35-micron, most IDMs will be using their internal capacity until the technology becomes more mature, so the SCM market will consist mainly of dedicated foundry suppliers and fabless customers. Current and planned 0.35-micron fab capacity was projected for the dedicated foundry companies, with the assumption that 80 percent of the dedicated foundry capacity at 0.35-micron serves fabless demand. The 0.35-micron portion of fabless demand was broken out based on a technology distribution derived from the Fabless Semiconductor Association's *1997 Wafer Demand Survey*. This survey captures about 60 percent of worldwide fabless demand, and the technology mix has been extrapolated to the greater market. Finally, capacity has again been shifted by four months to account for the inefficiencies of the market previously discussed.

To obtain an accurate view of the dynamics of capacity and demand in the SCM market, it is necessary to consider the technology segments separately. At any given time, quite different situations may exist between leading edge and mainstream technology markets, for example. Dataquest intends to expand its analysis to include a more detailed treatment of these technology segments in the future.

SCM Capacity Buildup Continues

Recent years have seen an explosion in foundry capacity. The early success of dedicated foundry companies has attracted new players and unprecedented investment in new foundry fabs, and the trend shows no sign of letting up. Table 3-1 compares the trends in 1997 capital spending of the top three dedicated foundry companies to the industry average. At a time when most semiconductor companies are reducing spending, the foundries are continuing to pursue aggressive capacity expansion plans.

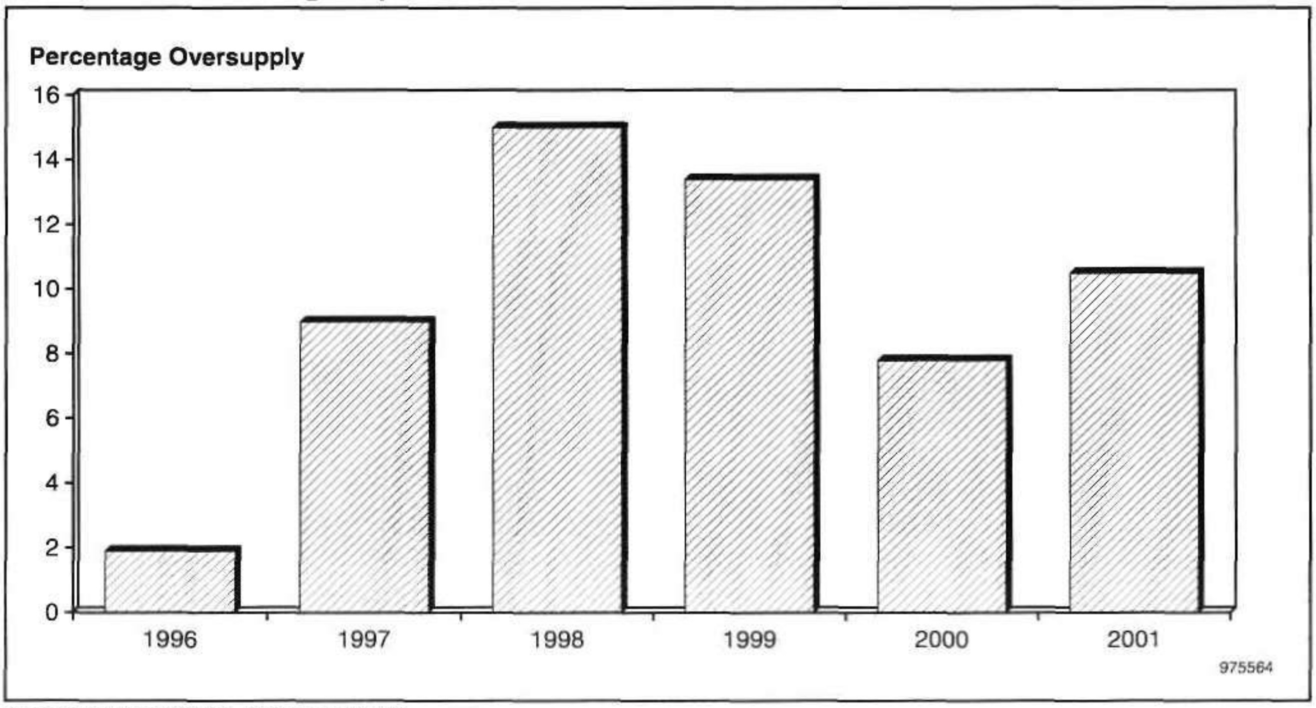
Add to this the influx of IDMs offering large chunks of their unused capacity to the market, and SCM capacity is finally sufficient to meet all demand. Indeed, 1996 marked the transition of the foundry market from capacity constraint to overcapacity, as can be seen in Figure 3-1.

Table 3-1
Capital Spending Trends of the Top Three Dedicated Foundry Companies, 1997

Company	Percentage Change, 1996 to 1997
Chartered Semiconductor Mfg.	11.9
TSMC	13.9
UMC	16.7
Total Worldwide Capital Spending	**-8.5**

Source: Dataquest (July 1997)

Figure 3-1
Worldwide SCM Capacity and Demand Imbalance, 1996 to 2001



Note: Excludes internal Japanese market
Source: Dataquest (July 1997)

Overcapacity continues to accelerate in 1997, as aggressive capacity expansion outstrips demand. This situation is reflected in the rapid fall of foundry wafer prices that began in mid-1996 and has continued through the first half of 1997. Peak overcapacity is expected to occur in 1998, after which it begins a slow decline as increasing demand starts to catch up with capacity. The trend toward balanced capacity and demand is interrupted in 2001, when Dataquest expects the next semiconductor industry slowdown to put the brakes on demand growth.

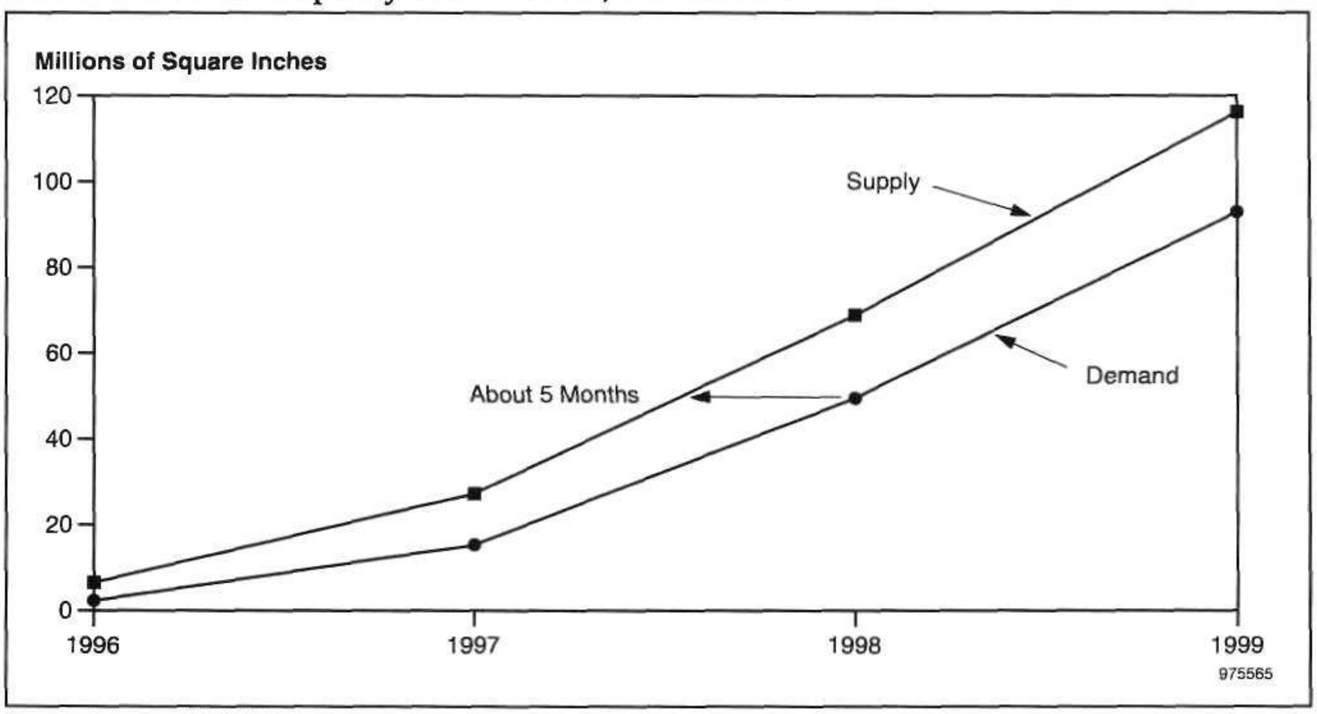
Because IDMs make up the majority of SCM capacity, their behavior can have a large effect on the market, and in some cases, their participation in the foundry business might be characterized as opportunistic. Tightening capacity in the greater semiconductor industry could elicit a retreat from the foundry market on the part of some IDMs. If this movement were sufficiently widespread, it might result in a capacity shortage as early as late 1999.

Dataquest believes the bulk of the overcapacity exists in the 0.5- to 0.8-micron range of technologies. Much of the recent increase in SCM capacity is the result of IDMs putting idled capacity on the market, and such capacity is probably in that range. At the same time, many fabless companies are moving their products to 0.35-micron, resulting in some decrease in demand for the 0.5- and 0.6-micron technologies they were using heavily one to two years ago. The following analysis of 0.35-micron capacity and demand is consistent with the idea that overcapacity is most acute in the 0.5- to 0.8-micron technology segment.

0.35-Micron Supply Leading Demand

The hottest segment of the SCM market today is 0.35-micron, with demand taking off and ample foundry capacity coming on line. But is the market in shortage or overcapacity? The best answer to this question is: neither. In fact, while capacity and demand are not technically "balanced," the situation is as close to ideal as can be reasonably expected in the real world, with capacity sufficient to meet growing demand and, at the same time, relatively high utilization levels in the foundry fabs. Figure 3-2 illustrates the current and projected capacity/demand picture at 0.35-micron.

Figure 3-2
0.35-Micron SCM Capacity and Demand, 1996 to 1999



Source: Dataquest (July 1997)

As shown, capacity is leading demand by about five months at present. (This is after applying the four-month shift in capacity discussed in the Methodology section; that is, the differential would be nine months without the shift.) Another way to visualize the current relationship between capacity and demand is to consider the difference in terms of MSI. In the middle of 1997, this difference is about equivalent to the output of a 200mm fab with 20,000 wafer starts per month, which is to say, the present overcapacity amounts to the idling of one 0.35-micron fab. However, because demand is ramping so steeply, this idle fab will be filled within five months, so capacity "feels" a little tighter than it actually is.

The rapidly increasing demand for 0.35-micron SCM services creates a market environment in which customers are working to secure needed 0.35-micron capacity as they ramp production of their new products, and suppliers are filling new fab capacity as it becomes available. This situation seems like tight capacity, but at the same time, rapidly increasing 0.35-micron capacity brought on by aggressive fab expansion is causing real competition for market share among suppliers. The result is a soft pricing environment, and Dataquest has seen foundry prices for 0.35-micron wafers fall 30 percent, on average, over the past year. Dataquest continues to hear of ever-lower prices for 0.35-micron wafers, so it would appear that prices remain under pressure in this market. With capacity continuing to lead demand, Dataquest would expect some weakness in 0.35-micron prices to persist well into 1998.

Appendix A
Tables and Background Data

Table A-1
Worldwide SCM Demand, 1996 to 2001 (Millions of Square Inches)

	1996	1997	1998	1999	2000	2001	CAGR (%) 1996-2001
Americas	109	135	162	206	270	311	23.3
Japan	118	124	139	161	185	200	11.1
Europe, Africa, and Middle East	33	37	44	51	60	66	14.7
Asia/Pacific	12	14	18	24	32	37	26.5
Worldwide	272	310	363	442	547	614	17.7

Source: Dataquest (July 1997)

Table A-2
Worldwide SCM Market by Geographic Region, 1996 to 2001 (Millions of U.S. Dollars)

	1996	1997	1998	1999	2000	2001	CAGR (%) 1996-2001
Americas	3,536	3,563	4,513	6,299	8,299	9,703	22.4
Japan	1,994	1,979	2,278	2,750	3,212	3,485	11.8
Europe, Africa, and Middle East	639	577	729	929	1,085	1,218	13.8
Asia/Pacific	338	345	446	655	895	1,053	25.6
Worldwide	6,506	6,464	7,967	10,633	13,491	15,460	18.9

Source: Dataquest (July 1997)

Table A-3
Worldwide SCM Market by Customer Type, 1996 to 2001 (Millions of U.S. Dollars)

	1996	1997	1998	1999	2000	2001	CAGR (%) 1996-2001
IDM	4,509	4,279	5,134	6,502	7,737	8,695	14.0
Fabless	1,832	2,000	2,589	3,791	5,288	6,251	27.8
System OEM	165	184	244	340	466	515	25.5
Worldwide	6,506	6,464	7,967	10,633	13,491	15,460	18.9

Source: Dataquest (July 1997)

Table A-4
Dedicated Foundry Capacity by Company, 1996 to 2001 (Millions of Square Inches)

	1996	1997	1998	1999	2000	2001
Americas						
Orbit Semiconductor	2.1	2.4	2.4	2.4	2.4	2.4
WaferTech	0	3.0	12.0	13.0	13.0	13.0
Europe, Africa, and Middle East						
Newport Wafer-Fab Ltd.	3.9	4.3	5.5	7.0	9.0	10.5
Tower Semiconductor	4.4	5.3	5.5	5.8	6.1	6.4
Asia/Pacific						
Anam	0	1.2	5.9	9.9	14.8	14.8
ASMC-Shanghai	4.1	5.8	7.5	9.8	12.2	15.2
Chartered Semiconductor Mfg.	14.4	23.8	40.8	49.5	61.2	73.5
Holtek	0	0	2.9	7.0	11.8	14.8
InterConnect Technology	0	0.5	3.5	8.8	11.7	11.7
Submicron Technology	0	0	1.0	2.8	8.2	11.8
TSMC	40.0	50.1	54.7	73.8	98.1	118.0
UMC Group	17.5	29.4	38.1	44.0	48.7	56.0
Worldwide Semiconductor Mfg. Corp.	0	0	2.9	7.0	11.8	14.8

Source: Dataquest (July 1997)

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Market Statistics

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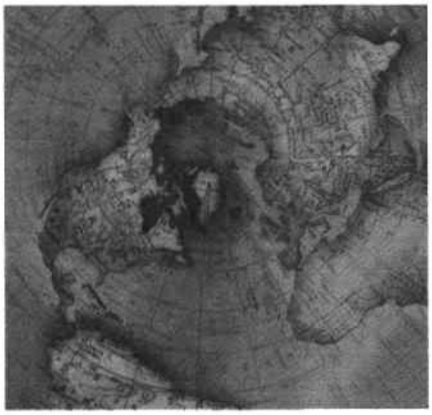

Dataquest

1996 Semiconductor Contract Manufacturing Market Share Estimates

Market Statistics

Program: Semiconductor Contract Manufacturing Services Worldwide
Product Code: SCMS-WW-MS-9701
Publication Date: November 24, 1997
Filing: Market Statistics

1996 Semiconductor Contract Manufacturing Market Share Estimates

Market Statistics

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Filing: Market Statistics

Table of Contents

List of Figures

List of Tables

Chapter 1
Introduction and Definitions

Introduction

This document contains detailed information on Dataquest's estimates of the semiconductor contract manufacturing (SCM), or foundry, market for the years 1993 through 1996. Each year, Dataquest surveys SCM service providers to estimate their annual revenue derived from sales of foundry-processed wafers. The 1996 survey canvassed about 45 SCM suppliers in four geographical regions. The information obtained is supplemented and cross-checked with Dataquest's various other information sources. Dataquest conducts this research on an annual basis.

Changes to Historical Data

In the process of collecting data and evaluating market statistics, Dataquest will sometimes consolidate or revise previously published market estimates. We revise beyond one year only in those situations when an individual company's market position or the size of a given regional market for SCM services would be altered significantly.

The semiconductor foundry is a relatively new business, and availability of historical market statistics is somewhat limited. In the course of expanding its research in the SCM market, Dataquest has gained deeper insights into the semiconductor foundry industry, and we now find it necessary to re-examine our past estimates of the market. The net result of this re-evaluation is a lowering of our estimates for the size of the SCM market for 1993 through 1996. This reduction is due in large part to an internal Japanese foundry market that is significantly smaller than previously estimated and shrinking.

The market statistics included in this report reflect the changes to Dataquest's previous estimates. We will publish a separate report in the coming months that will describe the changes in detail and explain the reasons behind the revisions.

Figure 1-1 shows sales revenue from shipments of foundry wafers to the world.

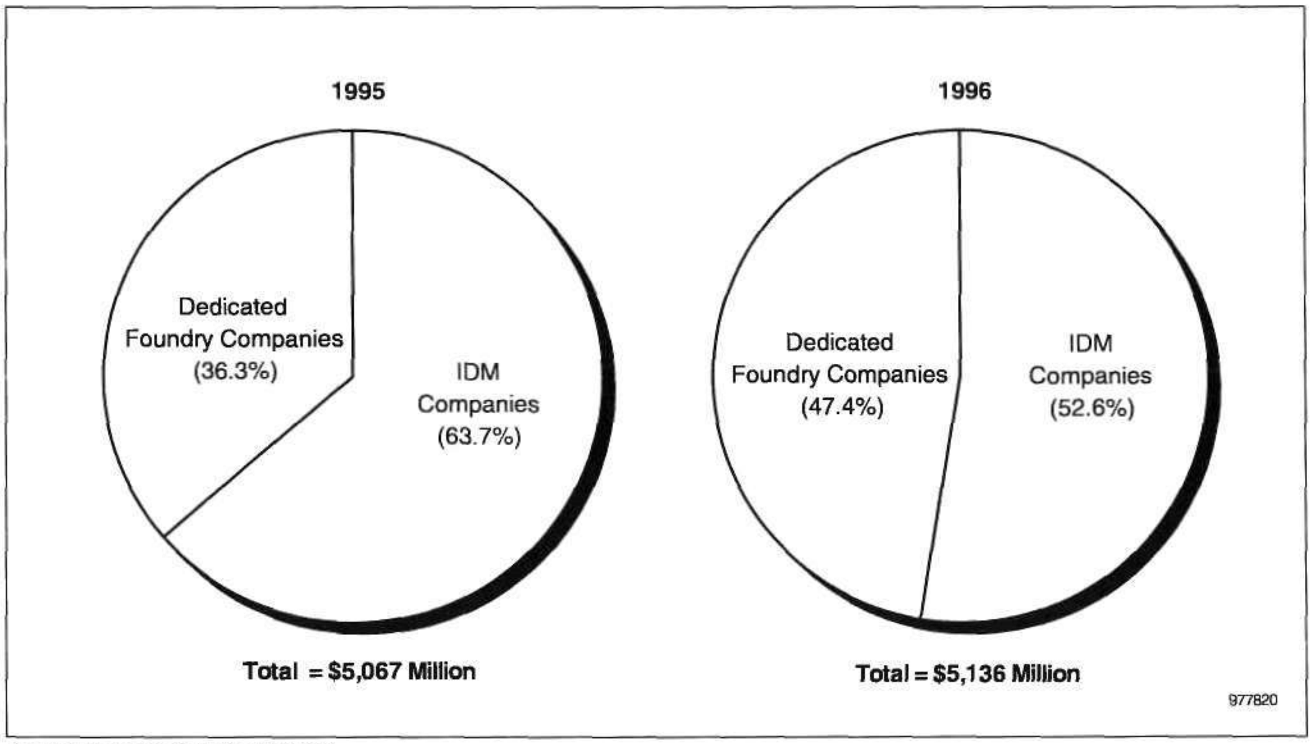
Definitions

The following definitions apply to terms used throughout this report:

- **Semiconductor contract manufacturing (SCM):** A service in which a supplier performs some or all semiconductor manufacturing operations under contract to a customer. In its broadest sense, SCM can encompass wafer fabrication, packaging/assembly, and testing of semiconductor products.
- **Foundry purchase:** Foundry purchases include unprobed wafers, probed wafers, tested wafers (known good die), or packaged chips.

- **Dedicated foundry provider:** Dedicated foundry providers are companies whose charter is to fabricate semiconductor products for other companies. Dataquest recognizes the following dedicated foundries: Advanced Semiconductor Manufacturing Company (Shanghai), Chartered Semiconductor Manufacturing Pte. Ltd., GMT Microelectronics, Newport Wafer-Fab Ltd., Orbit Semiconductor Inc., Taiwan Semiconductor Mfg. Co., Tower Semiconductor Ltd., and United Microelectronics Corporation (UMC Group).
- **Integrated device manufacturer (IDM):** An IDM is a semiconductor supplier, merchant or captive, that manufactures its own products. The defining attribute of an IDM is the exclusive ownership and operation of one or more wafer fabrication facilities.
- **Fabless company:** A fabless company is a merchant semiconductor supplier that designs and markets, but does not manufacture, its own semiconductor products. A fabless company is defined as one that obtains more than 75 percent of its wafers from outside sources.
- **System OEM:** A system OEM is an electronics equipment supplier that is neither a merchant nor captive semiconductor supplier but that designs semiconductor devices for its own internal use and outsources the manufacturing of such devices.
- **Company base:** Company base is the geographical region in which a company is based, determined by the location of the company's headquarters.
- **Region:** Except as defined for "company base," region refers to customer location—that is, shipping destination. Dataquest groups these destinations into four geographical regions: Americas; Japan; Europe, Middle East, and Africa; and Asia/Pacific. Note that this definition excludes any subsequent processing the product may undergo after it has been delivered to the primary foundry customer.

Figure 1-1
Sales Revenue from Shipments of SCM Wafers to the World by Supplier Type, 1995 and 1996



Source: Dataquest (October 1997)

Chapter 2
Market Statistics Tables

Tables 2-1 through 2-14 show market statistics for semiconductor contract manufacturing companies.

Table 2-1
Historical Sales Revenue from Shipments of SCM (Foundry) Wafers to the World, 1993 to 1996 (Millions of U.S. Dollars)

	1993	1994	1995	1996	CAGR (%) 1993-1996
North American Companies					
Allegro MicroSystems	NS	NS	3	5	NM
American Microsystems	50	62	77	110	30.1
Applied Micro Circuits Corp.	NS	NS	1	2	NM
GMT Microelectronics Corporation	NS	NS	2	2	NM
IBM Microelectronics	47	240	320	450	112.3
IC Works	NS	15	18	20	NM
IMP	NS	46	50	32	NM
Lucent	NS	NS	45	30	NM
Micrel	10	18	23	23	32.0
Mitel	NS	NS	25	20	NM
Orbit Semiconductor	27	32	44	50	22.8
Raytheon	-	-	1	1	NM
Texas Instruments	20	30	30	15	-9.1
VLSI Technology	NS	7	7	16	NM
Surveyed Companies	**154**	**450**	**646**	**776**	**71.4**
Japanese Companies					
Asahi Kasei Microsystems	20	22	25	30	14.5
Fujitsu	75	60	50	46	-15.0
Hitachi	20	15	12	9	-23.4
Kawasaki Semiconductor	85	70	60	55	-13.5
Matsushita	47	30	49	86	22.3
Mitsubishi	130	80	32	24	-43.1
NEC	50	40	33	28	-17.6
New Japan Radio Company	10	10	11	14	11.9
Nippon Steel Semiconductor	340	320	266	18	-62.5
Oki	130	85	35	28	-40.1
Ricoh	15	20	45	55	54.2
Rohm	18	30	25	28	15.9
SANYO	37	46	72	138	55.1

Table 2-1 (Continued)
Historical Sales Revenue from Shipments of SCM (Foundry) Wafers to the World, 1993 to 1996 (Millions of U.S. Dollars)

	1993	1994	1995	1996	CAGR (%) 1993-1996
Seiko Epson	220	250	260	230	1.5
Sharp	135	160	192	236	20.5
Sony	5	6	8	9	21.6
Toshiba	430	450	479	184	-24.6
Yamaha	32	38	40	46	12.9
Surveyed Companies	**1,799**	**1,732**	**1,694**	**1,264**	**-11.1**
European Companies					
Austria Mikro Systeme	NS	NS	38	23	NM
Newport Wafer-Fab Ltd.	-	14	30	32	NM
SGS-Thomson	30	50	75	69	32.0
Thesys	-	6	34	17	NM
Tower Semiconductor	37	57	100	98	38.4
Surveyed Companies	**67**	**127**	**277**	**239**	**52.8**
Asian Companies					
ASMC (Shanghai)	-	15	30	40	NM
Chartered Semiconductor	95	180	285	420	64.1
Daewoo	NS	NS	4	8	NM
Holtek	NS	14	17	63	NM
Hualon Microelectronics Corp.	-	15	15	16	NM
LG Semicon	240	320	567	337	12.0
Samsung	-	24	30	50	NM
Taiwan Semiconductor	480	750	1,085	1,435	44.1
United Microelectronics	134	165	262	350	37.7
Winbond Electronics	30	60	155	138	66.3
Surveyed Companies	**979**	**1,543**	**2,450**	**2,857**	**42.9**
Worldwide					
Surveyed Companies	**2,999**	**3,852**	**5,067**	**5,136**	**19.6**
Other Companies	**97**	**68**	**-**	**-**	**NM**
Total Market	**3,096**	**3,920**	**5,067**	**5,136**	**18.4**

NS = Not surveyed
NM = Not meaningful
Source: Dataquest (October 1997)

Table 2-2
All Companies' Sales Revenue from Shipments of SCM (Foundry) Wafers to the Americas Region, 1995 and 1996 (Millions of U.S. Dollars)

	1995 Revenue	1996 Revenue	Change (%)
North American Companies			
Allegro MicroSystems	3	5	66.7
American Microsystems	62	88	42.9
Applied Micro Circuits Corp.	1	2	100.0
GMT Microelectronics Corporation	2	2	0
IBM Microelectronics	304	428	40.6
IC Works	18	20	11.1
IMP	50	32	-36.0
Lucent	27	17	-38.9
Micrel	15	14	-7.7
Mitel	23	18	-20.0
Orbit Semiconductor	40	45	13.6
Raytheon	1	1	0
Texas Instruments	30	15	-50.0
VLSI Technology	7	16	128.6
Surveyed Companies	**582**	**702**	**20.7**
Japanese Companies			
Fujitsu	50	46	-8.0
Hitachi	12	9	-25.0
Matsushita	49	86	75.5
NEC	23	20	-15.2
New Japan Radio Company	10	13	27.3
Oki	28	27	-5.0
Ricoh	16	19	22.2
Rohm	25	28	12.0
SANYO	65	132	104.4
Seiko Epson	234	184	-21.4
Sharp	182	227	24.7
Sony	8	9	12.5
Toshiba	192	121	-36.6
Yamaha	32	39	22.2
Surveyed Companies	**926**	**960**	**3.7**
European Companies			
Austria Mikro Systeme	6	5	-13.0
Newport Wafer-Fab Ltd.	5	5	6.7
SGS-Thomson	64	59	-8.0
Thesys	34	17	-50.0
Tower Semiconductor	41	39	-4.4
Surveyed Companies	**149**	**125**	**-16.3**

Table 2-2 (Continued)
All Companies' Sales Revenue from Shipments of SCM (Foundry) Wafers to the Americas Region, 1995 and 1996 (Millions of U.S. Dollars)

	1995 Revenue	1996 Revenue	Change (%)
Asia/Pacific Companies			
ASMC (Shanghai)	8	10	33.3
Chartered Semiconductor	194	286	47.4
Daewoo	4	8	100.0
Holtek	1	4	764.7
Hualon Microelectronics Corp.	9	10	6.7
LG Semicon	23	40	78.3
Samsung	30	50	66.7
Taiwan Semiconductor	543	718	32.3
United Microelectronics	118	158	33.6
Winbond Electronics	124	113	-8.7
Surveyed Companies	**1,052**	**1,396**	**32.7**
All Companies	**2,708**	**3,183**	**17.5**

Source: Dataquest (October 1997)

Table 2-3
All Companies' Sales Revenue from Shipments of SCM (Foundry) Wafers to the Japan Region, 1995 and 1996 (Millions of U.S. Dollars)

	1995 Revenue	1996 Revenue	Change (%)
North American Companies			
Micrel	2	3	44.4
Surveyed Companies	**2**	**3**	**44.4**
Japanese Companies			
Asahi Kasei Microsystems	25	30	20.0
Kawasaki Semiconductor	60	55	-8.3
Mitsubishi	32	24	-25.0
NEC	7	6	-15.2
New Japan Radio Company	1	1	27.3
Nippon Steel Semiconductor	266	18	-93.2
Ricoh	29	36	22.2
SANYO	4	3	-23.3
Seiko Epson	13	32	147.7
Sharp	10	9	-7.9
Toshiba	240	18	-92.3
Surveyed Companies	**686**	**232**	**-66.2**
European Companies			
Tower Semiconductor	5	5	-2.0
Surveyed Companies	**5**	**5**	**-2.0**
Asia/Pacific Companies			
Holtek	-	3	NM
LG Semicon	544	297	-45.5
Taiwan Semiconductor	54	72	32.3
United Microelectronics	3	4	33.6
Winbond Electronics	-	1	NM
Surveyed Companies	**601**	**376**	**-37.4**
All Companies	**1,294**	**616**	**-52.4**

Source: Dataquest (October 1997)

Table 2-4
All Companies' Sales Revenue from Shipments of SCM (Foundry) Wafers to the Europe Region, 1995 and 1996 (Millions of U.S. Dollars)

	1995 Revenue	1996 Revenue	Change (%)
North American Companies			
American Microsystems	15	22	42.9
IBM Microelectronics	16	23	40.6
Lucent	9	3	-66.7
Micrel	3	3	-8.3
Mitel	3	2	-20.0
Orbit Semiconductor	4	5	13.6
Surveyed Companies	**50**	**57**	**13.9**
Japanese Companies			
NEC	3	3	-15.2
SANYO	4	3	-23.3
Seiko Epson	13	14	6.2
Toshiba	24	22	-7.8
Yamaha	8	7	-13.8
Surveyed Companies	**52**	**48**	**-6.8**
European Companies			
Austria Mikro Systeme	32	18	-44.5
Newport Wafer-Fab Ltd.	21	24	14.3
Tower Semiconductor	3	5	63.3
Surveyed Companies	56	47	-16.6
Asia/Pacific Companies			
ASMC (Shanghai)	21	28	33.3
Taiwan Semiconductor	163	215	32.3
United Microelectronics	13	7	-46.6
Winbond Electronics	2	3	78.1
Surveyed Companies	**198**	**253**	**27.5**
All Companies	**356**	**405**	**13.7**

Source: Dataquest (October 1997)

Table 2-5
All Companies' Sales Revenue from Shipments of SCM (Foundry) Wafers to the Asia/Pacific Region, 1995 and 1996 (Millions of U.S. Dollars)

	1995 Revenue	1996 Revenue	Change (%)
North American Companies			
Lucent	9	11	16.7
Micrel	3	4	14.3
Surveyed Companies	**12**	**14**	**16.0**
Japanese Companies			
Oki	7	1	-80.0
Toshiba	24	22	-7.8
Surveyed Companies	**31**	**23**	**-24.1**
European Companies			
Newport Wafer-Fab Ltd.	5	3	-28.9
SGS-Thomson	11	10	-8.0
Tower Semiconductor	51	49	-3.9
Surveyed Companies	**67**	**63**	**-6.3**
Asia/Pacific Companies			
ASMC (Shanghai)	2	2	33.3
Chartered Semiconductor	91	134	47.4
Holtek	16	55	236.2
Hualon Microelectronics Corp.	6	6	6.7
Taiwan Semiconductor	326	431	32.3
United Microelectronics	128	182	41.8
Winbond Electronics	29	21	-29.7
Surveyed Companies	**599**	**831**	**38.9**
All Companies	**708**	**932**	**31.5**

Source: Dataquest (October 1997)

Table 2-6
Top 15 Companies' Sales Revenue from Shipments of SCM (Foundry) Wafers to the World, 1996 (Millions of U.S. Dollars)

1995 Rank	1996 Rank		1995 Revenue	1996 Revenue	Change (%)	1996 Market Share (%)
1	1	Taiwan Semiconductor	1,085	1,435	32.3	28.0
4	2	IBM Microelectronics	320	450	40.6	8.8
5	3	Chartered Semiconductor	285	420	47.4	8.2
7	4	United Microelectronics	262	350	33.6	6.8
2	5	LG Semicon	567	337	-40.6	6.6
8	6	Seiko Epson	260	230	-11.5	4.5
9	7	Sharp	192	236	22.9	4.6
3	8	Toshiba	479	184	-61.6	3.6
10	9	Winbond Electronics	155	138	-11.0	2.7
14	9	SANYO	72	138	91.7	2.7
12	11	American Microsystems	77	110	42.9	2.1
11	12	Tower Semiconductor	100	98	-2.0	1.9
18	13	Matsushita	49	86	75.5	1.7
13	14	SGS-Thomson	75	69	-8.0	1.3
37	15	Holtek	17	63	270.6	1.2
		Top 15 Companies	**3,995**	**4,344**	**8.7**	**84.6**
		Other Companies	**1,072**	**792**	**-26.1**	**15.5**
		All Companies	**5,067**	**5,136**	**1.4**	**100.0**

Source: Dataquest (October 1997)

Table 2-7
Top 15 Companies' Sales Revenue from Shipments of SCM (Foundry) Wafers to the Americas Region, 1996 (Millions of U.S. Dollars)

1995 Rank	1996 Rank		1995 Revenue	1996 Revenue	Change (%)	1996 Market Share (%)
1	1	Taiwan Semiconductor	543	718	32.3	22.6
2	2	IBM Microelectronics	304	428	40.6	13.5
4	3	Chartered Semiconductor	194	286	47.4	9.0
6	4	Sharp	182	227	24.7	7.1
3	5	Seiko Epson	234	184	-21.4	5.8
8	6	United Microelectronics	118	158	33.6	5.0
9	7	SANYO	65	132	104.4	4.2
5	8	Toshiba	192	121	-36.6	3.8
7	9	Winbond Electronics	124	113	-8.7	3.6
11	10	American Microsystems	62	88	42.9	2.8
14	11	Matsushita	49	86	75.5	2.7
10	12	SGS-Thomson	64	59	-8.0	1.9
19	13	Samsung	30	50	66.7	1.6
12	14	Fujitsu	50	46	-8.0	1.5
16	15	Orbit Semiconductor	40	45	13.6	1.4
		Top 15 Companies	**2,249**	**2,740**	**21.8**	**86.1**
		Other Companies	**459**	**443**	**-3.5**	**14.0**
		All Companies	**2,708**	**3,183**	**17.5**	**100.0**

Source: Dataquest (October 1997)

Table 2-8
Top 10 Companies' Sales Revenue from Shipments of SCM (Foundry) Wafers to the Japan Region, 1996 (Millions of U.S. Dollars)

1995 Rank	1996 Rank		1995 Revenue	1996 Revenue	Change (%)	1996 Market Share (%)
1	1	LG Semicon	544	297	-45.5	48.1
5	2	Taiwan Semiconductor	54	72	32.3	11.6
4	3	Kawasaki Semiconductor	60	55	-8.3	8.9
7	4	Ricoh	29	36	22.2	5.8
9	5	Seiko Epson	13	32	147.7	5.2
8	6	Asahi Kasei Microsystems	25	30	20.0	4.9
6	7	Mitsubishi	32	24	-25.0	3.9
3	8	Toshiba	240	18	-92.3	3.0
2	9	Nippon Steel Semiconductor	266	18	-93.2	2.9
10	10	Sharp	10	9	-7.9	1.4
		Top 10 Companies	**1,273**	**591**	**-53.6**	**95.8**
		Other Companies	**21**	**26**	**22.3**	**4.2**
		All Companies	**1,294**	**616**	**-52.4**	**100.0**

Source: Dataquest (October 1997)

Table 2-9
Top 10 Companies' Sales Revenue from Shipments of SCM (Foundry) Wafers to the Europe Region, 1996 (Millions of U.S. Dollars)

1995 Rank	1996 Rank		1995 Revenue	1996 Revenue	Change (%)	1996 Market Share (%)
1	1	Taiwan Semiconductor	163	215	32.3	53.1
4	2	ASMC (Shanghai)	21	28	33.3	6.9
4	3	Newport Wafer-Fab Ltd.	21	24	14.3	5.9
6	4	IBM Microelectronics	16	23	40.6	5.6
3	5	Toshiba	24	22	-7.8	5.5
7	6	American Microsystems	15	22	42.9	5.4
2	7	Austria Mikro Systeme	32	18	-44.5	4.4
9	8	Seiko Epson	13	14	6.2	3.4
8	9	United Microelectronics	13	7	-46.6	1.7
11	10	Yamaha	8	7	-13.8	1.7
		Top 10 Companies	**326**	**379**	**16.3**	**93.6**
		Other Companies	**30**	**26**	**-14.5**	**6.4**
		All Companies	**356**	**405**	**13.7**	**100.0**

Source: Dataquest (October 1997)

Table 2-10
Top 10 Companies' Sales Revenue from Shipments of SCM (Foundry) Wafers to the Asia/Pacific Region, 1996 (Millions of U.S. Dollars)

1995 Rank	1996 Rank		1995 Revenue	1996 Revenue	Change (%)	1996 Market Share (%)
1	1	Taiwan Semiconductor	326	431	32.3	46.2
2	2	United Microelectronics	128	182	41.8	19.5
3	3	Chartered Semiconductor	91	134	47.4	14.4
7	4	Holtek	16	55	236.2	6.0
4	5	Tower Semiconductor	51	49	-3.9	5.3
6	6	Toshiba	24	22	-7.8	2.4
5	7	Winbond Electronics	29	21	-29.7	2.2
9	8	Lucent	9	11	16.7	1.1
8	9	SGS-Thomson	11	10	-8.0	1.1
11	10	Hualon Microelectronics Corp.	6	6	6.7	0.7
		Top 10 Companies	**692**	**921**	**33.1**	**98.9**
		Other Companies	**16**	**10**	**-36.6**	**1.1**
		All Companies	**708**	**932**	**31.5**	**100.0**

Source: Dataquest (October 1997)

Table 2-11
Sales Revenue from Shipments of SCM (Foundry) Wafers by Company Base into Each Region, 1995 and 1995 (Millions of U.S. Dollars)

	1995	1996	Change (%)
North American Companies			
Americas	582	702	20.7
Japan	2	3	44.4
Europe	50	57	13.9
Asia/Pacific	12	14	16.0
Worldwide	**646**	**776**	**20.1**
Japanese Companies			
Americas	926	960	3.7
Japan	686	232	-66.2
Europe	52	48	-6.8
Asia/Pacific	31	23	-24.1
Worldwide	**1,694**	**1,264**	**-25.4**
European Companies			
Americas	149	125	-16.3
Japan	5	5	-2.0
Europe	56	47	-16.6
Asia/Pacific	67	63	-6.3
Worldwide	**277**	**239**	**-13.7**
Asia/Pacific Companies			
Americas	1,052	1,396	32.7
Japan	601	376	-37.4
Europe	198	253	27.5
Asia/Pacific	599	831	38.9
All Companies	**2,450**	**2,857**	**16.6**
Worldwide Companies			
Americas	2,708	3,183	17.5
Japan	1,294	616	-52.4
Europe	356	405	13.7
Asia/Pacific	708	932	31.5
Worldwide	**5,067**	**5,136**	**1.4**

Source: Dataquest (October 1997)

Table 2-12
Distribution of Sales Revenue from Shipments of SCM (Foundry) Wafers by Company Base into Each Region, 1995 and 1996 (Percent)

	1995	1996
North American Companies		
Americas	90.0	90.4
Japan	0.3	0.4
Europe	7.7	7.3
Asia/Pacific	1.9	1.8
Worldwide	**100.0**	**100.0**
Japanese Companies		
Americas	54.6	76.0
Japan	40.5	18.4
Europe	3.1	3.8
Asia/Pacific	1.8	1.8
Worldwide	**100.0**	**100.0**
European Companies		
Americas	53.9	52.3
Japan	1.8	2.1
Europe	20.2	19.5
Asia/Pacific	24.1	26.2
Worldwide	**100.0**	**100.0**
Asia/Pacific Companies		
Americas	42.9	48.9
Japan	24.5	13.2
Europe	8.1	8.9
Asia/Pacific	24.4	29.1
Worldwide	**100.0**	**100.0**
All Companies		
Americas	53.5	62.0
Japan	25.5	12.0
Europe	7.0	7.9
Asia/Pacific	14.0	18.1
Worldwide	**100.0**	**100.0**

Source: Dataquest (October 1997)

Table 2-13
Sales Revenue from Shipments of SCM (Foundry) Wafers by Company Type into Each Region, 1995 and 1996 (Millions of U.S. Dollars)

	1995	1996	Change (%)
IDM Companies			
Americas	1,760	1,922	9.2
Japan	1,232	536	-56.5
Europe	131	121	-7.7
Asia/Pacific	106	131	22.7
Worldwide	**3,229**	**2,709**	**-16.1**
Dedicated Foundry Companies			
Americas	949	1,262	33.0
Japan	62	80	29.5
Europe	225	284	26.1
Asia/Pacific	602	801	33.1
Worldwide	**1,838**	**2,427**	**32.0**
All Companies			
Americas	2,708	3,183	17.5
Japan	1,294	616	-52.4
Europe	356	405	13.7
Asia/Pacific	708	932	31.5
Worldwide	**5,067**	**5,136**	**1.4**

Source: Dataquest (October 1997)

Table 2-14
Distribution of Sales Revenue from Shipments of SCM (Foundry) Wafers by Company Type into Each Region, 1995 and 1996 (Percent)

	1995	1996
IDM Companies		
Americas	54.5	70.9
Japan	38.2	19.8
Europe	4.1	4.5
Asia/Pacific	3.3	4.8
Worldwide	**100.0**	**100.0**
Dedicated Foundry Companies		
Americas	51.6	52.0
Japan	3.4	3.3
Europe	12.3	11.7
Asia/Pacific	32.8	33.0
Worldwide	**100.0**	**100.0**
All Companies		
Americas	53.5	62.0
Japan	25.5	12.0
Europe	7.0	7.9
Asia/Pacific	14.0	18.1
Worldwide	**100.0**	**100.0**

Source: Dataquest (October 1997)

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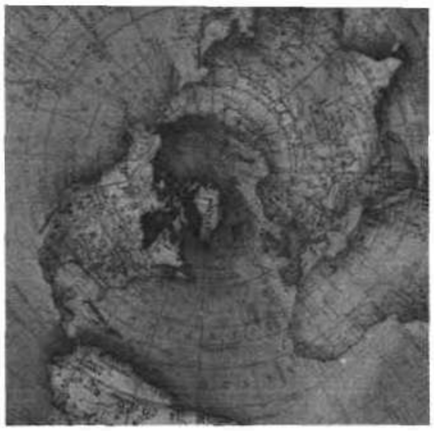

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1997 Worldwide Fabless Semiconductor Company Directory

Focus Report

Program: Semiconductor Contract Manufacturing Services Worldwide
Product Code: SCMS-WW-FR-9701
Publication Date: December 22, 1997
Filing: Reports

1997 Worldwide Fabless Semiconductor Company Directory

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Table of Contents

List of Figures

List of Tables

Chapter 1

Introduction

In recent years, the success of the fabless business model, supported by the complementary foundry business model, has become well established. Fabless semiconductor companies now represent 4.8 percent of the worldwide semiconductor market, and they are expected to continue to outpace the industry for the foreseeable future. (The Dataquest document "1996 Fabless Semiconductor Review," SCMS-WW-DP-9704, June 1997, analyzes fabless semiconductor company revenue and application markets.) The importance of this sector cannot be overstated, and the relationship between fabless semiconductor companies and growth in demand for foundry services is fundamental.

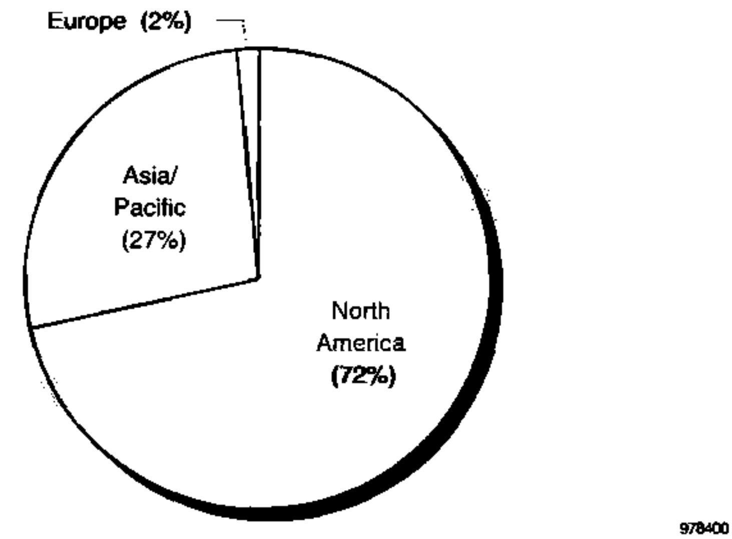
The number of fabless semiconductor companies is also growing. For the 1997 Fabless Directory, Dataquest has identified almost 200 fabless semiconductor companies around the world. Although many of these companies have attained a level of prominence in the industry, many more are relative newcomers, usually privately held, for which abundant information is not always available. The purpose of this report is to provide a directory of companies in the emerging fabless sector, along with some essential facts, such as company address, a brief description of product offerings, 1996 revenue (if available), stock symbol (if applicable), and the year the company was founded. It is hoped that the report will serve as a guide to the very dynamic fabless sector and provide a launching pad for further research into the fabless semiconductor companies.

Dataquest obtained the information in this directory through a combination of direct and secondary research. Using our extensive semiconductor and fab databases as sources, surveys were sent to about 200 companies that were believed to fit the criteria for a fabless company. Dataquest defines a fabless semiconductor company as one that designs and markets its own semiconductor products but relies on external sources for 75 percent or more of its wafer production needs. The resulting database of fabless companies was then augmented by secondary research of company literature, Web sites, and other sources of publicly available information about the companies.

Silicon Valley: The Fabless Hot Spot

There is no doubt about it—Silicon Valley is the center of the universe for the fabless semiconductor sector. Figure 1-1 shows the relative distribution of fabless semiconductor companies throughout regions of the world (excluding Japan). The vast majority of fabless companies are headquartered in North America, and almost all of those are located in Santa Clara County, California. The fabless phenomenon got its start in Silicon Valley, and there it has flourished. Although this report is not intended to examine the development of the fabless sector, it is safe to say that a large talent pool and access to venture capital were major contributors in the rise of fabless companies in the region.

Figure 1-1
Distribution of Fabless Semiconductor Companies by Headquarters Location



Source: Dataquest (November 1997)

There is a healthy community of fabless semiconductor companies growing up in Taiwan, reflected in the large slice of the pie (over one-quarter) attributed to the Asia/Pacific region. In fact, all but a handful of these companies are located in Taiwan, right next door to the world's leading dedicated foundries. Coincidence? Not likely. This is a geographically desirable relationship and one that can be expected to grow, provided enough technical talent can be found to feed it.

Dataquest Perspective

The large number of fabless semiconductor companies in this directory is a testament to the success of the foundry and fabless business models. Concentration of capital in the large fabs of foundry companies has dramatically lowered the cost of entry into the semiconductor market for dozens of fabless start-up companies. Division of R&D investment has given fabless companies a time-to-market advantage by allowing them to focus their efforts on product design and systems integration issues while the foundries take care of process technology development. Dataquest believes the fabless-foundry model will continue to grow in importance, and it will dramatically change the complexion of semiconductor manufacturing in the future.

Chapter 2
Directory of Fabless Semiconductor Companies

Tables 2-1, 2-2, and 2-3 list fabless semiconductor companies in North America, Europe, and Asia/Pacific.

Table 2-1
North American Fabless Companies (Revenue in Millions of U.S. Dollars)

	Year Founded	Initial Public Offering	Stock Symbol	1996 Revenue	Product and Market
Canada					
ATI Technologies Inc. 33 Commerce Valley Dr. East Thornhill, ONT L3T 7N6	1985	1993	ATY.TO	467	Graphics accelerators, multimedia accelerators
Focam Technology 3050 Blvd. Cartier West Laval, QUE H7V 1J4	1992	P			Analog, digital, and mixed-signal ICs, ASICs
Genesis Microchip Inc. 200 Town Centre Blvd., Suite 400 Markham, ONT L3R 8G5	1987				ICs for high performance, graphics/visualization, and imaging
Gennum Corporation PO Box 489, Station A Burlington, ONT L7R 3Y3	1973	1996	GND.TO	53	High-performance ICs for video and signal processing, integrated circuits and hybrids for hearing instruments.
MOSAID Technologies Inc. 2171 McGee Side Road Carp, ONT K0A 1L0		1995	MSD.TO		Memory ICs: DRAM, ASM, HDRAM
Tundra Semiconductor Corp. 603 March Road Kanata, ONT K2K 2M5	1995	P			Bus bridging and encryption ICs for high-speed data ciphering systems
United States					
3Dfx Interactive Inc. 4435 Fortran Drive San Jose CA 95134	1994	1997	TDFX		3-D graphic accelerators exclusively for the entertainment market, for video games only
3Dlabs Inc. 181 Metro Drive, Suite 520 San Jose, CA 95110	1994	P			3-D graphics processors and accelerators and software for multimedia, CAD, simulation, virtual reality, interactive TV, and video games
8x8 Inc. (Formerly known as Information Integration Technology) 2445 Mission College Blvd. Santa Clara, CA 95054	1987	1997	EGHT		Systems and technology products for video communications

Table 2-1 (Continued)
North American Fabless Companies (Revenue in Millions of U.S. Dollars)

	Year Founded	Initial Public Offering	Stock Symbol	1996 Revenue	Product and Market
Actel Corporation 955 East Arques Ave. Sunnyvale, CA 94086	1987	1993	ACTL	150	FPGAs
Adaptec Inc. 691 S. Milpitas Blvd. Milpitas, CA 95035	1981	1986	ADPT	659	Accelerators and controllers for multimedia, database backup, and networking
Adaptive Logic 800 Charcot Avenue, Suite 112 San Jose, CA 95131	1991	P			Programmable analog microcontrollers and recognition devices for solving control and pattern-recognition problems
Admos Inc. 2345 Harris Way San Jose, CA 95131	1991	P			DSPs for sound add-in cards, motherboards, and musical instruments
Advanced Hardware Architectures 2365 NE Hopkins Court Pullman, WA 99163-5601	1988	P		10	Coprocessors for error correction coding and data compression
Advanced Photonix Inc. 1240 Avenida Acaso Camarillo, CA 93012	1988	1991	API	8	LAAPD, VAPDs, photodiodes for light detection used in industrial, medical, military, space, science, and commercial applications
Alesis Semiconductor Corporation 12509 Beatrice Street Los Angeles, CA 90066	1996	P			Studio electronics, mostly R&D
Alliance Semiconductor Corp. 3099 North First Street San Jose, CA 95134	1985	1993	ALSC	90	High-performance memory and memory-intensive logic products
Altera Corporation 2610 Orchard Parkway San Jose, CA 95134-2020	1983	1988	ALTR	497	PLDs
AMP Sensors 470 Friendship Road Harrisburg, PA 17111	1941	1982			Sensors

Table 2-1 (Continued)
North American Fabless Companies (Revenue in Millions of U.S. Dollars)

	Year Founded	Initial Public Offering	Stock Symbol	1996 Revenue	Product and Market
Appian Technology Inc. (Formerly Zymos) 555 Republic Drive Plano, TX 75074			APPN		Microcomponents, ASICs
Aptek Williams 700 NW 12th Avenue Deerfield Beach, FL 33442	1982	1995			Thick-film hybrid circuits, communications components
Aptix Corporation 2880 North First Street San Jose, CA 95134	1989	P			FPICs and prototyping systems
Aptos Semiconductor 2254 North First Street San Jose CA 95131	1993	P			SRAMs, high-speed miniprocessors, speech and speaker recognition, neural net technology circuits, SRAM
Arithmos Inc. 2730 San Tomas Expwy., Suite 210 Santa Clara, CA 95051-0952	1993				Mixed-signal, chipsets for video compression applications
Armedia Inc. (Formerly Arcus Technology) 1885 Lundy Avenue San Jose, CA 95131	1987	P			Custom ICs, MPEGs
Array Microsystems Inc. 987 University Avenue Los Gatos, CA 95030	1990	P			DSP, video compression products
Auctor Corporation (Formerly ACC Microelectronics) 2401 Walsh Avenue 2nd Floor Santa Clara CA 95051	1987	P			Microcomponents
AuraVision Corporation 47865 Fremont Blvd. Fremont, CA 94538	1992				Video processors

Table 2-1 (Continued)
North American Fabless Companies (Revenue in Millions of U.S. Dollars)

	Year Founded	Initial Public Offering	Stock Symbol	1996 Revenue	Product and Market
Aureal Semiconductor Inc. (Formerly Media Vision) 4245 Technology Drive Fremont, CA 94538	1990	1997	AURL	NA	Audiovisual ICs for 3-D audio technology
Benchmarq Microelectronics Inc. 17919 Waterview Parkway Dallas, TX 75252	1989	1995	BMRQ	40	Battery-management products, NVSRAM products, RTC products, mixed-signal (analog and digital) ICs
C-Cube Microsystems Inc. 1778 McCarthy Blvd. Milpitas, CA 95035	1988	1994	CUBE	320	Processors, decoders, and encoders for video and still images in consumer electronics, computers, and communications
California ASIC (Division of Jaymar) 13845 Alton Parkway, Suite B Irvine, CA 92718					Gate arrays, X-ray lithography
Catalyst Semiconductor Inc. (Also known as Logical Silicon Solutions) 2231 Calle de Luna Santa Clara, CA 95054	1985	1993	CATS	47	EEPROMs, NVRAMs, and flash memories
Celerix Inc. 370 N. Westlake Blvd, Suite 220 Westlake Village, CA 91362	1996				High-performance analog and mixed-signal ASICs
Chip Express 2323 Owen Street Santa Clara, CA 95054	1989	P		29	High-performance ASICs
Chips & Technologies Inc. 2950 Zanker Road San Jose, CA 95134	1984	1985	CHPS	150	Video and graphics controllers and accelerators, chipsets for PCs
Chromatic Research Inc. 615 Tasman Drive Sunnyvale, CA 94089-1707	1993				Media processor

Table 2-1 (Continued)
North American Fabless Companies (Revenue in Millions of U.S. Dollars)

	Year Founded	Initial Public Offering	Stock Symbol	1996 Revenue	Product and Market
Chrontel Inc. 2210 O'Toole Avenue San Jose, CA 95131-1326	1987				Mixed-signal ICs for graphics, video, and audio, high-performance clocks
Cirrus Logic Inc. 3100 W. Warren Avenue Fremont, CA 94538-6423	1984	1988	CRUS	1,061	Multimedia, communications, mass storage, and data acquisition ICs
Clarkspur Design Inc. 12930 Saratoga Avenue, Suite B9 Saratoga, CA 95070-4661	1988	P		0	DSP core for modems, voice mail, and disk drivers
Colorado Micro Display 55 Roberts Road, Blvd. G Los Gatos, CA 95030	1996	P			Semiconductors for flat-panel displays
Comlinear Corp. 4800 Wheaton Drive Fort Collins, CO 80525					Mixed-signal, linear
CommQuest Technologies Inc. 527 Encinitas Blvd. Encinitas, CA 92024-2740	1991				ICs for wireless voice and data, cordless telephony, interactive cable modems, and satellite communications
CORSAIR Microsystems 160-D Albright Way Los Gatos, CA 90530	1994	P			Cache memory for PCs
CPU Technology Inc. 4900 Hopyard Road, Suite 300 Pleasanton, CA 94588	1989				Processors
CREE Research Inc. 2810 Meridian Parkway Durham, NC 27713	1987	1993	CREE	17	Silicon carbide (SiC) ICs (LEDs)
Crosspoint Solutions Inc. 694 Tasman Drive Milpitas, CA 95035					FPGAs (customer-programmable ASICs)

Table 2-1 (Continued)
North American Fabless Companies (Revenue in Millions of U.S. Dollars)

	Year Founded	Initial Public Offering	Stock Symbol	1996 Revenue	Product and Market
Cyrix Corporation 2703 N. Central Expressway Richardson, TX 75085-0118	1988	1993	CYRX	184	High-performance processors
DataPath Systems Inc. 2334 Walsh Avenue Santa Clara, CA 95051		P			CMOS and BiCMOS mixed-signal VLSI circuits
Dialight Corporation— A Roxboro Group Company 1913 Atlantic Avenue Manasquan, NJ 8736	1972	S			LED indicators for telecommunications, data processing, industrial, computer, diagnostic, and backlighting applications
Diamond Multimedia Systems Inc. 2880 Junction Avenue San Jose, CA 95134-1922	1982	1995	DIMD	598	Graphics accelerators, DVD, and videophone kits
Displaytech Inc. 2200 Central Avenue Boulder, CO 80301	1984	P			High-performance electro-optic components
DSP Group Inc. 3120 Scott Blvd. Santa Clara, CA 95054	1987	1994	DSPG	53	Digital signal processing ICs for digital speech
Edge Semiconductor Inc. 10021 Willow Creek Road San Diego, CA 92131	1994	P		14 est.	High-performance analog and mixed-signal ICs for ATE (bipolar and CMOS)
Electronic Designs Inc. (Division Crystallume) One Research Drive Westborough, MA 01581		1996	EDIX	59	High-density, high-performance memory devices for communications (SRAMs and monolithic devices)
Emulex Corporation 3535 Harbor Blvd. Costa Mesa, CA 92626	1979	1990	EMLX	51	Communication processors, LAN and WAN, fibre channel technology
ESS Technology Inc. 48401 Fremont Boulevard Fremont, CA 94538		1995	ESST	226	Highly integrated, mixed-signal ICs for multimedia

Table 2-1 (Continued)
North American Fabless Companies (Revenue in Millions of U.S. Dollars)

	Year Founded	Initial Public Offering	Stock Symbol	1996 Revenue	Product and Market
Etec Microsystems 1900 McCarthy Blvd., Suite 110 Milpitas, CA 95035-7413					Microcomponents
Eupec Inc. 1050 Route 22 Lebanon, NJ 8833		P			Discretes
Exar Corporation 48720 Kato Road Fremont, CA 94538	1971	1985	EXAR	126	Analog, digital, mixed-signal and SCF ICs
Exponential Technology Inc. 2001 Gateway Place, Suite 610 W. San Jose, CA 95110-1013	1993	P			Microprocessors for high-performance power PCs
Fagor Electronic Components 2250 Estes Avenue Elk Grove, IL 60007					Discretes
Focus Semiconductor Inc. 768 N. Bethlehem Pike, Suite 301 Lower Gwynedd, PA 19002-2659	1994	P			Mixed-signal ICs for the ASIC market
G-Link Technology 2701 Northwestern Parkway Santa Clara, CA 95051	1994		GLTK		Enabling technologies: memory and logic for the computer, multimedia, mass storage, and telecom markets (SRAMs, DRAMs), nonmemory ASIC products
Galileo Technology Ltd. 1735 N. First Street, Suite 308 San Jose, CA 95112	1993	1997	GALTF	NA	High-performance core logic, data communications controllers, and ASM buffers
ICT Inc. (Formerly International CMOS Technology Inc.) 2123 Ringwood Avenue San Jose, CA 95131	1983	P		9	Logic
I-Cube Inc. 2328-C Walsh Avenue Santa Clara, CA 95051	1990	P			ASIC switch sets and PSIDs for telecommunications, networking, DSP, image processing, ATE

Table 2-1 (Continued)
North American Fabless Companies (Revenue in Millions of U.S. Dollars)

	Year Founded	Initial Public Offering	Stock Symbol	1996 Revenue	Product and Market
Information Storage Devices Inc. 2045 Hamilton Avenue San Jose, CA 95125	1987	1995	ISDI	41	High-density storage and mixed-signal ICs for voice recording and playback and batteryless message storage
Integrated Circuit Systems Inc. 1271 Parkmore Ave. San Jose, CA 95126	1976	1991	ICST	101	Mixed-signal ICs for clocks, ASICs, multimedia, and data communications
Integrated Silicon Solution Inc. 2231 Lawson Lane Santa Clara CA 95054		1995	ISSI	110	High-performance SRAMs; EPROM, EEPROM, and flash, for networking, PCs, telecommunications, data communications, instrumentation, and consumer products, DRAM for graphics, 8051 microcontroller family
Integrated Telecom Technology Inc. 18310 Montgomery Village Gaithersburg, MD 20879	1991	P			Memory, microcomponents, logic, mixed signal, linear, discretes, ATM switches, some software
Irvine Sensors Corporation 3001 Red Hill Avenue, Bldg. 3 Costa Mesa, CA 92626	1980	1982	IRSN	12	Stacked memory: DRAM tall stacks, short stacks and modules, SRAM short stacks, and flash memory short stacks and modules; image processing and smart sensing devices; ICs: analog mixed signal and low power
Ixys Corporation 3540 Bassett Street Santa Clara, CA 95054	1983	P			MOSFETs, IGBTs, FREDs, smart power ICs, thyristors, rectifiers and diodes for the motion control and power conversion industries
Lattice Semiconductor Corporation 5555 Northeast Moore Court Hillsboro, OR 97124-6421	1983	1990	LSCC	204	ISPs, E2CMOS PLDs for communications, data processing, computer peripherals, instrumentation, industrial controls, and military systems
Level One Communications Inc. 9750 Goethe Road Sacramento, CA 95827	1985	1993	LEVL	95	ASSPs: Analog and digital mixed-signal ICs for networks, wireless, cable, telephony, digital Internet access, LAN, WAN, high-speed transmissions
Logic Devices Inc. 628 E. Evelyn Avenue Sunnyvale, CA 94086	1983	1990	LOGC	13	High-performance, digital ICs: DSPs and SRAMs

Table 2-1 (Continued)
North American Fabless Companies (Revenue in Millions of U.S. Dollars)

	Year Founded	Initial Public Offering	Stock Symbol	1996 Revenue	Product and Market
Maxford Semiconductor 1762 Technology Dr, Suite 128 San Jose, CA 95110		P			Communications ICs
Medianix Semiconductor Inc. 100 View Street, Suite 101 Mountain View, CA 94043	1994	P			Digital signal processors for consumer audio applications
Micro Linear Corporation 2092 Concourse Drive San Jose, CA 95131	1983	1994	MLIN	53	High-performance analog and mixed-signal ICs to communications, computer, and industrial markets (bipolar, CMOS, BiCMOS) for networks, video, power supply, battery management, motor controllers
MMC Networks Inc. 2855 Kifer Road, Suite 200 Santa Clara, CA 95051		P			ATM switch chipsets
MoSys Incorporated 1020 Stewart Drive Sunnyvale, CA 94086	1991	P			Memory ICs: DRAM, MDRAM for PC graphics
Music Semiconductors Inc. 1150 Academy Park Loop, Suite 202 Colorado Springs, CO 80910	1986	P			ICs for electronic and computer industries
NeoMagic Corporation 3260 Jay Street Santa Clara, CA 95054	1993	1997	NMGC	40,792	Multimedia accelerators for notebook computers
Nova Logic Inc. 465 A Fairchild Dr, Suite 102 Mountain View, CA 94043	1995				Content-addressable memories for networking applications
Nu Vision Technologies Inc. (Subsidiary of Vikay Industrial Ltd.) 1815 NW 169th Place, Bldg. 3060 Beaverton, OR 97006	1994				3-D technology for PC games

Table 2-1 (Continued)
North American Fabless Companies (Revenue in Millions of U.S. Dollars)

	Year Founded	Initial Public Offering	Stock Symbol	1996 Revenue	Product and Market
Nvidia Corp. 1226 Tiros Way Sunnyvale, CA 94086	1993	P			Multimedia accelerator ICs for PCs for 2-D and 3-D graphics
Oak Technology Inc. 139 Kifer Court Sunnyvale, CA 94086	1987	1995	OAKT		Graphics controllers (SVGA); CD-ROM controller; MPEGs for optical storage, compression/imaging, video/graphics, and PC audio
OPTi Inc. 888 Tasman Drive Milpitas, CA 95035	1989	1993	OPTI	119	Core logic and multimedia chipsets and graphics controllers for audio, graphics, and storage
Pacific Coast Engineering PO Box 1956 Thousand Oaks, CA 91358	1989	P			Low-frequency ICs in wireless receivers and transmitter systems for satellite TV reception and wireless TV antennas
Peregrine Semiconductor Corp. 1273 Scott Street San Diego, CA 92106-2735	1990				High-performance ICs (FPGA and SRAM), frequency synthesizer ICs (microcommunicators) for wireless systems
Pericom Semiconductor Corporation 2380 Bering Drive San Jose, CA 95131	1990	1997	PSEM		High-performance digital and mixed-signal ICs for PCs, workstations, peripherals, and networking
PMC-Sierra Semiconductor Corporation 2075 N. Capitol Avenue San Jose, CA 95132	1991	1991	PMCS		ICs for broadband infrastructure, LAN, and net access or user interface
Power Semiconductors Inc. 6352 Corte del Abeto, Suite F Carlsbad, CA 92009	1968	P			Power semiconductors
Purdy Electronics Corporation 720 Palomar Avenue Sunnyvale, CA 94086	1995	P			LEDs, LCDs for computers, medical, and industrial instrumentation

Table 2-1 (Continued)
North American Fabless Companies (Revenue in Millions of U.S. Dollars)

	Year Founded	Initial Public Offering	Stock Symbol	1996 Revenue	Product and Market
QLogic Corp. (Formerly Emulex Micro Devices) 3545 Harbor Blvd. Costa Mesa, CA 92626	1980	1994	QLGC	54	Controllers, processors for minicomputers, workstations, and high-end PCs
Quality Semiconductor Inc. 851 Mattin Avenue Santa Clara, CA 95050-2903	1988	1994	QUAL	45	High-performance logic (FCT) and logic-intensive specialty memory ICs (RAMs) for networking, PC, workstations
Quality Technologies Corp. 610 N. Mary Avenue Sunnyvale, CA 94086					Optical ICs
QuickLogic Corp. 1277 Orleans Drive Sunnyvale CA 94089-1138	1988	P		24	FPGAs
Rambus Inc. 2465 Latham Street Mountain View, CA 94040	1990	1997	RMBS	NA	DRAMs for graphics and video in PCs
Rendition Inc. 1675 N. Shoreline Blvd. Mountain View, CA 94043	1993	P			3-D graphics processors for PCs and multimedia-based systems
RF Monolithics Inc. 4441 Sigma Road Dallas, TX 75244	1979	1994	RFMI	36	SAW devices and RF modules for low-power wireless, high-frequency timing, and telecommunications
Ross Technology Inc. 5316 Highway 290 W., Suite 500 Austin, TX 78735	1988	1995	RTEC	101	RISC microprocessors for SPARC workstations, servers, and embedded applications serving the computationally intensive markets (scientific, engineering, file server, and high-end commercial markets)
S3 Inc. 2801 Mission College Blvd. Santa Clara, CA 95052	1989	1993	SIII	465	Multimedia acceleration solutions for PCs

Table 2-1 (Continued)
North American Fabless Companies (Revenue in Millions of U.S. Dollars)

	Year Founded	Initial Public Offering	Stock Symbol	1996 Revenue	Product and Market
SanDisk Corporation 140 Caspian Court Sunnyvale CA 94089	1988	1995	SNDK	90	Flash memory data storage products for industrial, communications, highly portable computing, and consumer electronics
Seeq Technology Corporation 47200 Bayside Parkway Fremont, CA 94538	1981	1983	SEEQ	31	LAN ICs for networking connectivity (controllers, media interface adapters, and transceivers)
Sensory Circuits Inc. 521 E. Wendell Drive Sunnyvale CA 94089	1994	P			Interactive speech ICs for speech recognition, speech and music synthesis, voice recording and playback, speaker verification
Silicon Engines Inc. 950 N. California Avenue, Suite 201 Palo Alto, CA 94303	1986	P			High-performance parallel processors for visual computing systems
Silicon Magic Inc. 20300 Stevens Creek Blvd., Suite 400 Cupertino, CA 95014	1994	P			EDO DRAMs for graphics/video applications
Silicon Storage Technology Inc. 1171 Sonora Court Sunnyvale, CA 94086	1989	1995	SSTI	93	EEPROMs and flash memories
Single Chip Systems Corp. 16885 W. Bernardo Dr., Suite 295 San Diego, CA 92127	1992	P			Interactive identification in inventory control, asset management, document management and ticketing systems for high volume identification markets
Siquest Inc. 1731 Technology Drive, Suite 550 San Jose, CA 95110	1991	P			CMOS gate arrays, FPEG conversions for consumer electronics, telecommunications, and industrial controls and ATE
SiRF Technology Inc. 3970 Freedom Cr. Santa Clara, CA 95054	1995	P			Chipsets and digital signal processor chips for consumer GPS navigation and wireless communications markets

Table 2-1 (Continued)
North American Fabless Companies (Revenue in Millions of U.S. Dollars)

	Year Founded	Initial Public Offering	Stock Symbol	1996 Revenue	Product and Market
Solidas Corp. 100 Century Centre Court, Suite 503 San Jose, CA 95112-4512	1992				ZRAM for video, chipset, DSP, HDD file, and graphics chip memories
Space Electronics Inc. 4031 Sorrento Valley Blvd. San Diego, CA 92121	1992	Emp.			Advanced-function, highest-density, monolithic, radiation-hardened ICs (memory and microprocessor) for spacecraft
Space Power Electronic Inc. 305 Jeffrey Lane Glen Gardner, NJ 8826	1960	P			Microwave and discrete signal ICs
Stanford Telecommunications Inc. 1221 Crossman Avenue Sunnyvale, CA 94089	1973	1990	STII	167	All technologies required for communications systems
Swift Microelectronics Corp. 2635 N. First Street, Suite 220 San Jose, CA 95134	1992	P			Single-mask, customization gate arrays
Syclone Semiconductor 2115 De Le Cruz Blvd. Santa Clara, CA 95050	1995				SRAMs
Teltone Corporation 2121 20th Avenue SE Bothell, WA 98201	1968	1990	TTNC	10	DSPs, analog ICs for telecommunications
The Engineering Consortium Inc. 3130B Coronado Drive Santa Clara, CA 95054					Mixed-signal ICs for hearing devices, modems, and military smart power
TranSwitch Corp. 8 Progress Drive Shelton, CT 06484	1988	1995	TXCC	19	High-speed, mixed-signal, and digital ICs for broadband telecommunications and data communications applications
Trident Microsystems Inc. 189 N. Bernardo Avenue Mountain View, CA 94043-5203	1987	1992	TRID	168	Video/graphics accelerators, controllers, and multimedia video processors for IBM PCs

Table 2-1 (Continued)
North American Fabless Companies (Revenue in Millions of U.S. Dollars)

	Year Founded	Initial Public Offering	Stock Symbol	1996 Revenue	Product and Market
Tseng Labs Inc. 6 Terry Drive Newton, PA 18940		1990	TSNG	26	Video/graphics controller and processor ICs for advanced graphics and multimedia applications in PCs
Ultra Sound Technology Assoc. 644 Towle Place Palo Alto, CA 94306		P			Radiation-hardened custom ICs and ASICs, semicustom and military-standard VLSIs to external high-reliability aerospace and defense companies
Unichip Inc. 244 E. Capitol Avenue Milpitas, CA 95035	1991				MOS logic ASICs for PCs
USMikroChips Inc. 15 Sutton Road Webster, MA 01570	1993	P			High-volume Hall-effect sensors and power transistor arrays
V3 Semiconductor Inc. 2348 Walsh Avenue, Suite G Santa Clara, CA 95051		1996	VVVI	NA	Chipsets for RISC processors
Vadem Ltd. 1960 Zanker Road San Jose, CA 95112	1983				Microprocessors, display controllers, PCMCIA host adapters, and PC card controllers for portable systems, Windows CE solutions, including reference designs, device driver development, and adaptation development tools
VIA Technologies Inc. 5020 Brandin Court Fremont, CA 94538	1987	P			Chipsets for multiprocessor, desktop, and portable PC systems
ViComp Technology Inc. 1580 Oakland Rd, Suite C-206 San Jose, CA 95131	1995				MPEGs in consumer and computer systems for video, PC multimedia, satellite and cable receiver boxes, compressed video and audio data
Vivid Semiconductor Inc. 7400 W. Detroit St, Suite 100 Chandler, AZ 85226	1993	P			Extended voltage-range column drivers for LCD panels for notebook and CRT replacement flat-panel displays
Weitek Corporation 2801 Orchard Parkway San Jose, CA 95134	1990	1990	WWTK	8	Processors and controllers to accelerate the performance of PCs, workstations, and laser printers

Table 2-1 (Continued)
North American Fabless Companies (Revenue in Millions of U.S. Dollars)

	Year Founded	Initial Public Offering	Stock Symbol	1996 Revenue	Product and Market
Western Design Center Inc. 2166 E. Brown Road Mesa, AZ 85213	1978	P			Microprocessors and controllers for high-volume or special purpose solutions
WSI Inc. (Formerly WaferScale Integration Inc.) 47280 Kato Road Fremont, CA 94538	1984	P			High-performance, field-programmable/microcontroller peripheral ICs (PSD microcontrollers, PROMs, EPROMs) for technologically advanced electronics companies
Xilinx Incorporated 2100 Logic Drive San Jose, CA 95124	1984	1990	XLNX	568	FPGAs and CPLDs for computers peripherals, telecommunications, industrial control and instrumentation, and military markets
Zoran Corporation 3112 Scott Boulevard Santa Clara, CA 95054		1995	ZRAN	44	High-performance DSPs for leading-edge compression solutions to high-volume PC and consumer applications (JPEGs, MPEGs, and Dolby Digital)
Zycad Corporation 47100 Bayside Parkway Fremont, CA 94538-9942	1981	1990	ZCAD	34	FPGAs

P = Privately held
Source: Dataquest (December 1997)

Table 2-2
European Fabless Companies (Revenue in Millions of U.S. Dollars)

	Year Founded	1996 Revenue	Product and Market
England			
Advanced RISC Machines Ltd. 90 Fulbourn Road Cherry Hinton Cambridge, CB1 4JN, England	1990	26.4	Microprocessors
France			
TCS (Parent: Thomson-CSF SA) 38521 Saint Egreve Calex, France		100	Microprocessors, optical, discretes, ASIC, mixed-signal, linear
Switzerland			
CSEM IC Design Jaquet-Droz 1 Neuchatel, CH-2007 Switzerland			Analog CMOS and BiCMOS; high-performance, mixed-mode signal processing ICs; low-power/low-voltage ICs

Source: Dataquest (December 1997)

Table 2-3
Asia/Pacific Fabless Companies (Revenue in Millions of U.S. Dollars)

	Business Started	1996 Revenue	Major Products
Korea			
Am Semiconductor and Technology Am Bldg. 154-17 Samsung-dong, Kangnam-gu Seoul, Korea	1987	27	ASICs for CDMA, DVD, set-top boxes
ASIC Plasa 734-11 Yeoksam-dong, Kangnam-gu Seoul, Korea	1995	1	ASICs for peripherals, set-top boxes, LEDs, and decode ICs
C&S Technology 6F Haejoo Bldg. 175-4 Nonhyun-dong, Kangnam-gu Seoul, Korea	1993	9	ASICs for multimedia/communications, chipsets for pagers
Singapore			
Tritech Microelectronics International 16A Science Park Dr. No. 04-01/02 The Pascal Singapore Science Park, Singapore 118228	1990		ASICs, ASSPs, and CSICs
Taiwan			
Acer Laboratories Inc. 5F, No. 156 Tung Hsing St. Taipei, Taiwan	1987	101	Core logic, ASICs, I/O peripherals, graphics, multimedia
Advanced Reality Technology Inc. 3F, No. 609 Kuang Fu Rd. Sec. 1 Hsinchu City, Taiwan	1994	1	ASICs, gate arrays
Alog Integration Co. 4F, No. 9 Industry Rd. 9 Science-Based Industrial Park Hsinchu, Taiwan	1992		Monolithic and hybrid analog ICs

Table 2-3 (Continued)
Asia/Pacific Fabless Companies (Revenue in Millions of U.S. Dollars)

	Business Started	1996 Revenue	Major Products
Aplus Integrated Circuits Inc. 6F-3, No. 7 75 Lane Ta An Rd. Taipei, Taiwan	1992		Audio ICs
Aslic Microelectronics Co. 5F, No 317 Sung Chiang Rd. Taipei, Taiwan	1987		Consumer ICs, encoders, decoders
Avid Electronics 4F, 11 Park Ave. II Science-Based Industrial Park Hsinchu, Taiwan	1996	1	Logic ICs
Brilliance Technology 2F, 40 Park Ave. II Science-Based Industrial Park Hsinchu, Taiwan	1996	3	Communications ICs
Chesen Electronics Co. 5F-2, No. 94 Pao Chung Rd. Hsin Tien City, Taiwan	1984	12	Communications IC
Chip Design Technology Inc. 4F-3, No. 26 Wu Chuan 2nd Rd. Wu Ku Industry Dist., Wu Ku Shing Chuang City, Taiwan	1985		ASICs
Davicom Semiconductor Inc. 4F, 17 Park Ave. II Science-Based Industrial Park Hsinchu, Taiwan	1996	3	Communications IC

Table 2-3 (Continued)
Asia/Pacific Fabless Companies (Revenue in Millions of U.S. Dollars)

	Business Started	1996 Revenue	Major Products
E-CMOS Co. 1F, No. 58 Park Ave. 2 Science-Based Industrial Park Hsinchu, Taiwan	1987		Memory ICs, PC I/O ICs, consumer ICs
Elan Microelectronics Co. 7F-1, No. 9 Prosperity Rd. I Science-Based Industrial Park Hsinchu, Taiwan	1994	51	Neural-fuzzy logic, DSPs, 8 bit microcontrollers, ASICs
Eplus Co. 2F-2, No. 2 253 Lane Fu Shing S. Rd. Sec. 1 Taipei, Taiwan	1989		PIR
Etron Technology Inc. 1F, No. 1 Prosperity Rd. I Science-Based Industrial Park Hsinchu, Taiwan	1991	40	SRAM, DRAM, ASICs
Faraday Technology Co. 7F-3, No. 9 Prosperity 1 Rd. Science-Based Industrial Park Hsinchu, Taiwan	1993		ASICs
G-Link Technology Co. 2F, 12 R&D Rd. II Science-Based Industrial Park Hsinchu, Taiwan	1995	11	DRAM, SRAM
GinJet Technology Co. No. 18-1 76 Lane Long Chiang Rd. Taipei, Taiwan	1989		ASICs

Table 2-3 (Continued)
Asia/Pacific Fabless Companies (Revenue in Millions of U.S. Dollars)

	Business Started	1996 Revenue	Major Products
Hitachi Asia Pte. Ltd. 3F, 167 Dun Hua N. Rd. Taipei, Taiwan	1987		
Holylite Microelectronics Co. 10F-2, No. 67 Chih Hu Rd. Hsinchu City, Taiwan	1992		Memory, analog ICs, mixed-mode ICs
Hwa Mye Electronic Co. Ltd 8F, No. 80 Sung Te Rd. Taipei, Taiwan	1988		ASICs
Inno Technology Ltd. 7F, No. 181 Yung Chi Rd. Taipei, Taiwan	1993		Consumer ICs
Integrated Silicon Solution (Taiwan) Inc. 1F, No. 10 Prosperity Rd. II Science-Based Industrial Park Hsinchu, Taiwan	1990		EEPROM, flash, SRAM, DSP, voice storage
Integrated Technology Express (Taiwan) Inc. 15F, 376 Sec. 4 Jen Ai Rd. Taipei, Taiwan	1996		Core logic
Micro Advanced Technology Co. Ltd 8F, No. 26 204 Lane Sung San Rd. Taipei, Taiwan	1992		ASICs

Table 2-3 (Continued)
Asia/Pacific Fabless Companies (Revenue in Millions of U.S. Dollars)

	Business Started	1996 Revenue	Major Products
Micro Electronic Co. Ltd. 5F-5, No 12 609 Lane Chung Shing Rd. Sec. 5 San Chung City, Taiwan	1991		ASICs
MOS Design Semiconductor Co. 6F-5, No. 10 609 Lane Chung Shin Rd. San Chung City, Taiwan	1988	8	Memory, sound processors
MOSART Semiconductor Co. 11F-2, No. 33 Ming Shen Rd. Sec. 1 Pan Chiao City, Taiwan	1993		Communications, consumer ICs
Motorola Electronics Taiwan Ltd. 9F, 296 Sec. 4, Jen Ai Rd. Taipei, Taiwan	1967		Communications, consumer ICs
Myson Technology Inc. No. 2 Industry E Rd. 3 Science-Based Industrial Park Hsinchu, Taiwan	1991	23	ASICs, LAN ICs, bipolar ICs
NEC Electronics Taiwan Ltd. 7F, 363 Fu Shing N. Rd. Taipei, Taiwan	1990		ASICs
Princeton Technology Co. 2F, No. 233-1 Pao Chiao Rd. Hsin Tien City, Taiwan	1986	9	Remote controller, encoder/decoder, audio ICs

Table 2-3 (Continued)
Asia/Pacific Fabless Companies (Revenue in Millions of U.S. Dollars)

	Business Started	1996 Revenue	Major Products
Progate Group Co. 14F, No. 482 Chung Hsiao E. Rd. Taipei Taiwan	1991		ASICs
Realtek Semiconductor Co. Ltd. 1F, No. 11 Industry E Rd. 9 Science-Based Industrial Park Hsinchu, Taiwan	1987	55	Video/graphics IC, consumer ICs, LAN ICs, ASICs
Roco Enterprise Co. 2F, 33 Yung Chi Rd. Taipei, Taiwan	1985		Consumer ICs
SARC Technology Co. 15F-1, No. 159 Sung Te Rd. Taipei, Taiwan	1989		ASICs
Silicon-Based Technology Co. 1F, 23 R&D Rd. I Science-Based Industrial Park Hsinchu, Taiwan	1995	4	SRAM
Silicon Integrated Systems Co. 2F, No. 17 Innovation Rd. 1 Science-Based Industrial Park Hsinchu, Taiwan	1987	162	Core logic, ASICs
Sun Plus Technology Co. Ltd. 1F, No. 21 R&D Rd. II Science-Based Industrial Park Hsinchu, Taiwan	1990	56	DSP, ASICs, consumer IC, voice and music synthesizer, multimedia-related ICs

Table 2-3 (Continued)
Asia/Pacific Fabless Companies (Revenue in Millions of U.S. Dollars)

	Business Started	1996 Revenue	Major Products
Syntek Design Technology Ltd. 1F, No. 40 Park Ave. II Science-Based Industrial Park Hsinchu, Taiwan	1992	16	Microcomputer peripheral ICs
Taiwan Memory Technology Inc. No. 3 R&D Rd. I Science-Based Industrial Park Hsinchu, Taiwan	1993	14	DRAM, SRAM
Tamarack Microelectronics Inc. 16F-4 Fu Shing N. Rd. Taipei, Taiwan	1987	7	Hybrid IC, ASICs, LAN chipsets
Tontek Design 6F, 770 Chung Zan Rd. Chung Ho City, Taiwan	1986	5	
Utron Technology Inc. 1F, No. 11 R&D Rd. II Science-Based Industrial Park Hsinchu, Taiwan	1993	11	ASICs, SRAM
VIA Technologies Inc. 8F, No. 533 ChunZan Rd. Hsin Tien City, Taiwan	1987	65	Core logic, ISA/PCI/PCMCIA LAN chips
VLSI Technology Asia Ltd. Room C 15F, No. 170 Tun Hua N. Rd. Taipei, Taiwan	1990		Core logic

Table 2-3 (Continued)
Asia/Pacific Fabless Companies (Revenue in Millions of U.S. Dollars)

	Business Started	1996 Revenue	Major Products
Weltrend Semiconductor Inc. 2F, No. 24 Industry E. Rd. IX Science-Based Industrial Park Hsinchu, Taiwan	1989	15	Multisync monitor discriminator ICs, consumer ICs
Yuban Co. 5F, No. 29 Jen Ai Rd. Sec. 3 Taipei, Taiwan	1993		DRAM, SRAM

Source: Dataquest (December 1997)

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