7 MOS MEMORY MARKET TRENDS

OVERVIEW

Memory integrated circuits (ICs) fabricated with metal oxide semiconductor (MOS) technology include dynamic random access memory (DRAM), static RAM (SRAM), read only memory (ROM), electrically programmable ROM (EPROM), electrically erasable and programmable ROM (EEPROM), and flash memory. Each of these categories of the MOS memory market is discussed in detail in this section.

In 1997, MOS memory ICs accounted for an estimated 24 percent of the total IC market. This was a continued loss in percentage of the overall market compared to 42 percent in 1995 and 30% in 1996 (Figure 7-1); this is the first time in semiconductor history that the memory market has experienced consecutive double-digit yearly declines.

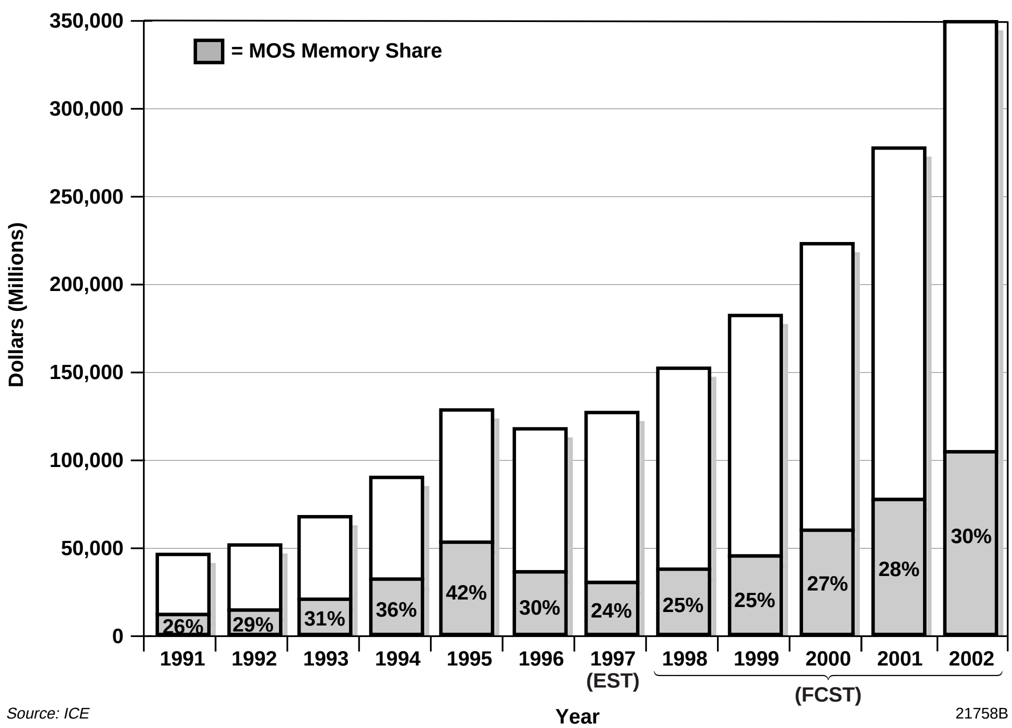
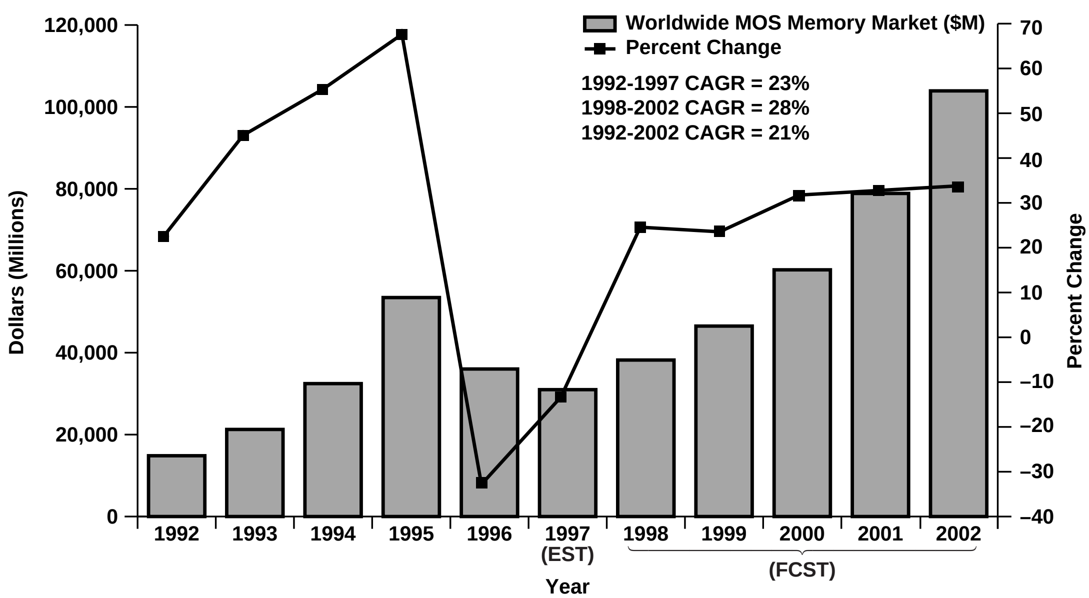


Figure 7-1. MOS Memory Share of Total Worldwide IC Market

This decline in the MOS memory segment of the total IC market has been a direct result of declining average selling prices (ASPs) coupled with extensive memory fabrication capacity worldwide; following three straight years of better than 40 percent growth, the MOS memory market in 1996 and 1997 has experienced an anticipated "correction." ICE forecasts that with enough wafer fabrication capacity to meet the demand for DRAMs, SRAMs, and flash memory for the foreseeable future, there should be greater stability in ASPs for memory ICs after 1997. Thus, 1997 should be the bottom of the decline; the memory market should slowly climb in percentage through the turn of the century.

Despite its decline over the past few years, the memory market remains one of the best growing and competitive markets in the IC industry. From 1998 through 2002, the MOS memory market is forecast to have a cumulative average annual growth rate (CAGR) of 28 percent (Figure 7-2). Even with the declines in 1996 and 1997, from 1992 through 2002 ICE forecasts that the MOS memory market will show an average 21 percent annual growth in market size. Figure 7-3 shows ICE's forecast of various MOS memory IC product categories through 2002, compared to 1997's estimated results.



MOS Memory Market ($M)	14,840	21,260	32,450	53,460	36,015	30,975	38,205	46,494	60,230	78,879	103,916
Percent Change	21	43	53	65	–33	–14	23	22	30	31	32

Source: ICE

18903H

Figure 7-2. 1992-2002 MOS Memory Market Growth and Forecast

	1997 (EST)	1998	1999	2000	2001	2002
WW IC Market ($M)	127,225	152,408	182,427	223,260	277,665	349,546
WW MOS Memory Market ($M)	30,975	38,205	46,494	60,230	78,879	103,916
WW Memory Percent Change	–14%	23%	22%	30%	31%	32%
Percent Memory of Total IC	24%	25%	25%	27%	28%	30%
DRAM ($M)	21,485	27,750	34,605	46,080	61,890	82,870
SRAM ($M)	3,500	3,955	4,509	5,275	6,014	6,916
EPROM ($M)	760	670	580	500	420	375
Flash ($M)	3,000	3,585	4,530	6,050	8,175	11,280
ROM ($M)	1,000	900	810	720	635	560
EEPROM ($M)	1,075	1,205	1,335	1,495	1,645	1,825
Other Memory ($M)	155	140	125	110	100	90
Total MOS Memory ($M)	30,975	38,205	46,494	60,230	78,879	103,916

Source: ICE 18914K

Figure 7-3. MOS Memory Market Forecast by Memory Category

DRAMs make up the majority of MOS memory sales and are forecast to be the dominant memory product through 2002 (Figure 7-4). ICE forecasts that in 2002, 80 percent of the MOS memory market will be attributed to sales of DRAM or derivative DRAM products. Flash memory sales, which accounted for an estimated 10 percent of the MOS memory market in 1997, are forecast to remain around this double-digit percentage through 2002.

Figure 7-5 provides a summary of MOS memory IC unit shipments. The 1997 15 percent increase in memory IC units shipped reflects the continued strong demand for DRAM and flash memory in 1997.

ICE shows that MOS memory consumption remained relatively stable for all regions in 1997 (Figure 7-6), with North America maintaining its consumption level. On the other hand, Japanese companies still hold the greatest share of memory production.

Regional production for each MOS memory segment is shown in Figure 7-7. Based on final 1996 data, Japanese companies supplied the biggest portions of DRAMs, SRAMs, and ROMs—the largest memory market segments. However, ROW companies, mainly the large Korean semiconductor manufacturers, continued to challenge the production leadership of Japan in the DRAM and SRAM markets.

Listed in Figure 7-8 are the top five worldwide MOS memory suppliers based on final 1995 and 1996 data. ICE shows that Samsung continued as the leading supplier of MOS memory ICs in 1996, although its sales were down by a large margin compared to 1995. Again, the huge decrease in ASPs led to the smaller sales figures.

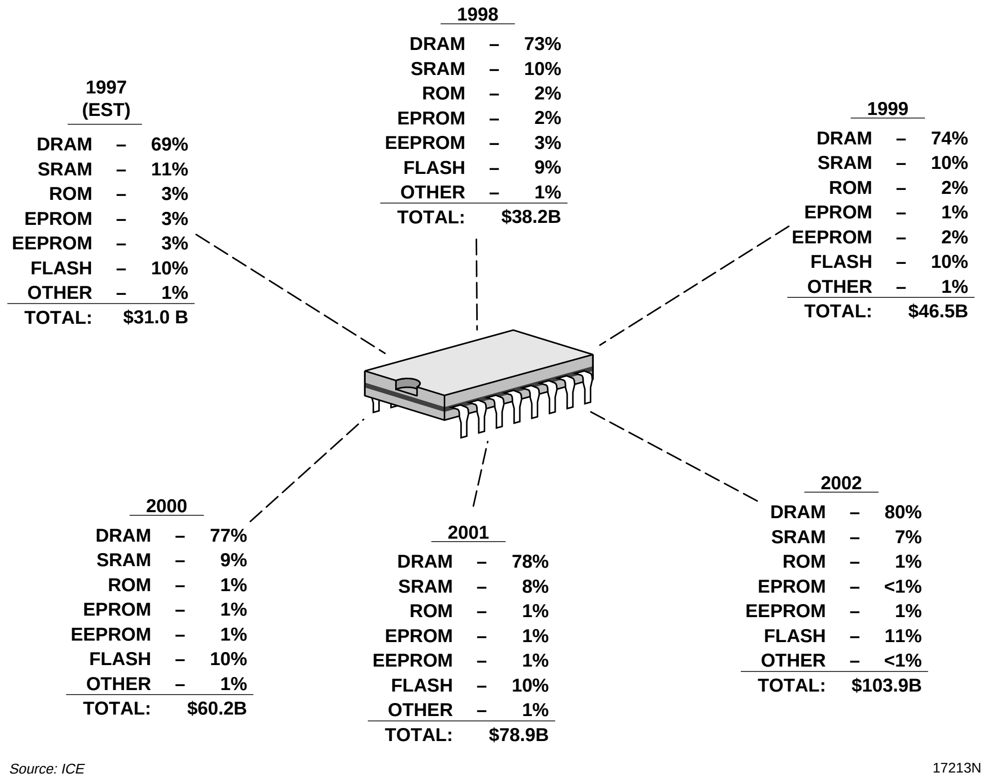
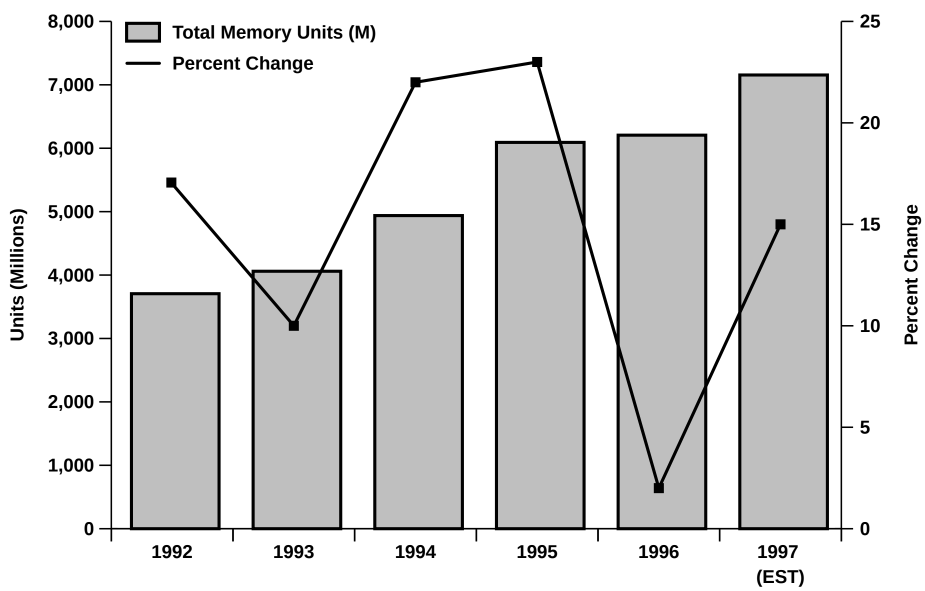


Figure 7-4. MOS Memory Product Market Share Forecast



	1992	1993	1994	1995	1996	1997 (EST)
Total Memory Units (M)	3,706	4,060	4,938	6,092	6,206	7,155
Percent Change	17	10	22	23	2	15

Source: ICE 22427B

Figure 7-5. Total MOS Memory IC Unit Shipments

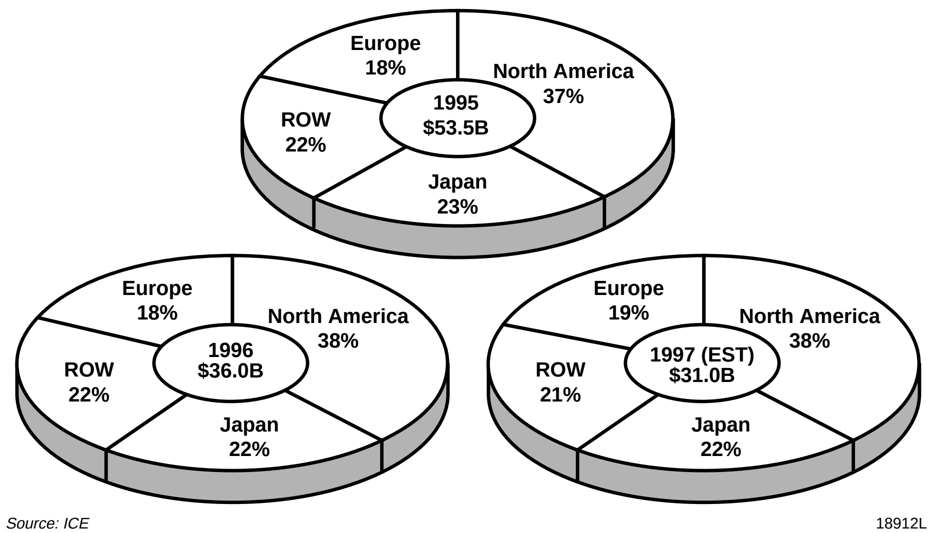


Figure 7-6. MOS Memory Consumption by Region

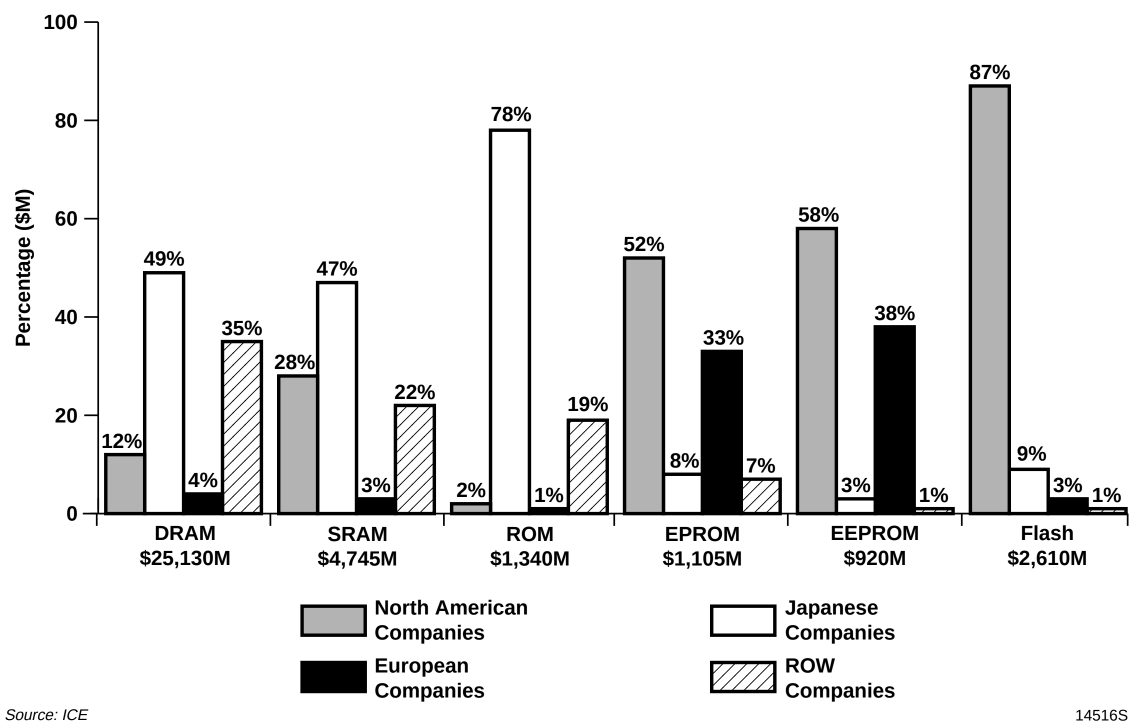


Figure 7-7. 1996 MOS Memory Production by Product Category and Regional Companies

In Figure 7-9, ICE shows memory IC application by system type. Over the course of five years, memory applications changed very little while the market tripled in size.

Rank	1995			1996		
	Company	Sales ($M)	Market Share (%)	Company	Sales ($M)	Market Share (%)
1	Samsung	7,545	14	Samsung	5,428	15
2	NEC	5,630	11	NEC	4,180	12
3	Hitachi	5,028	9	Hitachi	3,360	9
4	Toshiba	4,535	8	Toshiba	2,885	8
5	TI	3,555	7	Hyundai	2,300	6
Other	—	27,172	50	—	17,862	49
Total	—	53,465	100	—	36,015	100

Source: ICE 14495S

Figure 7-8. Total MOS Memory Market Leaders

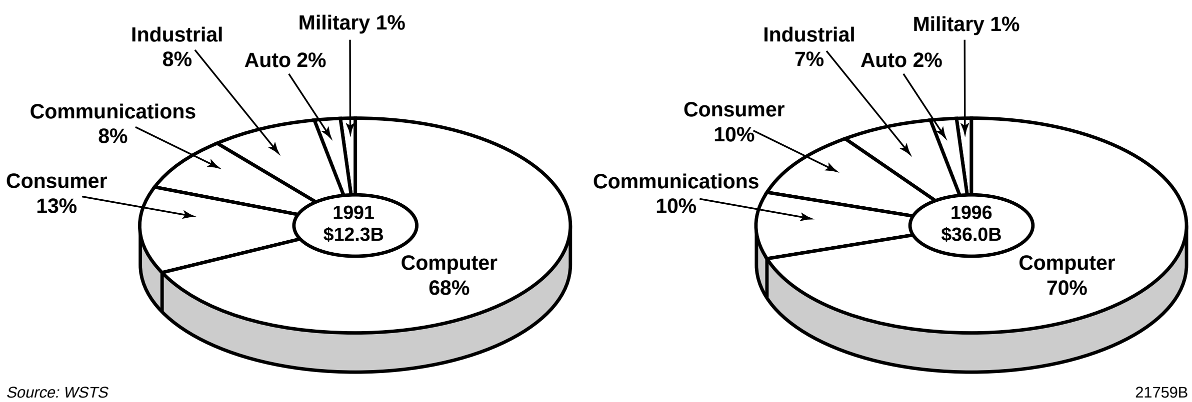
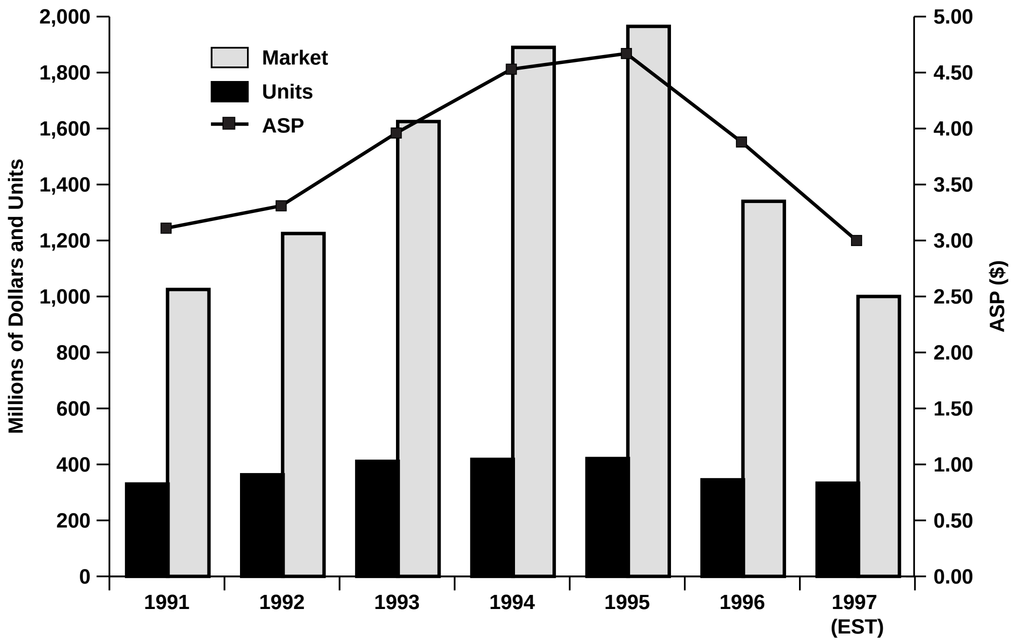


Figure 7-9. Memory IC Application by System Type

NON-VOLATILE MEMORY ICs

The ROM Market

Read-only memory (ROM) is the least expensive type of semiconductor memory. ROM is used primarily for permanent data storage in electronic equipment for applications such as laser printer fonts, dictionary data in word processors, and sound-source data in electronic musical instruments. ROM is also used extensively in video game software. The ROM market grew well through the first half of the 1990s, coinciding closely with a jump in personal computer (PC) sales and other consumer-oriented electronic systems. Figure 7-10 displays a brief history of the ROM market, including unit shipments and ASPs, and the estimated 1997 market.



Market ($M)	1,025	1,225	1,625	1,890	1,965	1,340	1,000
Units (M)	330	363	411	418	421	345	333
ASP ($)	3.11	3.37	3.96	4.53	4.67	3.88	3.00

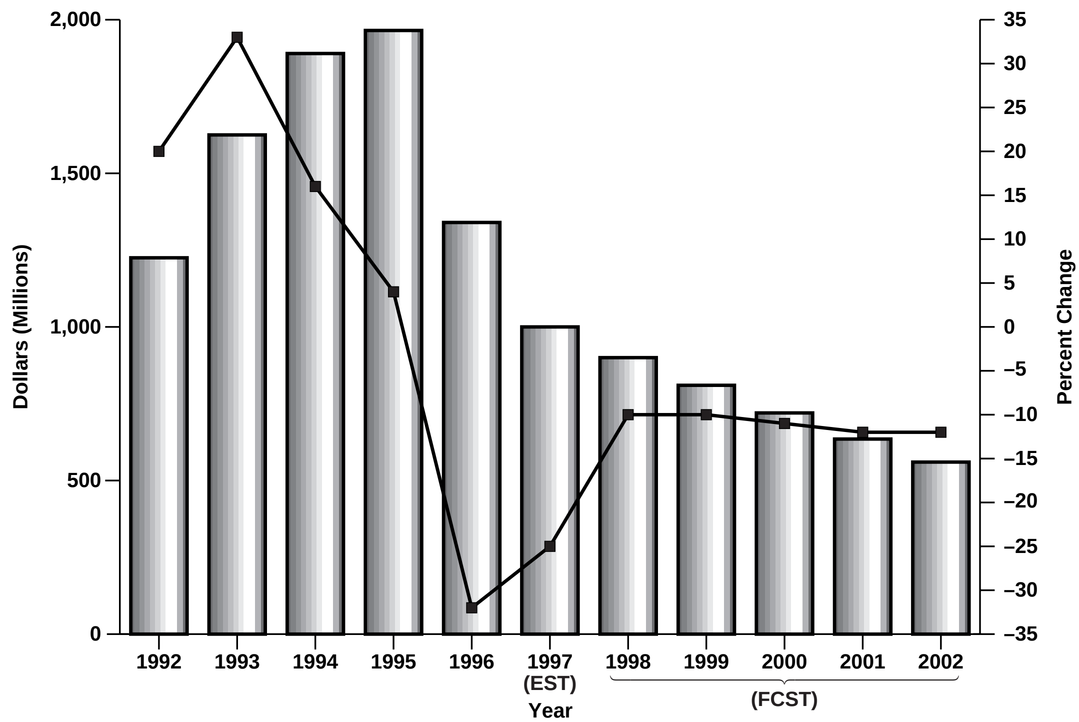
Source: WSTS 20607D

Figure 7-10. ROM Market History

As shown in Figure 7-11, the ROM market has been decreasing significantly: –32 percent in 1996 and an estimated –25 percent in 1997. One reason for this decline was the weak Japanese yen measured against the dollar, for example, 109 yen to the dollar in 1996 versus 94 yen to the dollar in 1995. Since the ROM market is largely dominated by Japanese semiconductor manufacturers and end users, it is closely tied to fluctuations in the yen.

Another factor contributing to the ROM market decline was that one of the biggest applications for these ICs—video games—moved toward compact disc ROM (CD-ROM) based systems. Additionally, other memory products that afford greater functionality have become relatively cost competitive with ROM. As shown in the figure, ICE believes that the ROM market will continue to decline through 2002.

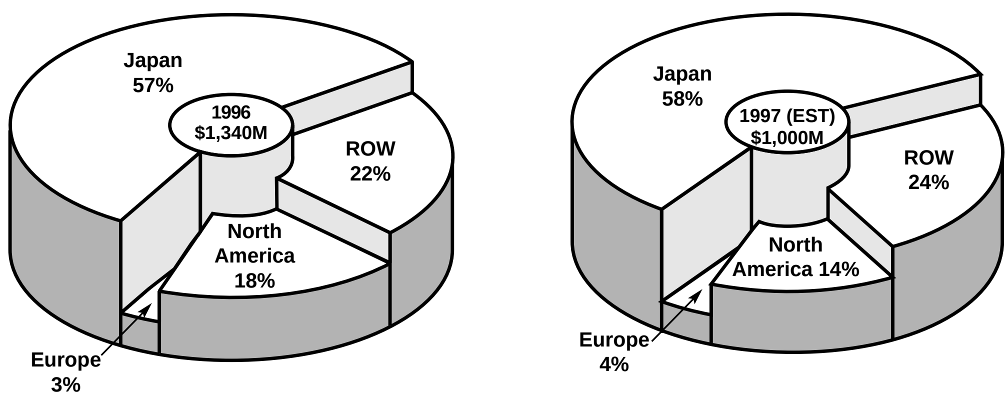
ROM consumption by region is shown in Figure 7-12. ICE forecasts that when the final data are tabulated for 1997 it will show that the North American region, which was never a large consuming region of ROM, will have bought even fewer of these ICs in 1997. North America is turning to memory products that afford greater flexibility and functionality.



ROM Market ($M)	1,225	1,625	1,890	1,965	1,340	1,000	900	810	720	635	560
Percent Change	20	33	16	4	–32	–25	–10	–10	–11	–12	–12

Source: WSTS 20348H

Figure 7-11. The ROM Market Growth and Forecast



Source: WSTS 16790P

Figure 7-12. ROM Market by Region

Despite market share gains made by suppliers in the ROW region, Japanese IC makers continued to hold a tight grip as the leading suppliers of ROM ICs (Figure 7-13). Together, Sharp and NEC held about half of the ROM market based on final 1995 and 1996 data.

Rank	1995			1996		
	Company	Sales ($M)	Marketshare (%)	Company	Sales ($M)	Marketshare (%)
1	Sharp	500	25	Sharp	375	28
2	NEC	400	20	NEC	280	21
3	Samsung	230	12	Macronix	204	15
4	Toshiba	255	13	Toshiba	170	13
5	Hitachi	245	13	Hitachi	160	12
Other	—	335	17	—	151	11
Total	—	1,965	100	—	1,340	100

Source: ICE 14496U

Figure 7-13. ROM Manufacturing Market Leaders

Increasingly, high-density ROM will be the ICs that continue to ship; Figure 7-14 shows this trend. Most manufacturers have kept their ROM production at the 4 megabit (4M) level. However, companies such as Sharp, NEC, and Macronix have developed mask ROM at and above the 32M density.

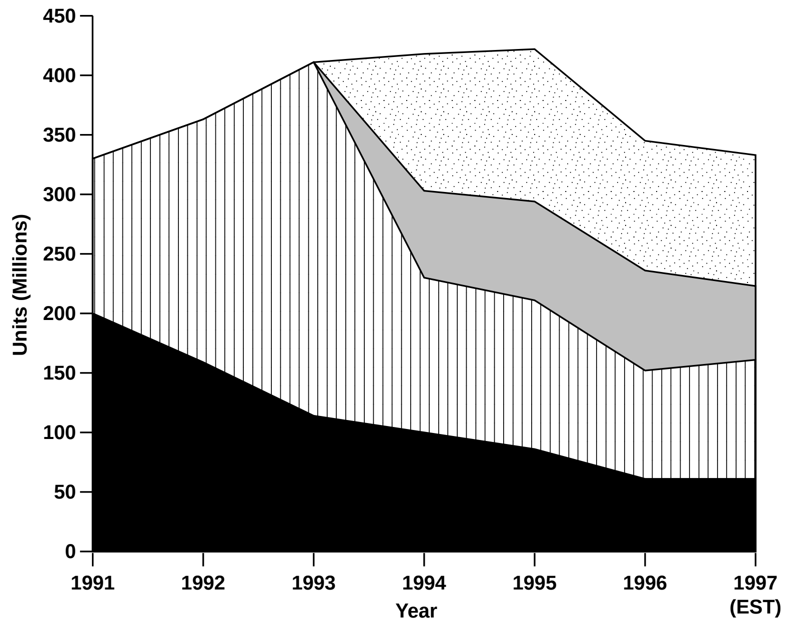
The EEPROM Market

EEPROM (electrically erasable and programmable read only memory) offers users excellent capabilities and performance. Two key advantages of using EEPROM include in-system reprogrammability and bit-by-bit erasure capability.

The EEPROM market history and forecast through 2002 are shown in Figure 7-15. In 1997, the EEPROM market grew an estimated 17 percent. ICE forecasts that through 2002, this market will average 11 percent annual growth.

EEPROM consumption by region is shown in Figure 7-16. Due in part to military use, the North American region was the largest market for EEPROM in 1996 and again in 1997.

EEPROMs are available in either serial or parallel versions. Parallel EEPROMs are generally faster, offer high endurance and reliability, but also cost more than their serial counterparts. Parallel EEPROMs are found mostly in military applications. Serial EEPROMs, though generally less dense and slower than parallel versions, are much cheaper and used more in consumer-oriented applications.



	1991	1992	1993	1994	1995	1996	1997 (EST)
≤2M	200	159	114	100	86	61	61
4M	130*	204*	297*	130	124	91	100
8M	—	—	—	73	83	84	62
≥8M	—	—	—	115	128	109	110
Total Units (M)	330	363	411	418	421	345	333

*** Includes ≥4M densities.**

Source: WSTS 20609C

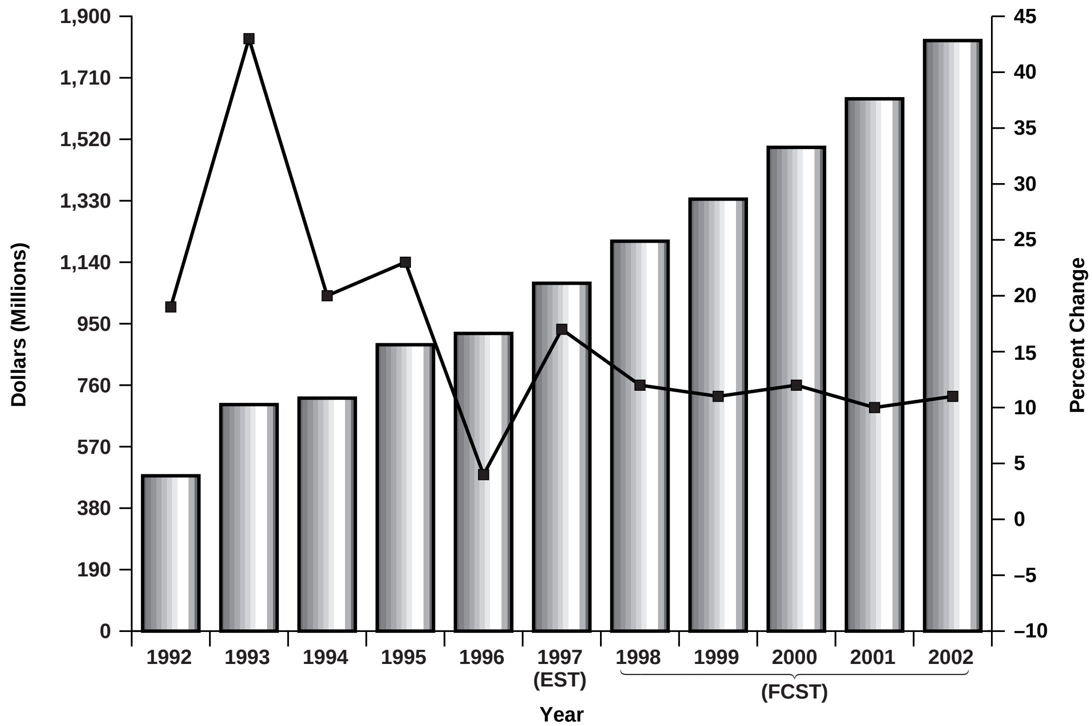
Figure 7-14. ROM Unit Shipments by IC Density

ICE estimates that serial EEPROM accounted for 92 percent of the $1,075 million EEPROM market in 1997 (Figure 7-17). With few exceptions, the largest serial EEPROM density shipping in volume was 64 kilobit (64K). Companies such as Atmel, Xicor, and SGS-Thomson (ST) supplied the large majority of these ICs.

Until late in 1996, designers who needed more than 64K of EEPROM had to use two or more smaller serial EEPROMs connected in parallel. In late 1996 and early 1997, ST started shipping serial EEPROM with densities as high as 128K and 256K.

The largest parallel EEPROMs built in volume during 1996 were 1M ICs. They were used extensively, although not exclusively, in military applications. Parallel EEPROM is of particular interest in the military because it offer more flexibility than other kinds of solid-state memory.

Parallel EEPROMs can be found in military applications such as flight controllers, vehicle control systems, field communications equipment, secure radios, command and control systems, radar, and guidance subsystems. The lightness, ruggedness, and fast performance of parallel EEPROM makes it well suited for harsh environments.

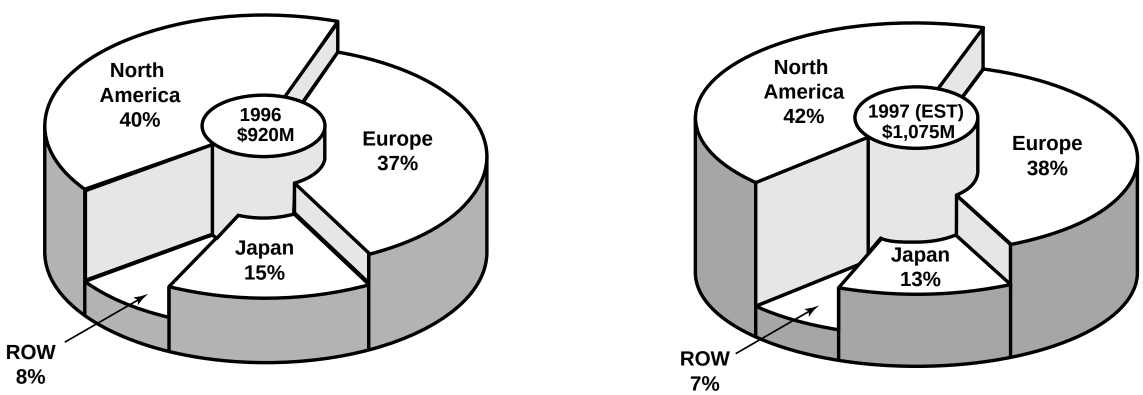


EEPROM Market ($M)	480	700	720	885	920	1,075	1,205	1,335	1,495	1,645	1,825
Percent Change	19	43	20	23	4	17	12	11	12	10	11

Source: ICE

20347G

Figure 7-15. EEPROM Market Growth and Forecast



Source: WSTS

16792M

Figure 7-16. 1996 and 1997 EEPROM Markets by Region

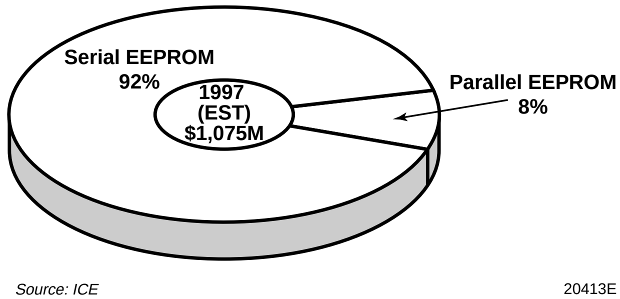


Figure 7-17. 1997 EEPROM Market by Type

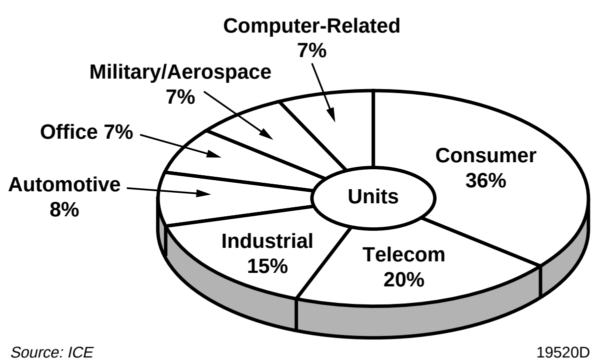


Figure 7-18. Serial EEPROM Applications

Consumer-oriented applications represented the largest end-use of serial EEPROM in 1997 (Figure 7-18). Led by low-voltage parts, EEPROM suppliers should continue to find a healthy and vibrant business in rapidly growing portable consumer and industrial applications.

Small density serial EEPROMs were used extensively in portable, battery-powered applications including pagers, modems, and cellular and cordless phones. They have also appeared in parameter and configuration setups in disk drives, printers, and industrial data-acquisition applications. In automotive applications, EEPROMs are used in air bags, antilock braking systems, and car radios.

Newer EEPROM applications include satellite communications boxes and monitors, and sense-detect functions in memory modules. Suppliers are also excited about the potential for EEPROM in the smart-card market.

Several leading EEPROM manufacturers have begun to offer their ICs in low-voltage versions. ST's Eagle Range serial EEPROM family, for example, supports operation as low as 1.8V; the next generation will support 1V operation. Atmel introduced the first 3V 1M parallel EEPROM in 1996. Most of the other leading EEPROM suppliers will probably have some ≤3.3V low-voltage ICs in their portfolio by the beginning of 1998.

Innovative features have been added to EEPROMs by many manufacturers. Within the past year, Xicor introduced Block Lock protection on two of its EEPROMs. By allowing a user to partition with 25, 50, or 100 percent write protection, Block Lock allows them to combine alterable data with secured data.

Suppliers agree that EEPROM technology is facing increased competition from flash memory. However, flash memory remains a mass-storage technology and is virtually unavailable, and not as cost effective, in densities under 1M. EEPROMs, on the other hand, are mainly used for storing small amounts of data that are frequently changed.

Leading EEPROM suppliers are shown in Figure 7-19. Atmel, ST, and Xicor continued to make strides in the market. For these and other companies that manufacture them, the EEPROM business should remain reasonably healthy and stable through 2002.

Rank	1995			1996		
	Company	Sales ($M)	Market Share (%)	Company	Sales ($M)	Market Share (%)
1	SGS-Thomson	167	19	SGS-Thomson	280	30
2	Atmel	154	17	Atmel	180	20
3	Xicor	100	11	Xicor	115	12
4	Microchip	85	10	Microchip	109	12
5	National	64	7	National	70	8
6	Siemens	53	6	Siemens	66	7
Other		262	30	—	100	11
Total		885	100	—	920	100

Source: ICE 14498S

Figure 7-19. EEPROM Manufacturing Market Leaders

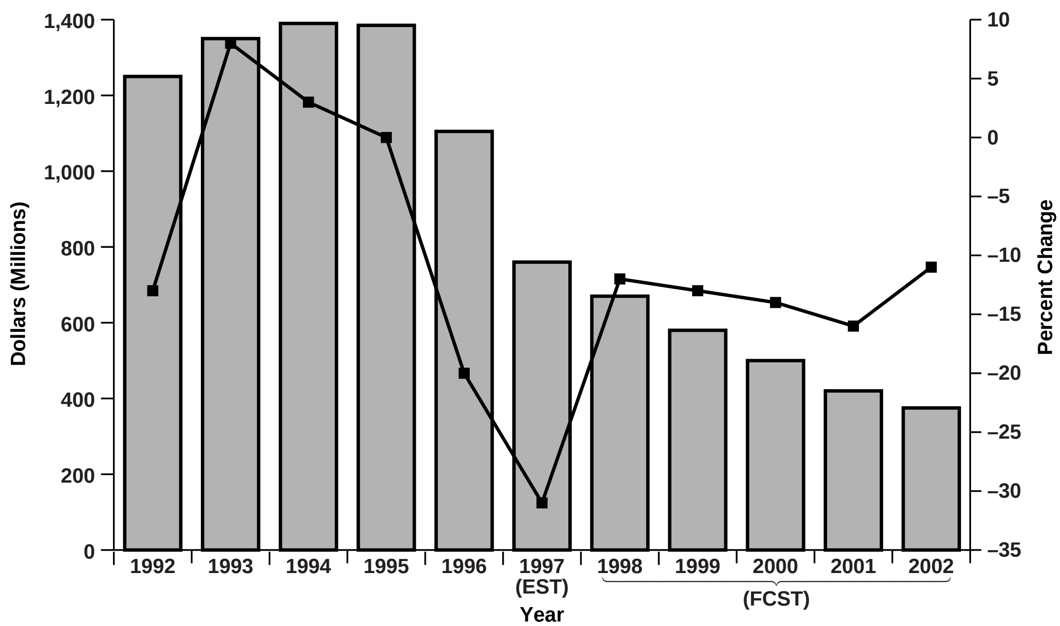
The EPROM Market

EPROM (electrically programmable read only memory) has been the cornerstone of the non-volatile memory market. Created in the 1970s with Intel's invention of the ultra-violet erasable PROM, these ICs have since been produced in an assortment of part types with varying speeds and densities.

Since the early 1990s, the stronghold of EPROM in the non-volatile memory market has been tested by the emergence of flash memory; many forecasts called for the quick demise of the EPROM market due to the greater presence and influence of flash memory ICs.

Yet demand from high-volume applications such as cellular phones, modems, BIOS operating system storage, and numerous embedded systems, allowed the EPROM market to remain healthy for a longer time that most anticipated. Additionally, EPROM advantages over flash memory include smaller die size, cheaper technology, and the absence of peripheral circuitry and external components.

Over the past several years, the EPROM market has shown a definite downward trend in dollar volume. ICE estimates that 1997, which is estimated at a –31 percent change, will be the first year that the EPROM market does not reach the one billion-dollar level (Figure 7-20). Further, this market should continue to decline at an annual rate of –13 percent through 2002.



Total Market ($M)	1,250	1,350	1,390	1,385	1,105	760	670	580	500	420	375
Percent Change	–13	8	3	0	–20	–31	–12	–13	–14	–16	–11

Source: ICE 19518G

Figure 7-20. EPROM Market Decline and Forecast

Figure 7-21 shows that, in 1996 and again in 1997, the majority of EPROM shipments were ICs with densities equal to or smaller than 256K. Further, 75 percent of EPROM shipments were of densities equal to or less than 1M.

In the smaller density domain, EPROM ICs still hold a price and performance advantage over flash memory. For instance, EPROMs have grown in the peripheral market, driven largely by the explosive growth of CD-ROM drives. Each CD-ROM drive uses a 256K or 512K EPROM. Furthermore, sales of modems have escalated with increased use of the Internet. Emerging 56K-per-second modems will likely use EPROM over flash memory once a standard has been adopted by the telecommunications industry. Another potential application is the television set-top box market. In applications where volume is high and cost is crucial, EPROM remains an attractive, low-cost solution.

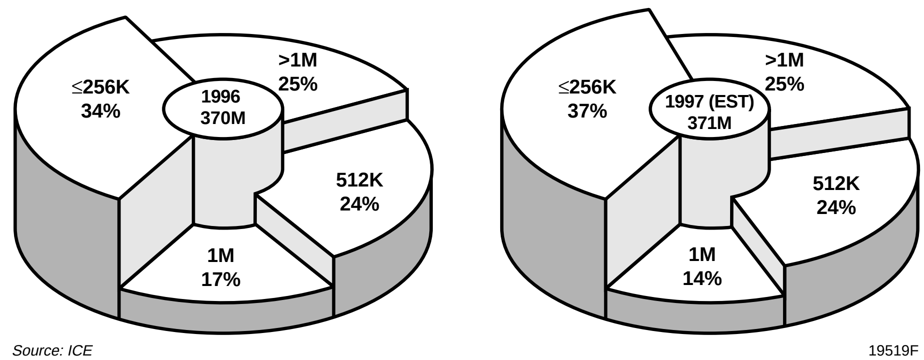


Figure 7-21. EPROM Unit Shipments by IC Density

The choice between EPROM and flash memory comes into play at densities greater than or equal to 1M. In some cases, the lower cost of some EPROMs may offer an advantage for a system designer. However, the trade-off of lower price is sometimes met with less flexibility (Figure 7-22).

	EPROM	Flash	EEPROM
Typical Storage Use	Fixed programs	In-system modifiable programs	Frequently updated programs and data
Typical Number of Writes	Write once	Write up to 100,000 times	Write up to one million times
Densities Available	256K to 16M	256K to 64M	1K to 64K (serial) 64K to 4M (parallel)
Flexibility	Least ←→ Most		
Cost Per Bit	Least ←→ Most		

Source: Atmel 20411B

Figure 7-22. Flash Finds its Non-Volatile Niche

Figure 7-23 briefly summarizes the recent EPROM activities of several suppliers. During the past few years, many suppliers had difficulty determining just how aggressively they would participate in the EPROM market. An exodus of EPROM suppliers started in 1995 when formidable manufacturers such as Advanced Micro Devices (AMD), Texas Instruments (TI), National Semiconductor, and many Japanese suppliers, including NEC, Fujitsu, and Mitsubishi, announced they would curtail their support of this market to focus on other products.

Not every company distanced itself from the EPROM market, however. ST, though shown with only a small EPROM sales increase in 1996 compared to 1995 (Figure 7-24), remained committed to being the number one EPROM supplier through the end of the decade. ST continued to invest in EPROM technology. It currently uses 0.5μm and 0.6μm process technologies to build all its EPROM ICs.

AMD

- Still committed to EPROM production, but ...
- Evaluating in-house capacity allocation.
- Lost two EPROM foundry suppliers.
- More wafer starts at flash memory facility (FASL) in Japan.

Atmel

- $30 million capital equipment investment to bring up 0.5µm EPROM manufacturing process. Roadmap takes the process to 0.18µm.

Cypress

- Primarily a high-speed EPROM player, but now also attacking slow, low-cost segment left behind by others.

Fairchild (formerly National)

- Aggressively pursuing EPROM market. Trying to win back customers it led to competitors two years ago when it as National Semiconductor decided to exit the market.
- Integrating EPROM and flash memory capabilities with MCU and MPU technology to create application-specific products.

Fujitsu

- Announced it would halt its EPROM production by the end of 1Q97 and concentrate on DRAM and flash memory production.

Integrated Silicon Solution

- High-performance EPROMs for code storage applications.

SGS-Thomson

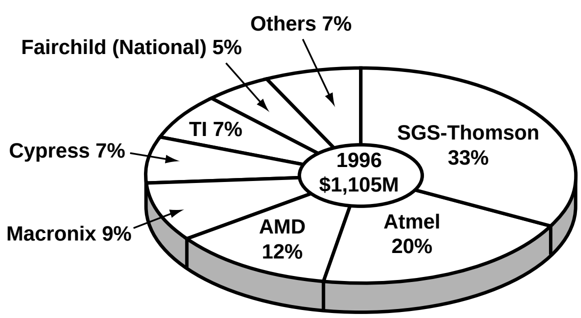
- Upgrading EPROM process to 0.5µm.
- Densities to 16M; many low-voltage versions.

Texas Instruments

- After reducing its EPROM production by 50 percent two years ago, TI recommitted to the market. The company rebalanced its capacity to bring EPROM production back to previous levels.

Source: ICE 20412C

Figure 7-23. EPROM Suppliers and How They are Committed to the Market



Company	1996 Sales ($M)	1995 Sales ($M)	1996/1995 Percent Change
SGS-Thomson	360	345	4%
Atmel	225	165	36%
AMD	135	170	–21%
Macronix	98	76	29%
Cypress	80	65	23%
TI	75	135	–44%
Fairchild (National)	50	118	–58%
Others	82	311	–74%
Total	1,105	1,385	–20%

Source: ICE 20524B

Figure 7-24. 1996 EPROM Manufacturing Sales Leaders

Low voltage is one of ST's strengths when it comes to EPROMs. With approximately one-third of the total market, the company offers a broad range of products starting at 16K and scaling to a 16M density. The company also offers 45ns and 70ns EPROMs for digital signal processing oriented applications.

Atmel and Cypress both increased their presence in the EPROM market over the past several months. Cypress anticipates greater opportunities in the commodity EPROM business. It started making slow versions, with access times slower than 55ns, of its fast EPROMs. In doing so, Cypress believes it will better cover the complete range of speed requirements for many applications.

AMD's EPROM business went from that of a leading supplier to that of an alternate-source supplier. AMD lost two of its primary EPROM foundry partners in 1995. They abandoned AMD's EPROM production in favor of ICs with higher ASPs. As a result, AMD had to closely re-evaluate its production commitments. Following the re-evaluation, AMD decided it would focus more on the growth potential of its flash memory business.

National Semiconductor planned to pull out of the commodity EPROM market altogether and focus instead on application specific oriented solutions. It did not seek new customers and led its existing EPROM customer base to new suppliers. Between 1994 and 1996, the company's EPROM sales plummeted from $160 million to $50 million.

The situation changed when National spun off Fairchild Semiconductor in 1996. Despite it being a tough market, Fairchild wanted to re-energizing its EPROM business and take a leadership position in it. It made a long-term commitment to this market with the goal of becoming one of the last three EPROM suppliers. The company plans to extend its low-voltage EPROM family to 1M, 2M, and 4M densities.

Through the years, the EPROM market has been more evenly balanced by region than other memory segments (Figure 7-25). Although Japan still is the EPROM market leader, ICE forecasts that the ROW region will capture more of the EPROM market in the coming years. The reason for this shift is that North America, Japan, and Europe will be quicker to accept and implement flash memory in different systems, thus leaving the EPROM market to others.

The Flash Memory Market

In the semiconductor memory hierarchy, flash memory is a member of the non-volatile family (Figure 7-26). Expanding the non-volatile memory family (Figure 7-27), flash memory represents a middle-of-the-road alternative in terms of cost and functionality.

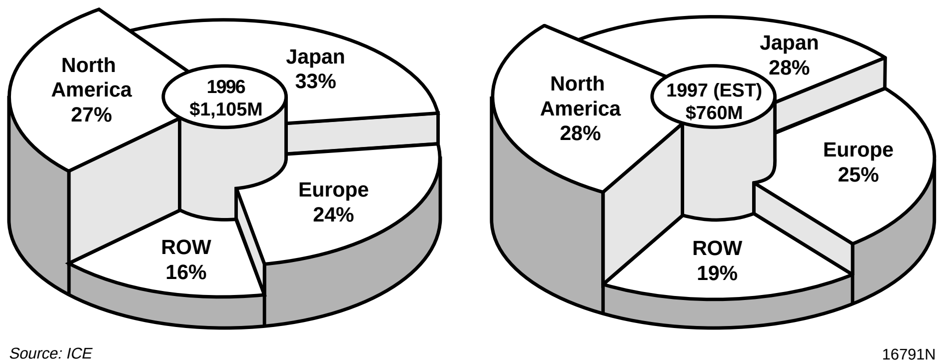


Figure 7-25. EPROM Market by Region

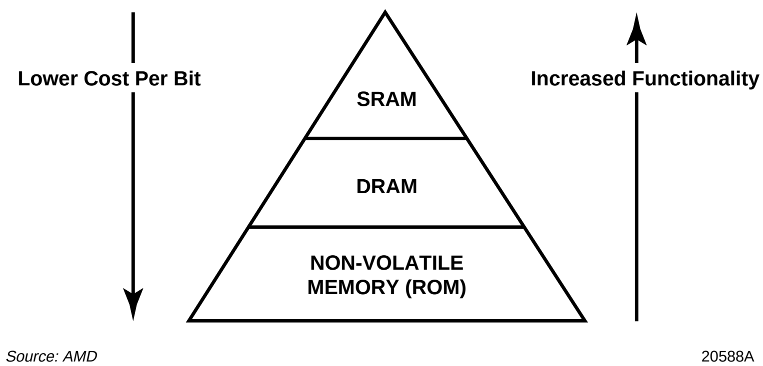


Figure 7-26. Semiconductor Memory IC Hierarchy

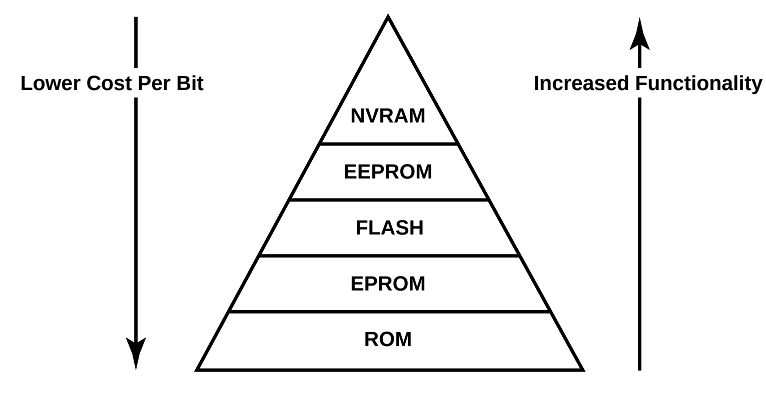
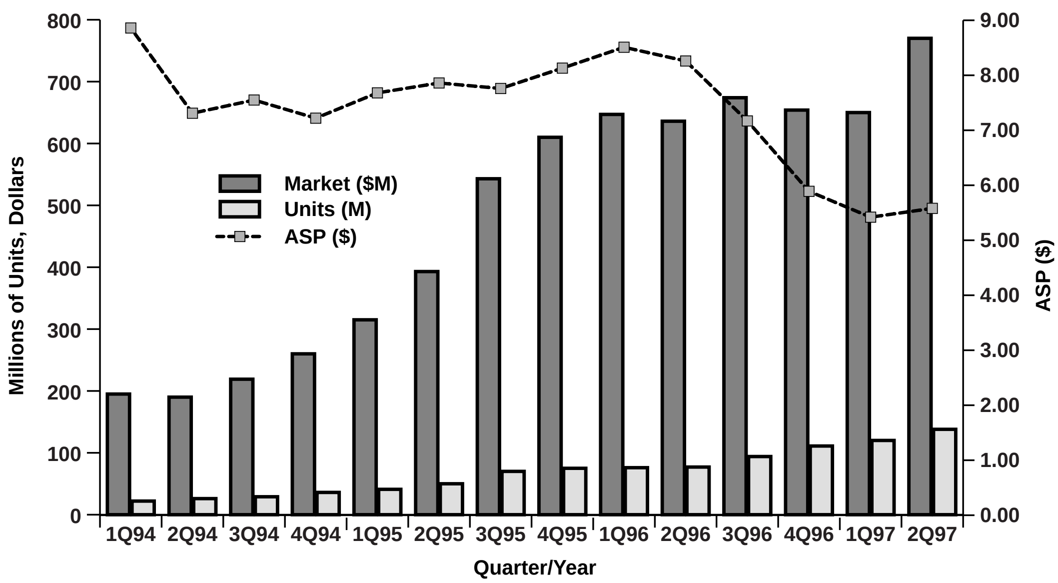


Figure 7-27. Non-Volatile Memory IC Hierarchy

Over the last five years, flash memory has matured at a rapid pace. Contributing to this was the development of new systems and products that were smarter, more integrated, all-encompassing, and more economical. Also contributing to flash memory market growth was the gradual acceptance of industry-wide specifications. The flash memory industry also grew due to the adoption of various interface specifications, especially those relating to the PC-card market.

The flash memory market is one that ICE projects will be among the fastest growing semiconductor product segments through 2002. Though not as big as DRAM or SRAM markets, its sales growth makes it an important market to follow.

Recent market history of flash memory ICs is plotted by quarter through mid-1997 in Figure 7-28. This figure shows a market history in which supply shortages and high prices were followed by an abundant supply and plunging prices. One key to the flash memory market growing well in 1996 was the fact that ASPs declined steadily during the year, but especially in the last quarter. ICE estimates that when final data are tabulated flash memory ASPs will show that they continued to decline through 1997 and into 1998.

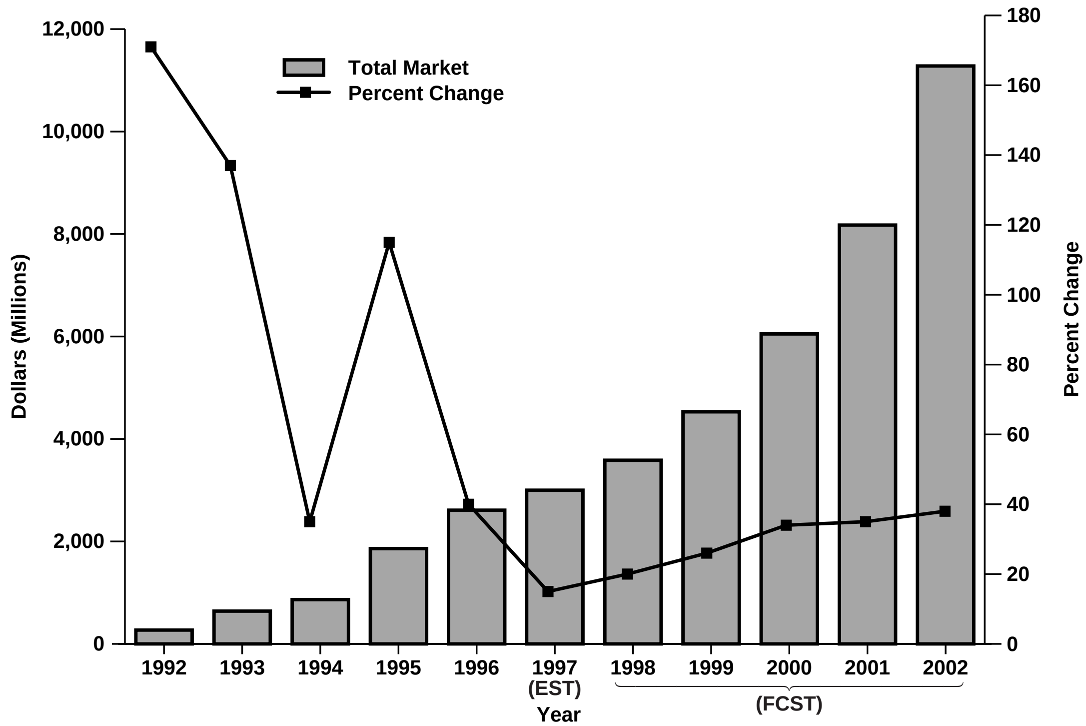


Market ($M)	195	190	219	260	315	393	543	610	647	636	674	654	650	770
Units (M)	22	26	29	36	41	50	70	75	76	77	94	111	120	138
ASP ($)	8.86	7.31	7.55	7.22	7.68	7.86	7.76	8.13	8.51	8.26	7.17	5.89	5.42	5.58

Source: ICE 20597C

Figure 7-28. Quarterly Flash Memory Market Summary

The flash memory market finished 1996 at $2.6 billion. Although growth rates moderated in 1997, ICE nevertheless projects a cumulative average annual growth rate of 31 percent for the flash memory market from 1998 through 2002, when the market size is forecast to be $11.3 billion (Figure 7-29). Further, ICE believes flash memory dollar volume, as a percent of the total MOS memory market, will increase slightly through 2002.



Total Market ($M)	270	640	865	1,860	2,610	3,000	3,585	4,530	6,050	8,175	11,280
Percent Change	171	137	35	115	40	15	20	26	34	35	38

Source: ICE 20587B

Figure 7-29. Flash Memory Market Growth and Forecast

Flash memory consumption (Figure 7-30) was dominated by the North American region during 1997, as it was in 1996. ICE projects regional consumption will likely remain about the same for 1998.

The leading flash memory suppliers for 1995 and 1996 are shown in Figure 7-31. Since its inception, the flash memory market has been dominated by Intel and AMD. In 1996, several additional players entered the flash memory market and competition between suppliers increased. As a result, Intel's flash memory business, which was very good in the first half of 1996, dropped sharply due to pricing pressures. However, Intel managed to increase its flash memory business 22 percent during 1996. The scenario was somewhat the same at AMD. That company's flash memory revenue increased marginally despite a significant upturn in unit shipments. Both Intel and AMD will be the front-runners in the flash memory business when 1997 data are tabulated, and again in 1998.

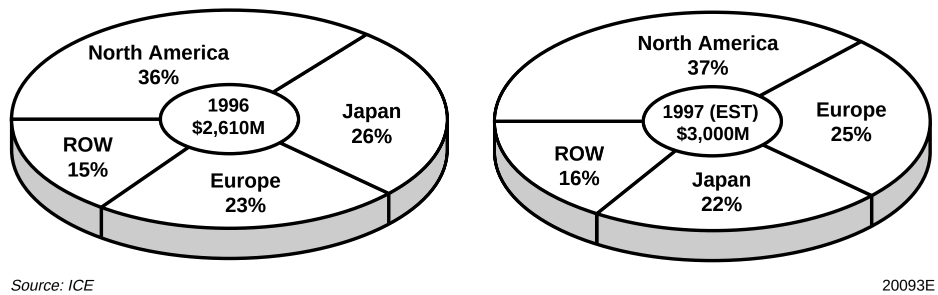
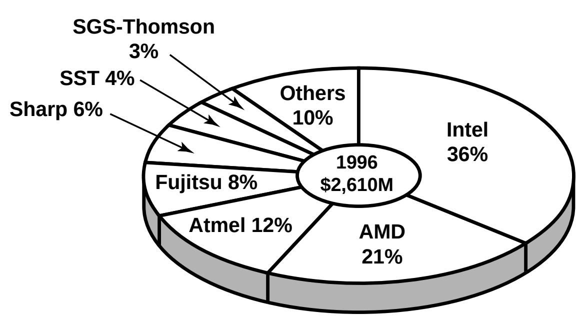


Figure 7-30. Flash Memory Market by Region



Company	1996 Sales ($M)	1995 Sales ($M)	Percent Change
Intel	945	775	22
AMD	550	510	8
Atmel	305	180	69
Fujitsu	210	185	14
Sharp	150	45	233
SST	93	40	133
SGS-Thomson	91	92	–1
Others	266	33	706
Total	2,610	1,860	40

20614E

Source: ICE

Figure 7-31. Flash Memory Manufacturing Sales Leaders

Activities from the leading flash memory suppliers are reviewed below:

Intel

The flash memory leader is Intel. Along with AMD, it is the dominant supplier of flash memory for code-storage applications. Intel offers its SmartVoltage flash memory ICs that provide read and write voltages from 3V to 12V. Intel maintains that this feature gives its customers more choices of programming speed because higher voltage equates to higher programming speed.

SmartVoltage flash memory ICs are manufactured using low-cost, leading-edge 0.4µm process technology. At 0.4µm, Intel's ETOX V process is similar to the 0.35µm process used for its microprocessors. It provides a 44 percent die size reduction over 0.6µm processes for 8M flash memory ICs.

Intel expanded its SmartVoltage lineup with the Smart3 and Smart5 families that provide embedded system designers with 3V or 5V read and write capabilities, while enabling fast 12V programming. These ICs are available in densities up to 16M.

Intel sampled a new generation of SmartVoltage ICs in the second quarter of 1997; these store both code and data in a single component without using special on-chip circuitry. By using a software innovation, the new Smart3 Advanced Boot Block flash memory IC eliminates the need for EEPROM-based data storage in many memory subsystems. The ICs are targeted for space-constrained applications such as new, streamlined digital cellular phones.

Intel also introduced 16M and 32M flash memory ICs from the FlashFile memory family that are among the first in the industry to support the Common Flash Memory Interface (CFI), a specification set up by Intel, Sharp, AMD, and Fujitsu to allow forward migration and alternate sources via software. The parts are designed to provide faster write times at lower voltages.

Flash production capacity increased greatly at Intel during the past few years after the company spent several billion dollars to upgrade existing facilities and build completely new flash-memory dedicated wafer fabrication facilities. It is now positioned, along with its flash-memory manufacturing partner Sharp, to capture additional worldwide business.

Intel also started construction on its first manufacturing plant in China. The plant will be a flash-memory IC test-and-assembly facility in the Free Trade Zone of Shanghai. The site will be used to test and assemble Intel's entire line of flash-memory ICs by mid-1998.

Advanced Micro Devices

Although AMD's flash memory revenue growth was slower than anticipated in 1996, demand and shipments were very solid, and the company remained optimistic about its future in this product category. In fact, in the first quarter of 1997, AMD saw a 20 percent increase in sales of its flash memory ICs.

Architecturally, AMD's flash memories are similar to Intel's. However, rather than varying voltages for read and write as Intel does, AMD offers the single-voltage-only option for both functions. AMD maintains that single-voltage parts offer original equipment manufacturers (OEMs) a simpler solution.

AMD continues to quickly ramp volume production of its low-voltage ICs. In 1996, AMD announced three new members of its 2.7V-only flash memory family. The two 4M and one 8M ICs, with access times as fast as 100ns, are targeted for emerging and existing battery-powered applications including digital cellular phones, flash memory cards, and digital cameras. One year later, the company announced a family of flash memory ICs that operates at 2.2V. The new family, called Am29LLXXX, represents one generation toward 1.8V and, eventually, 0.9V flash memories; the first available was an 8M design.

Embedded flash memory is one end use that AMD continues to serve. Currently, embedded flash memory represents the vast majority of uses for flash memory including code storage for applications such as PC BIOS, cellular phones, and networking equipment. AMD believes that the flash memory market will be driven by low-voltage embedded ICs and has set up its flash memory product line to match these potential end uses.

In another move, AMD began selling bare-die versions of its flash memory chips in response to requests for known-good-die (KGD) from its non-volatile-memory customers. Over the long term, AMD believes about 10 percent of its flash memory sales will be in KGD format.

Atmel

Atmel is also a leader in the flash memory business. Atmel's flash memory ICs provide users the ability to erase information in small, bit-size increments rather than in large blocks like flash memories from most other suppliers.

Atmel views low voltage as a key to its product strategy and design wins. It has been particularly successful targeting portable applications such as cell phones. Atmel was one of the first companies to offer a 3V flash memory. Demand for its low-voltage ICs jumped in 1996 and is estimated to have grown more in 1997. Besides 3V ICs, it also developed a 2.5V, single-voltage read and write flash memory family. The new flash memory family will have densities ranging from 1M to 8M. Additionally, the company is working feverishly on a 1.8V IC slated to be released in 1997.

Atmel has also pursued cell-phone manufacturers that are interested in adding another applications-level of flash memory to their designs. The company developed a flash memory tailored for storing large amounts of data, including voice recordings, and has targeted this IC to serve voice mail applications on cellular phones. Called Serial DataFlash, it boasts low power and better performance than more established flash memory ICs. The first product is a 4M chip.

Fujitsu

Fujitsu works closely with AMD to develop and manufacture flash memory ICs. The company plans to triple flash-memory output at its FASL facility, increasing it to 12 million units per month by March 1998. The FASL No. 1 facility is moving to 0.35μm process technology, which helped increase output from four million to eight million units per month in September 1997. Once production line No. 2 comes on-line, output should increase to the planned 12 million units per month level.

Fujitsu announced that it would add NAND-type flash memory to its product portfolio beginning in 1998. Along with its joint-venture partner AMD, Fujitsu decided to produce NAND-type designs because they are better suited for file applications than the NOR-type. Additionally, Fujitsu thinks it is essential to have a wider product line.

Hitachi and Mitsubishi

Hitachi stressed development of its DINOR technology in 1996 and offered end users several densities built on this body of knowledge. Together with Mitsubishi, it introduced two 3V-only 8M ICs in late 1996. The two companies believe that with the 8M DINOR ICs, they will be able to quickly catch up to leaders Intel and AMD in the flash memory market.

Additionally, Mitsubishi licensed its DINOR technology to Motorola. Motorola joins Hitachi, which previously signed a joint-development agreement with Mitsubishi, as an alternate source for the DINOR technology. After first purchasing Mitsubishi's finished products for resale under the Motorola brand name, late in 1997 Motorola began purchasing bare die from Mitsubishi to package, assemble, and test to its own specifications. The first products from Motorola were 8M ICs.

Late in 1996, Hitachi and Mitsubishi rolled out a 64M flash memory device that initially served as the storage centerpiece in Hitachi's 75MB ATA-standard PC cards. The ICs were manufactured using 0.4μm AND-flash memory process technology. A second-generation 64M AND flash memory IC built using sub-0.4μm technology was set to debut by the end of 1997. The new IC will be 30 percent smaller than the first generation IC. Hitachi planned to increase output of its 64M flash memory ICs to 500,000 units per month by the end of 1997.

Mitsubishi planned to raise output of its 8M DINOR-type flash memories to two million units per month by the end of 1997. The company increased its flash memory offerings in 1997, focusing its product line on 2.7V low-voltage ICs. In addition, it planned to develop a 1.8V flash memory prototype by the end of 1997. Mitsubishi also makes NOR-type flash memory, but will not increase output of these ICs. Instead, it will focus on producing DINOR and AND-based flash memory.

SGS-Thomson

Amid reports of a possible shortage of flash memory capacity, ST joined a growing list of companies that made announcements of expanded fabrication capacity for flash memory fabrication. Early in 1997, it increased production capacity for flash memories with particular emphasis on 2M and 4M ICs. Moreover, the company was working quickly to qualify its 200mm wafer fabrication facility in Catania, Sicily, to gain additional flash memory fab capacity in 1997. By the end of 1997, ST's Catania fab was in volume production of flash memory ICs.

ST offers both multiple-voltage and single-voltage only flash memory ICs to its customers. ST sampled Intel-compatible 8M flash memory ICs in the second quarter of 1997 and increased production by the end of the year. It will bring a 16M flash memory ICs to the market in 1998.

SanDisk

SanDisk achieved a major victory when the U.S. International Trade Commission upheld a ruling in a cross-licensing dispute between SanDisk and Samsung. The ruling barred Samsung from importing into the United States any flash memory products containing SanDisk's AND flash memory designs.

Fresh from that legal victory, SanDisk planned to license its technology to additional companies including Toshiba and NEC. Further, it plans to cross-license flash memory technology with Hitachi.

Sharp

Sharp was able to expand into the lucrative U.S. flash memory market in 1995 after its initial licensing agreement with Intel, which restricted its flash memory market to Japan, expired. Now, it sells to the U.S. both its Intel-compatible dual-voltage flash memory ICs and its own single-voltage flash memory ICs that compete with those made by Fujitsu and AMD.

In building nearly half of the flash memory ICs for Intel along with those produced using its own design, Sharp supplied a substantial portion of the world's flash memory supply. Its own designs include low power 3V-only 16M designs, chip-size packages, and dual-works flash memory enabling simultaneous read, write and erase functions.

Also, Sharp increased flash memory output at its Fukuyama plant by replacing 0.6μm process technology with 0.4μm lines. Sharp further committed to the flash memory market when it announced plans to build a $1 billion flash memory wafer fabrication facility in Hiroshima.

Silicon Storage Technology

SST designs, manufactures, and markets single power supply (i.e., 5V-only, 3V-only, or 2.7V-only) and small erase-block flash memory ICs. All SST products are based on its proprietary SuperFlash technology. The SST SuperFlash technology typically uses a process of 13 mask layers, compared to 19 or more layers for other flash memory approaches. The company claims its fewer masking steps lead to reduced cost and improved reliability.

Texas Instruments

TI introduced a series of 1M, 2M, and 4M flash memory ICs with separate versions that conform to both Intel (dual supply and autoselect) and AMD (single supply) standards. In the first half of 1997, the company developed a basic 8M design that can be tailored for either standard by changing the metal mask, a step TI claims is a relatively simple manufacturing adjustment.

TI also revealed its plans to move to 4M custom, 8M burst, and 8M embedded flash memory for the automobile and engine control markets by 2000. At the high end, the firm plans to offer 8M and 16M flash memory for networking and hub control applications by 1998, and 32M and 64M ICs by 2000.

To build all these ICs, TI announced that it signed a $1.2 billion agreement with the Italian government to build a 300mm wafer fabrication facility in Avezzano, Italy, to manufacture its flash memory products. Dubbed AMOS 3, this wafer fabrication facility will initially use a 0.28μm process that is scalable to 0.18μm and below. Volume production at the facility is currently slated for 1999.

In addition, a development consortium was established in Europe to build on non-volatile memory cell work by ST, Siemens, and Philips. The goals of the consortium include the following:

- Turn the non-volatile memory cell into a cost-effective technology that will lead to innovative European electronic-design solutions.
- Minimize the dependence of European customers, system houses, and design centers on non-European flash memory manufacturers.
- Distribute the knowledge accumulated in European research institutes.
- Strengthen the position of European non-volatile manufacturers in the global market for embedded applications.

Trends in Flash Memory

Architecture

What differentiates flash memories most is the architecture used to design them; there are four significant flash memory architectures available to OEMs (Figure 7-32). The two most prominent architectures are NOR and NAND. Both are based on technology from flash memory's predecessors, the EPROM and EEPROM, respectively. Of these two styles, the most ubiquitous type is the NOR architecture.

Architecture	NOR	DINOR	NAND	AND
Program Method	Hot carrier injection	Tunnel current	Tunnel current	Tunnel current
Erase Method	Tunnel current	Tunnel current	Tunnel current	Tunnel current
Access	Random	Random	Serial	Serial/Random
Sector Size	64Kbytes	64Kbytes	4Kbytes	512bytes
Possible Power Supply				
• single 3.3V	Yes	Yes	Yes	Yes
• single 5V	Yes	No	Yes	No
• dual 5V/12V	Yes	No	Yes	No
Die Size (using NOR as reference)	1	0.6 - 0.7	0.6 - 0.7	0.6 - 0.7
Suitable Applications (by density)				
• 1M to 4M	• BIOS, EPROM replacement, communications, low-density XIP cards	• Not suitable	• BIOS, EPROM replacement, communications, low-density XIP cards	• Not suitable
• 8M to 16M	• PDA, cellular, networking, low-density ATA cards	• PDA, cellular, networking, low-density ATA cards	• PDA, cellular, networking, low-density ATA cards	• Not suitable
• 32M to 256M	• Not suitable	• Not suitable	• High-density ATA cards (10-100Mbytes)	• High-density ATA cards (10-100Mbytes)

Source: Computer Design/Mitsubishi 20418C

Figure 7-32. Flash Architectures Stretch to Fit Memory Requirements

Rivalry exists among suppliers as to which type is the best architecture. In most cases, NOR is considered best for fast-access, lower-density code-storage applications, while NAND is deemed advantageous for high-density, lower-cost, high-end mass storage applications.

Emerging flash memory architectures include Mitsubishi's DINOR architecture and Hitachi's AND architecture. DINOR is an attempt to combine the speed and random access of conventional NOR-type flash memory ICs with the small cell size of NAND flash memory. Hitachi's AND structure and a technology called NexFlash from Nexcom Technology promote high density and low cost per bit.

Figure 7-33 looks at the various flash memory architectures and the semiconductor manufacturers who support them. Figure 7-34 samples some of the flash memory ICs available from these suppliers. A standard architecture for all flash memory ICs will not likely occur within the next five years. Each architecture appears to have advantages depending on application. To support the needs of a growing customer base, several suppliers have announced that they would support two or more types of flash memory architectures beginning in 1997 and 1998. Eventually, look for customers to pressure suppliers to standardize on a specific architecture for specific applications.

NOR	NAND	AND	DINOR
Intel	National	Hitachi	Mitsubishi
AMD	Samsung	Mitsubishi	Hitachi
Atmel	Toshiba		Motorola
Fujitsu	Fujitsu		
TI	AMD		
Micron			
SGS-Thomson			
Macronix			
UMC			
Mitsubishi			
Samsung			
Toshiba			

Winbond uses its proprietary "split-gate" architecture.

Source: ICE 20080D

Figure 7-33. Suppliers' Support of Flash Memory Architectures

Voltage

Another issue being addressed in the flash memory market is that of single versus dual-supply voltage, and the implementation of low-voltage ICs. Intel offers its SmartVoltage ICs that provide several voltages for reading and erasing data from storage. AMD, on the other hand, is among the leading proponents of single-voltage flash memory ICs.

Currently, both dual and single-voltage ICs have different advantages. Again, the end use usually determines the best solution for a given design implement. Long-term, the trend is for users to design single-voltage ICs into their systems. In 1996, flash memory unit shipments quickly shifted to single, low-voltage (5V/5V and 3V/3V, read, erase and program) ICs and are forecast to continue migrating to lower voltages (Figure 7-35).

	Cell Architecture	Transistors Per Bit	Maximum Density Available*	Main Applications
AMD	NOR	1	16M	Embedded Code
Atmel	NOR	2	4M	Embedded Code
Intel	NOR	1	16M	Embedded Code
Hitachi, Mitsubishi	DINOR	1	16M	Audio, Data, Images, Embedded Code
Nexcom	NOR	1	8M	Audio, Data, Images, Embedded Code
SST, Winbond	Split-Gate NOR	1.5	4M	Embedded Code
Toshiba, Samsung	NAND	1**	16M	Audio, Data, Images
Hitachi, Mitsubishi	AND	1	32M	High-Density ATA Cards (10-100Mbytes)

* Some companies have announced higher densities.
** In addition, two select transistors are required for every 16 cells, but no bit line contacts are needed between transistor pairs, as in NOR cells.

Source: Electronic Business Today 21773B

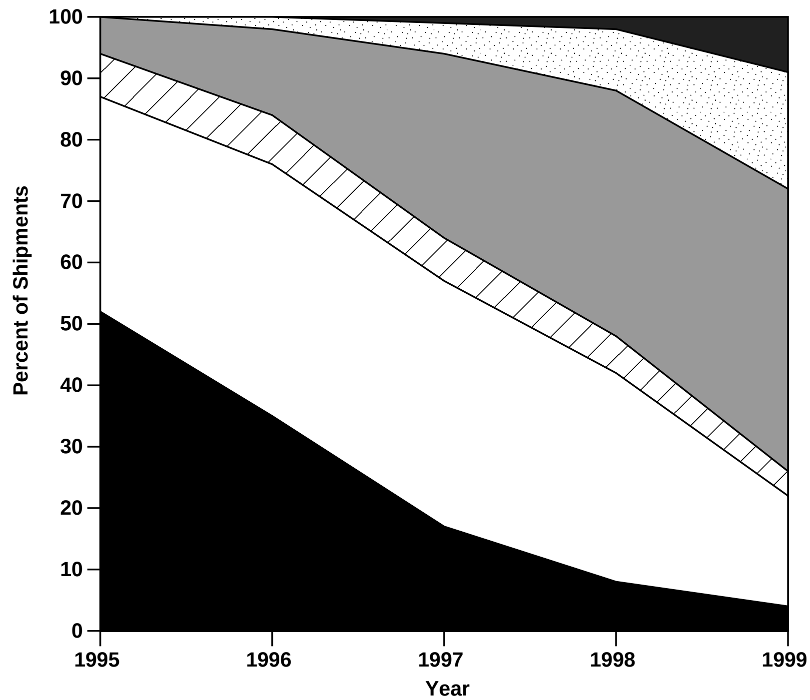
Figure 7-34. A Sampling of Flash Memory Products

Multi-Level Cell Technology

Most flash memory ICs store one bit of data in each memory cell. However, for some time, engineers have wanted to increase storage capacity to two or more bits of data in each memory cell. Today, this concept is not far from reality. Multi-state flash memory is a great way to boost density in memory cells without greatly increasing the size of the die. Intel calls this technology multi-level cell or MLCflash memory; SanDisk calls it Double Density or D2.

Intel and SanDisk are the two leaders in implementing this technology. SanDisk estimates that it can cut storage prices in half from year to year with every new generation; from $10 per megabyte to $5 per megabyte by the end of 1997, to $2.50 per megabyte by the end of 1998, using its Double Density technology.

SanDisk, along with manufacturing partner Matsushita, used the technology in flash memory ICs to boost single-chip capacity to 64M. The SanDisk implementation stores four discrete voltage levels in each NOR cell, thereby representing two bits per cell. SanDisk claims that the 64M die is only 10 percent larger than the company's 32M die. It sampled this IC in the first quarter of 1997. Meanwhile, the company is also working on a 256M Double Density flash memory.



5V/12V	52	35	17	8	4
5V/5V	35	41	40	34	18
3V/5V	7	8	7	6	4
3V/3V	6	14	30	40	46
2.7V/2.7V	—	2	5	10	19
≤2.2V	—	—	1	2	9

Source: Mitsubishi 20594C

Figure 7-35. Percentage of Flash Memory Unit Shipments by Read, Erase, and Program Voltages

Intel introduced its long-awaited MLC-based 64M flash memory in mid-1997. With its MLC product, Intel plans to target the market for NAND-flash memory by offering comparable or better performance at a lower price. At the December 1996 International Electron Devices Meeting, SGS-Thomson presented a study, and the tradeoffs, on MCL for different flash memories. Highlights of this study are presented in Figure 7-36.

Embedded Flash Memory

Reprogrammability and in-circuit programming capability provide a highly flexible solution to rapidly changing market demands. To provide a solution for OEMs who desire this flexibility, several IC suppliers now embed flash memory onto microcontrollers or other logic ICs. Typical embedded code applications include smart sensors, rolling code remote-keyless-entry, home security systems, and space-constrained applications such as pagers.

Array Architecture	Cell Size*	Advantage as Single-Bit Concept	Disadvantage as Single-Bit Concept	Advantage as Multi-Bit Concept	Disadvantage as Multi-Bit Concept
Common Ground	9-11F^2	1. General purpose applications and most understood array and technology	1. Relatively large cell size	1. Minimum interaction between neighbors 2. CHEI for programming	1. Closely coupled metal bitline 2. V_t distribution affected by neighbor data
DINOR	7.5F^2	1. Reduced cell size while preserving the common ground array	1. Requires triple poly	1. Reduction in BL-BL coupling	1. Tunneling during programming 2. Source resistance
AND	8F^2	1. Good combination of CG and DINOR 2. Drain contact every 32-128 cells	—	1. Reduction in BL-BL coupling	1. Tunneling during programming 2. Source resistance
NOR Virtual Ground - AMG	6F^2	1. Small cell size 2. Low current programming	—	1. CHE programming 2. Reduction in BL-BL coupling	1. Resistive diffusion bitlines 2. Neighbor interaction affecting V_t distribution
NOR Virtual Ground - Split Gate Poly-Poly Erase	7.5F^2	1. Overerase not an issue	1. Requires triple poly	1. CHEI programming 2. Disturb reduction due to poly-poly erase	1. Neighbor interaction affecting V_t distribution 2. Low read current and high erase voltages
NAND	6F^2	1. Small cell size	1. Read thru stack of 15 cells 2. High read and programming voltages	—	1. Programming by tunneling in the channel

*F is the technology feature size

Source: SGS-Thomson

22595A

Figure 7-36. Trade-Off of MLC Versus Flash Memory Architecture

On-chip flash provides an OEM with a host of benefits including lower overall system cost and less board real estate. Further, the microcontroller performs faster memory accesses to integrated flash memory, flash memory on-chip significantly lowers the system power consumption, and on-chip flash memory provides higher reliability. These ICs also accelerate product testing, allowing the easy substitution of test vectors for operating code during final assembly stages. In addition, product scrapping due to misprogramming or bugs is no longer an issue as every IC is reprogrammable. In summary, on-chip flash memory helps reduce time-to-market for many systems at only a marginally higher cost.

Among the suppliers who provide logic with embedded flash memory are Atmel, Hitachi, Motorola, Microchip Technology, NEC, and Toshiba. Atmel's AT89x series of microcontrollers contain between 1Kbyte and 20Kbytes of flash memory. The AT89x microcontrollers are socket and function compatible with the industry-standard 80C52, but the integrated flash memory greatly increases the capabilities of these microcontrollers.

Microchip Technology features a 2V 8-bit flash memory microcontroller. Also, Toshiba introduced a 16-bit microcontroller with 64K of flash memory and NEC provides its 3V 16-bit microcontroller with 128K of built-in flash memory.

Hitachi developed a 32-bit reduced instruction set computing (RISC) microcontroller that is offered with 128K or 256K of built-in flash memory and sampled this IC early in 1997. Sanyo teamed with Silicon Storage Technology to offer 8-bit and 16-bit microcontrollers with flash memory. And, Lucent Technology provides flash memory built into its digital signal processor ICs (FlashDSP).

Flash Memory Manufacturing Capacity

Manufacturing capacity—whether too much or not enough—was, and continues to be, an issue in the flash memory market much like it has been for other memory market categories during the past several years. In early 1997, Intel claimed its flash memory capacity was sold out for the year. Intel's announcement put the whole industry on alert that perhaps there might be a flash memory capacity shortage in 1997.

ICE believes that overall flash memory supply and demand will continue to be fairly well balanced. In fact there is a potential for excess flash memory capacity and a drop in ASPs. The potential for greater-than-normal price erosion is very real across all densities if one looks at the amount of flash memory wafer fabrication capacity that started in 1997.

Consider the number of companies that recently converted existing memory lines or that pledged to bring additional new flash memory capacity on line last year. For example, Intel converted its Fab 9 in New Mexico, a fab previously dedicated to logic ICs, to flash memory production in 1996 and also retrofitted its Fab 7 facility in New Mexico with upgrades and design shrinks to increase output. Furthermore, Intel is constructing its state-of-the-art flash memory fab in Kiryat Gat, Israel. In addition, Intel is keeping alive its flash memory alliance with Sharp in Japan. The partnership was a strong source of growth for Intel's flash memory business in 1996.

For its part, Sharp intends to make flash memory product revenue second only to that of flat-panel displays. To do so the company is building a $1 billion wafer fabrication facility near Hiroshima, Japan, dedicated to flash memory ICs. Initially, beginning in 1998, the plant will produce 10,000 200mm wafers a month, but eventually will increase production to 20,000 wafers a month. The alliance Sharp has with Intel calls for it to sell a portion of its new Hiroshima plant production to the North American company.

AMD and Fujitsu formed a flash memory alliance that competes directly with Intel and Sharp. AMD and Fujitsu announced the second phase of their joint-venture flash memory wafer fabrication facility in Japan. The phase two was completed in mid-1997 with initial production slated to come on-line in 1998. These leading companies also reduced process feature size to increase production capacity during 1996 and 1997.

SGS-Thomson announced a substantial increase in its production capacity for flash memory, with particular emphasis on the 2M and 4M densities. The capacity increase resulted from ST's yield improvements, technology upgrades that resulted in reduced chip size, and the introduction of new fab capacity in Agrate, Italy. The company also qualified a new 200mm fab in Catania, Sicily, as quickly as possible; flash memory production began late in 1997.

Meanwhile, Macronix, Taiwan's largest flash memory supplier began volume production of flash memory ICs in the second quarter of 1997 from its new 200mm wafer fabrication facility. The company planned to triple its flash memory business in 1997. In late 1996, Texas Instruments signed a $1.2 billion four-year agreement with the Italian government to build a 300mm wafer fabrication facility in Avezzano, Italy, for the manufacture of flash memory ICs, although volume production is not expected until 1999.

Over the past several months, several other memory manufacturers around the world including Hitachi, Hyundai, Mitsubishi, Samsung, Sanyo, Siemens, and Winbond announced new wafer fabs for flash memory or considered converting some of their DRAM lines to flash memory production.

Is it possible for the market to absorb a doubling of flash memory manufacturing capacity in each of the next few years? Chip makers must think so as the spending for and building of flash memory facilities is set to increase dramatically. The additional fab capacity could lead to a further decline in ASPs even as demand increases.

A review of flash memory wafer fab capacity plans from several leading suppliers is shown in Figure 7-37.

Small Form-Factor Flash Memory Cards

With the promise of huge potential markets for hand held and portable electronic equipment such as digital cameras, voice recorders, and personal digital assistants, developers of miniature flash memory cards started to round up support for their specific formats. The three primary contenders of sub-PCMCIA ("PC-card") format memory cards are SanDisk's CompactFlash, Intel's Miniature Card, and Toshiba's Solid-State Floppy Disk Card (SSFDC). They are supported by the CompactFlash Association (CFA), Miniature Card Implementers Forum (MCIF), and the SSFDC Forum, respectively.

Flash cards represented approximately 10 percent of the total flash memory market in 1996. However, refinement of the miniature card market will likely increase this percentage by bringing miniature postage-stamp size flash memory-based cards into mainstream, high-volume consumer applications. Much like the different architecture styles available for flash memory ICs, there is not a so-called one-size-fits-all standard for miniature flash memory cards. However, end users have begun to understand which formats are best matched with specific applications. Figure 7-38 reviews the three miniature flash memory card solutions.

Company	Location	Process Technology	Comments
Intel	Fab 7 New Mexico, USA 150mm wafers	0.4µm	Wafer starts increased 25% in 1996. Mostly 5V/12V parts. Die shrinks to improve effective capacity/yields.
	Fab 9 New Mexico, USA 200mm wafers	0.4µm	Production started 4Q96.
	Fab 18 Kiryat Gat, Israel 200mm wafers	0.25µm	$1 billion investment. First silicon due 4Q97. Production ramp slated for 1998. When fully operational, Fab 18 will increase Intel's flash output 350% over 1995 levels.
Sharp	Fab 3 Fukuyama, Japan 200mm wafers	0.4µm	Builds devices for Intel as well as for sale under its own label. Running 8M, 16M parts for Intel. Also builds its own line of 2M, 4M, 8M, and 16M devices. Accelerating development of Intel's SmartVoltage technology.
	Fab 4 Hiroshima, Japan 200mm wafers	0.4µm	$1 billion investment. Initial production in 1998.
AMD/Fujitsu	FASL Aizu-Wakamatsu, Japan 200mm wafers	0.5µm	Opened 4Q94. Aggressive ramp schedule. Second joint-venture (FASL-2) in Japan delayed six months. Production now slated to begin in late 1998.
Mitsubishi	Saijo Facility Japan	0.5µm	Greater emphasis on flash memories, less emphasis on DRAMs.
SGS-Thomson	Catania, Sicily 200mm wafers	≤0.35µm	Hopes to begin volume production of flash devices from this fab in 2H97.
Texas Instruments	AMOS 3 Avezzano, Italy 300mm wafers	0.28µm - 0.18µm	300mm fab dedicated to flash and other memory devices will not break ground until late 1997 with volume production slated for early 1999.

Source: ICE 20079E

Figure 7-37. New Flash Memory Capacity to Meet Demand

	CompactFlash	Miniature Card	SSFDC
Original Developers	SanDisk	Intel/AMD	Toshiba
Industry Alliance	CampactFlash Association	Miniature Card Implementers Forum	SSFDC Forum
Module Dimensions	43 x 36 x 3.3mm	38 x 33 x 3.5mm	45 x 37 x 0.76mm
Memory Type	NOR Flash	NOR Flash, DRAM, SRAM, OTP, ROM	NAND Flash
Capacity	2 to 15Mbytes	2, 4Mbytes	2, 4Mbytes
Connector Type	50-Pin subset of PCMCIA	40-Pad Elastomeric	68-Pin PCMCIA With Adapter
Number of Contacts	Circular Pins	Flat-Edge Contacts	Flat-Surface Contacts
Software Interface	ATA	FTL (Flash Translation Layer)	Host-Based Controller
Built-In Controller?	Yes	No	No

Source: ICE 22598

Figure 7-38. Standards for Small Flash-Memory Modules

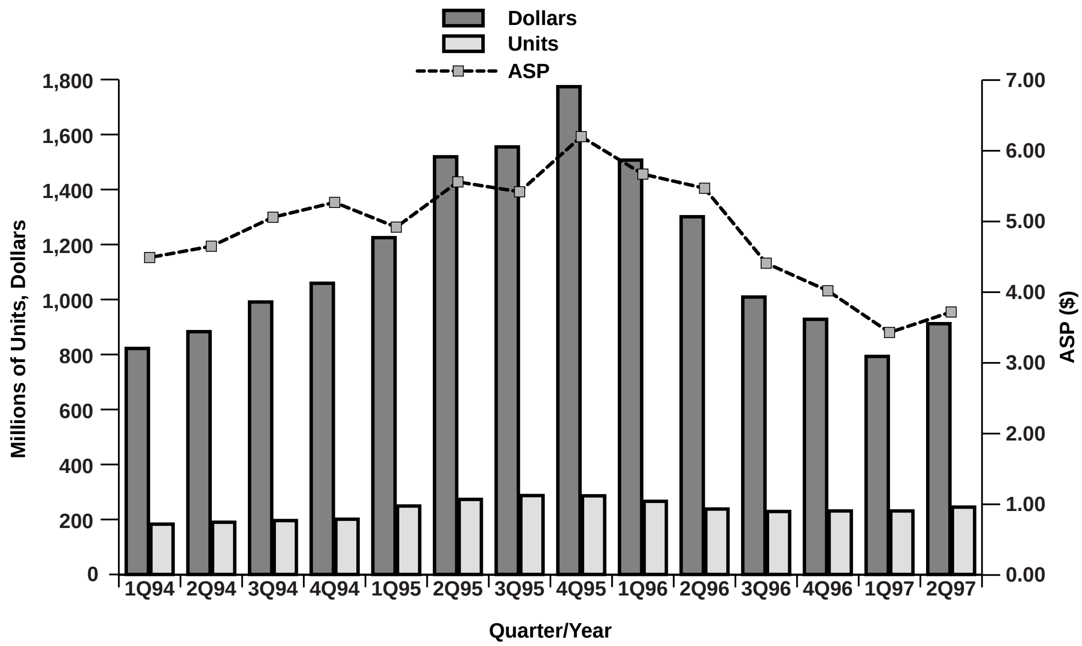
VOLATILE MEMORY ICS

The SRAM Market

For many suppliers, the recent SRAM market has been one of incredible ups and downs. At the beginning of 1996, SRAM suppliers were anticipating that large numbers of Pentium-based PCs would ship with level two (L2) cache memory. As it turned out, the acceptance rate of SRAM for this application was less than expected, and the SRAM market has been soft ever since. So soft, in fact, that many suppliers exited the SRAM market altogether. Hardest hit were Taiwanese suppliers. Through 1996, many of Taiwan's SRAM companies closed down after prices dropped due to a saturated market and thin profit margins.

The quarterly SRAM market through mid-1997 shown in Figure 7-39 reflects the surge in shipments and ASPs for SRAMs that actually started in 1993 then peaked in 1995. Again, the market growth and subsequent decline was largely centered around orders and order cancellations for L2 cache memory in high-speed computers. A bit of good news, however, is that the market appeared to bottom out in the first quarter of 1997.

The total SRAM market for 1992 through 2002 is shown in Figure 7-40. Once again, the steep decline in year-to-year market growth is evident from the percent-change data. Beginning in 1998 and continuing through 2002, ICE forecasts that the SRAM market will grow at a cumulative annual growth rate of 15 percent, resulting in a $6.9 billion market in 2002.



Market ($M)	822	883	991	1,059	1,225	1,519	1,555	1,774	1,507	1,301	1,009	928	793	912
Units (M)	183	190	196	201	249	273	287	286	266	238	229	231	231	245
ASP ($)	4.49	4.65	5.06	5.27	4.92	5.56	5.42	6.20	5.67	5.47	4.41	4.02	3.43	3.72

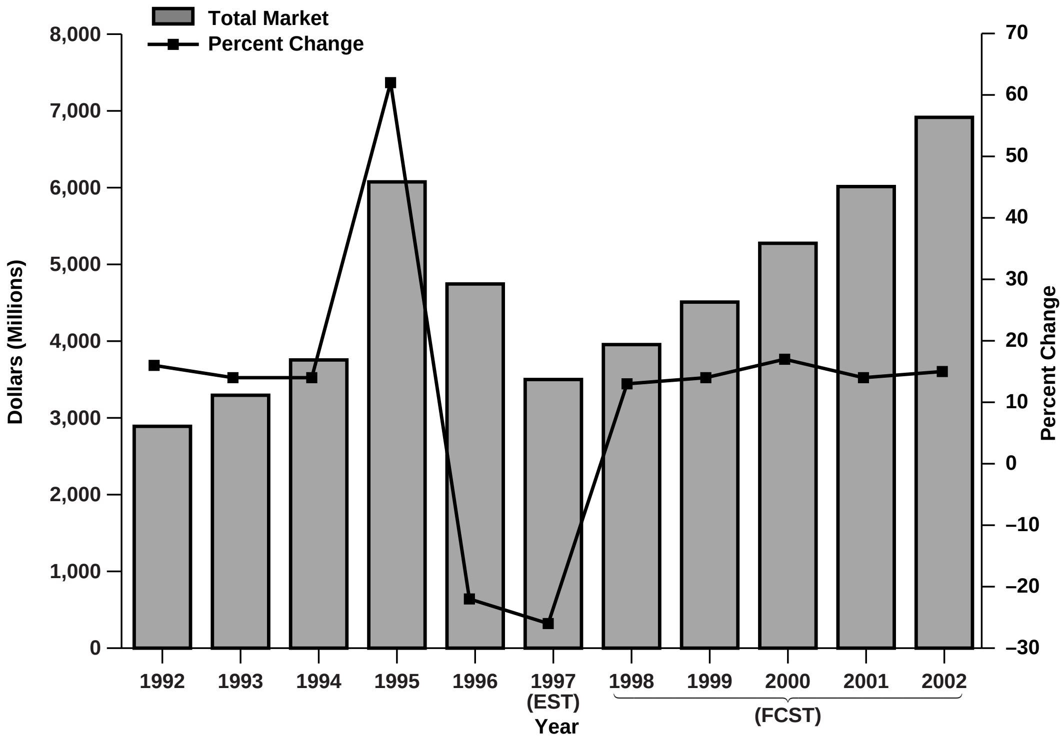
Source: ICE 20624C

Figure 7-39. Quarterly SRAM Market Summary

Figure 7-41 shows mainstream-density SRAM unit shipments from 1991 through estimated 1997. While high-density is a key issue with several other memory products, it is not the highest concern for users of SRAM. In fact, as shown in the figure, the 64K and smaller category was the dominate category in terms of unit shipments for many years. Only in recent years has the 256K density had the highest shipment volume. Also, the 1M-and-greater density out-shipped 64Ks and became the second highest density shipped in 1996.

For the next five years, ICE believes SRAM unit shipments will increase modestly, averaging three percent growth per year through 2002. What has the potential to dramatically influence unit shipments is the growth of microprocessors that use L2 cache memory. Intel’s P6 with MMX and AMD’s K6 microprocessors may each contribute to a greater increase in SRAM shipments than ICE forecasts, especially beginning in 1998.

Speed, or access time, is a key issue for many manufacturers and buyers of SRAM. Several buyers need high performance and demand SRAMs with fast access times. Others may be satisfied with slower, more commodity-like ICs. Figure 7-42 provides a look at SRAM shipments, through mid-1997, by speed: <30ns “fast” SRAMs and ≥30ns “slow” SRAMs.



Total Market ($M)	2,890	3,295	3,755	6,075	4,745	3,500	3,955	4,509	5,275	6,014	6,916
Percent Change	16	14	14	62	–22	–26	13	14	17	14	15

Source: ICE 20618C

Figure 7-40. SRAM Market Growth and Forecast

Fast SRAM

Fast SRAMs are those ICs with an access time faster than 30ns. In the fast SRAM market, PC cache memory is the driving force. As microprocessors race to ever higher clock rates, fast SRAM represents a solid solution for retrieving memory at the rapid pace required by a microprocessor.

Most microprocessor bus speeds now require a second-level cache built with fast SRAM to tap the full potential of the microprocessor. The first Pentium Pro microprocessors used 256K SRAMs in L2 cache memory applications. Subsequent Pentium Pro ICs now incorporate 512K ICs. In mass-volume consumer applications, the transition to higher density cache will be largely dependent on cost. Doubling the cache memory to 512K on some systems may net as much as a 15 percent improvement in system performance. In many cases, however, the performance gain may not be enough to justify the extra cost.

It is a different story in the PC-server market. For high-priced systems, the cost of adding additional cache memory is usually justified. Other markets for fast SRAM include multimedia computers and networking applications.

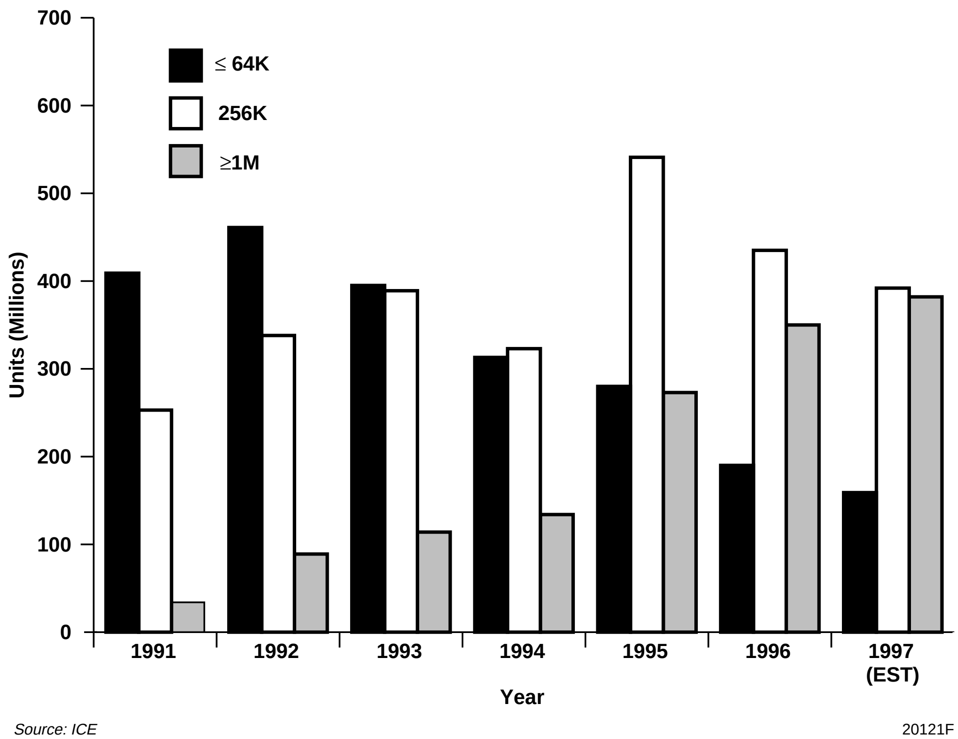


Figure 7-41. Annual Shipments of Mainstream-Density SRAM

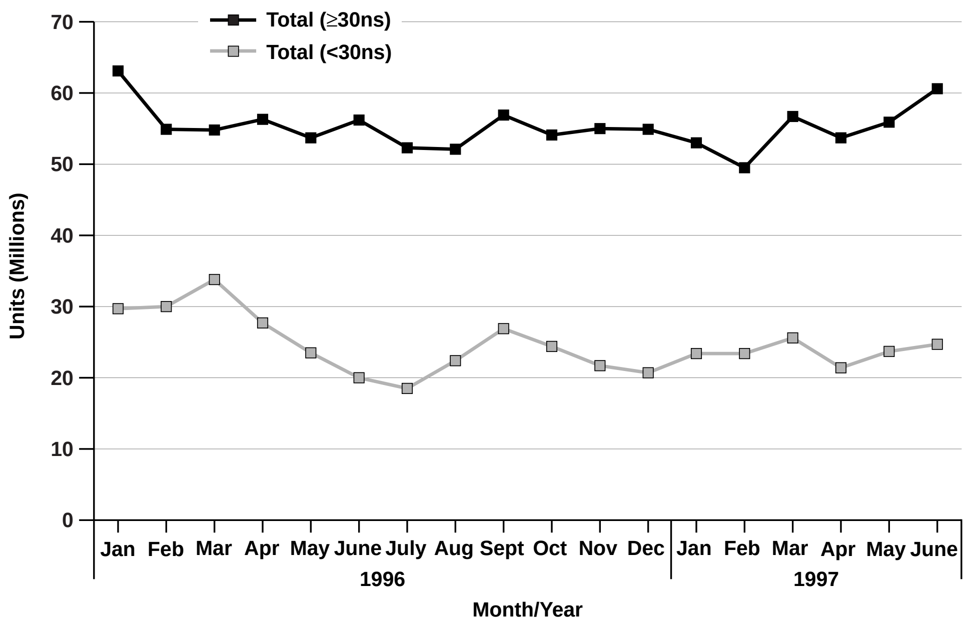
Slow SRAM

Slow SRAMs are those that have access times equal to or greater than 30ns. These ICs are beneficial because of their low power consumption. Users also desire low standby current so that the IC does not lose power between uses or lose data retention current. In 1996, approximately 70 percent of the slow SRAM market featured 5V ICs, with 30 percent 3V ICs. Some manufacturers anticipate that 1.8V ICs will be standard in 1999.

The driving application for slow SRAM is cellular phones. Other end uses include all portable data collection and storage ICs.

Figure 7-43 shows SRAM shipments by speed for 1996. As shown, most fast SRAMs shipped in 1996 were 256K and 1M densities.

SRAM performance targets have a dramatic effect on cell size. Figure 7-44 shows cell sizes and other characteristics of SRAM ICs analyzed in ICE's laboratory. It is interesting to note that the die size of the only 4M part, Toshiba's CMOS SRAM date-coded 9509, which ICE analyzed in 1995, was larger than an NEC 4M SRAM die analyzed a few years earlier. In fact, Toshiba's 4M cell size is actually larger than the cache SRAM on Intel's Pentium microprocessor.



	Jan 1996	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan 1997	Feb	Mar	Apr	May	June
Total Units (≥30ns)	63.1	54.9	54.8	56.3	53.7	56.2	52.3	52.1	56.9	54.1	55.0	54.9	53.0	49.5	56.7	53.7	55.9	60.6
Total Units (<30ns)	29.7	30.0	33.8	27.7	23.5	20.2	18.5	22.4	26.9	24.4	21.7	20.7	23.4	23.4	25.6	21.4	23.7	24.7

Source: ICE 22573B

Figure 7-42. SRAM Shipments by IC Speed

	<30ns	≥30ns
64K	2%	18%
256K	14%	31%
1M	15%	18%
>1M	<1%	2%

Source: WSTS 21194C

Figure 7-43. 1996 SRAM Unit Shipments by IC Speed

SRAM Cache Memory

A significant segment of the SRAM market is cache memory. Figure 7-45 depicts how cache memory has become a more significant factor in PCs. As already noted, most microprocessor bus speeds now require a second-level cache built with fast SRAM to tap the full potential of the microprocessor.

	TOSHIBA TC554161FTL-70L 4Mb (x16) 9509	SAMSUNG KM732V588 1Mb (x32) 1995	GALVANTECH GVT7132C32Q7 1Mb (x32) 9524	HITACHI HM67W1664JP-12 1Mb (x16) 9539	NEC D461018LG5-A12 1Mb (x18) 9436	MOTOROLA MCM67C618FN7 1Mb (x18) 9443
Technology	CMOS	BiCMOS	CMOS	BiCMOS	BiCMOS	BiCMOS
Die Size	7.7 x 18.7mm ($144mm^2$)	5 x 6.6mm ($33mm^2$)	4.5 x 6.8mm ($31mm^2$)	6.4 x 10.1mm ($64mm^2$)	5.7 x 11.7mm ($67mm^2$)	9.2 x 11.8mm ($108mm^2$)
Min Gate - (N)	0.65µm	0.5µm	0.4µm	0.45µm	0.6µm	0.6µm
Cell Pitch	3.7 x 6µm	3.0 x 4.75µm	3.4 x 4.9µm	3.3 x 5.7µm	3.5 x 5.5µm	4.9 x 8.2µm
Cell Area	$22\mu m^2$	$14.25\mu m^2$	$16.5\mu m^2$	$19\mu m^2$	$19\mu m^2$	$40\mu m^2$
Cell Type	4T	4T	4T	4T	4T	4T
V_{CC}	5V	3.3V	3.3V	3.3V	3.3V	5V
Access Time	70ns	—	7ns	12ns	12ns	7ns

Source: ICE 20859

Figure 7-44. Physical Geometries of SRAMs

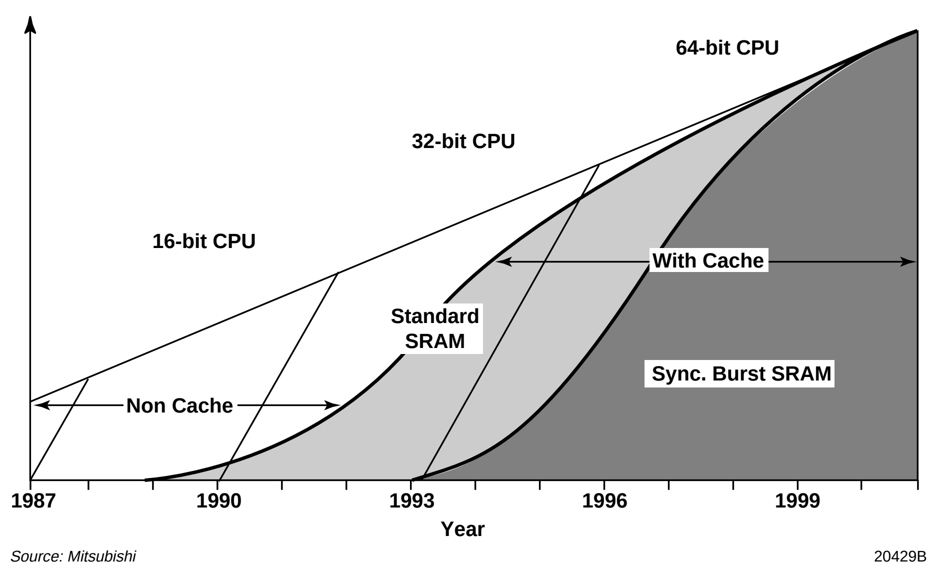
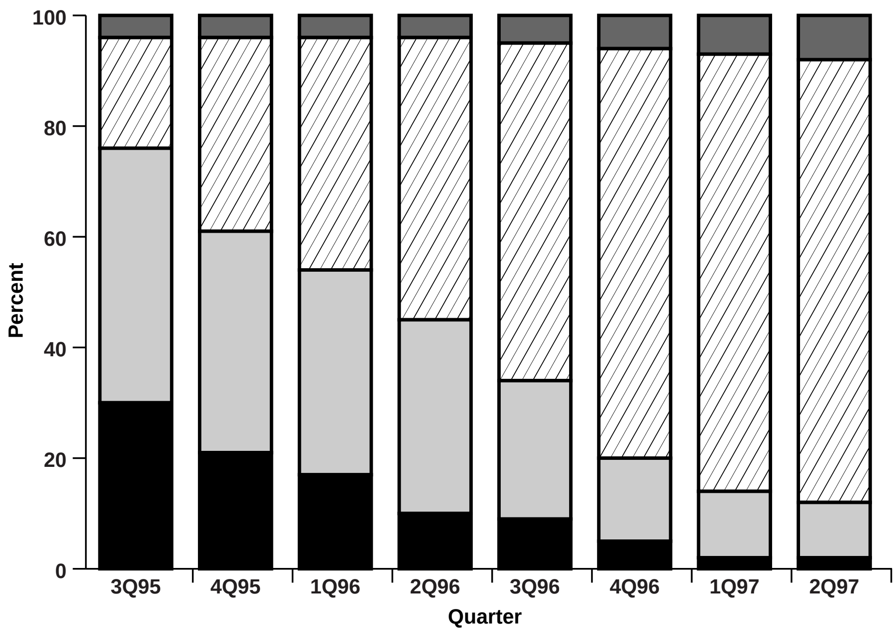


Figure 7-45. Trend of PC Cache SRAM Applications

Cache memory serves as temporary storage between the microprocessor's central processing unit (CPU) and the main system memory. Cache SRAMs are synchronous ICs. That is, their clock frequency is synchronized with the microprocessor's clock speed. Access times for synchronous SRAM used in PC cache applications are generally in the 8ns to 15ns range. With SRAM serving as cache memory in PCs, system performance can be increased by as much as 15 to 20 percent.

As shown in Figure 7-46, the market for cache SRAMs transitioned from the 32K-by-8 configuration to the 32K-by-32 configuration in 1996. Eight 256K SRAMs configured as 32K-by-8 are needed to build a 256Kbytes level-two cache system. With the 32K-by-32 configuration, only two chips are needed. ICE believes the average size of PC cache will jump from 256Kbytes to 512Kbytes in 1997, which requires four 32K-by-32 ICs.



	3Q95	4Q95	1Q96	2Q96	3Q96	4Q96	1Q97	2Q97
32K x 8, 5V	30	21	17	10	9	5	2	2
32K x 8, 3.3V	46	40	37	35	25	15	12	10
32K x 32	20	35	42	51	61	74	79	80
Other Synch.	4	4	4	4	5	6	7	8

Source: Samsung Semiconductor 20631B

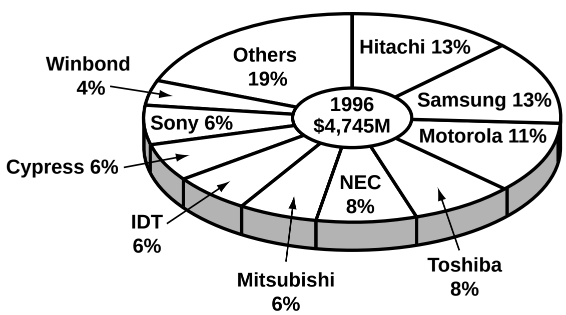
Figure 7-46. Cache SRAM Architecture Trends

SRAM Sales Leaders

Like the DRAM market category, the typical SRAM market usually swings from an extremely profitable market category to one that declines quickly. With these shifts, competitors enter and exit the market, making SRAM pricing fluctuate. Companies must be willing and prepared to endure difficult times that accompany bountiful years.

Market conditions that hit the SRAM market and its participants in 1996 eased somewhat in 1997 as supply and demand where more in balance.

Leading SRAM suppliers of 1995 and 1996 are shown in Figure 7-47. ICE shows that Hitachi surpassed Samsung by a slight margin in total SRAM sales during 1996. Samsung has not been content to be the world's leading DRAM supplier. It has worked aggressively to place itself among the leading suppliers of SRAM as well. After being the world's leading SRAM supplier in 1995, Samsung witnessed a decline in its 1996 SRAM sales.



Company	1996 Sales ($M)	1995 Sales ($M)	Percent Change
Hitachi	624	670	–7%
Samsung	623	850	–27%
Motorola	518	521	–1%
Toshiba	380	500	–24%
NEC	375	480	–22%
Mitsubishi	300	310	–3%
IDT	275	350	–21%
Cypress	270	300	–10%
Sony	265	300	–12%
Winbond	180	275	–35%
Others	935	1,517	–38%
Total	4,745	6,073	–22%

Source: ICE

20630D

Figure 7-47. SRAM Manufacturing Sales Leaders

NEC, Toshiba, and Mitsubishi saw an increase in SRAM orders in 1997 and anticipates such for 1998. These three firms were tagged by Intel to be among the initial primary suppliers of SRAM for that company's Pentium II processor.

SRAM consumption by region is shown in Figure 7-48. A large portion of SRAM consumption in North America was due to PC applications whereas SRAM consumption in Japan and Europe was based more on consumer electronics and telecommunications-related products. SRAM consumption continues to be led by North America.

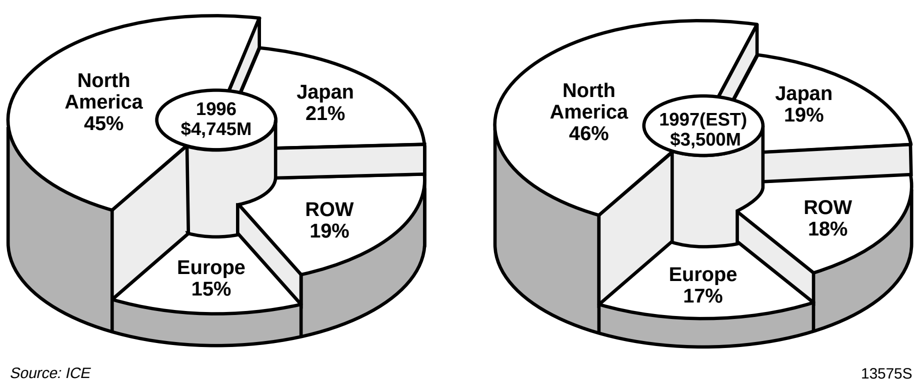


Figure 7-48. Worldwide MOS SRAM Consumption by Region

Japanese companies continue to hold the lead in terms of SRAM production through 1997 (Figure 7-49). With the strength of Hitachi, Toshiba, NEC, and Mitsubishi, ICE expects Japan to continue its solid share of worldwide SRAM production.

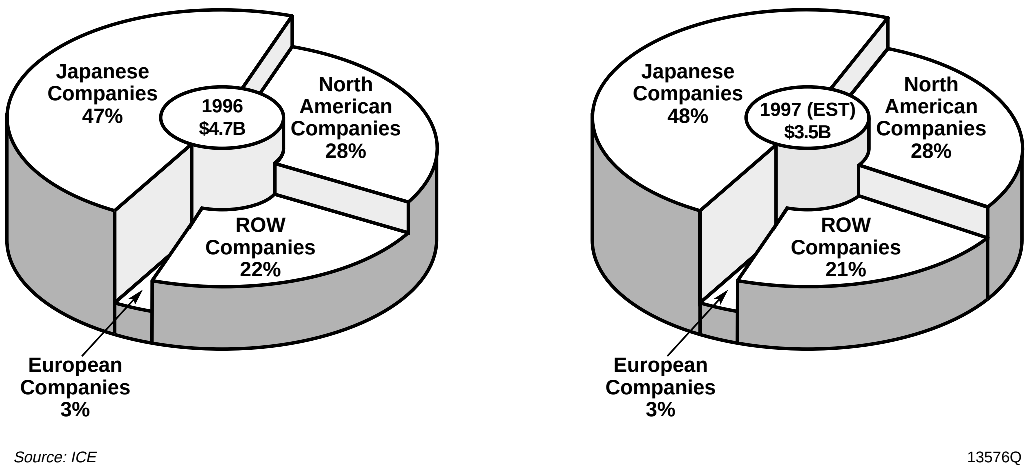


Figure 7-49. Worldwide MOS SRAM Production by Regional Companies

Select SRAM vendor highlights:

Cypress

The strategy at Cypress is to become the supplier with the broadest portfolio of SRAM products. To do so, it developed several slow-speed versions of its high-speed SRAMs. Using its RAM3 SRAM process, Cypress added SRAMs with high speed and low standby power to its product listing. Targeting battery-powered applications, Cypress also offered low-power, low-voltage SRAMs in 1997 manufactured using the same 0.5μm RAM3 process.

The company has placed a greater emphasis on its SRAM for embedded applications. It developed a six-transistor cell that it hopes will bring it to the forefront of application-specific designs while giving it an edge in standard SRAM as well as programmable logic ICs.

Cypress broadened its portfolio with the launch of a synchronous SRAM family designed specifically for networking applications. Based on a synchronous pipelined architecture designed to remove latency between read and write operations, the NoBL (No Bus Latency) ICs are claimed to improve memory bandwidth up to 133MHz.

Hitachi

Hitachi began production of two 1M synchronized high-speed SRAM models that are targeted for engineering workstations and servers containing SPARC processors. The SRAMs have maximum access times of 4ns and are packaged in a plastic ball grid array (BGA), Hitachi's first use of such packaging technology for a memory device.

Hitachi also began sample shipments of two new 4M synchronous fast SRAMs in early in 1997. The ICs are built as 128K-by-36 and 256K-by-18 configurations and target L2 cache in engineering workstations and servers. They possess access times of 7ns and are packaged in BGAs.

Citing a need for low-power, high-density SRAMs for power-efficient personal-access applications, such as smart phones and other hand-held products, Hitachi developed a series of slow-to-medium-speed 4M SRAMs that operate on 3.3V. Early in 1997, samples were available for $29. Volume production began late in 1997.

IBM

IBM jumped into the merchant SRAM market in 1995 when it introduced its 32K-by-32 pipeline burst SRAM for Pentium computers. However, following the dramatic drop in ASPs for these ICs in 1996, the company decided that it would target the high end of the SRAM market, which typically calls for access times below 10ns.

As a result, IBM introduced a lineup of ultra-fast SRAMs early in 1997 that it believes will help it avoid the pricing wars in the SRAM market. The ICs are intended exclusively for the RISC workstation market, rather than the PC market.

IBM's SRAMs, a 250MHz 1M with a 2.25ns access time and 225MHz 4M with a 2.5ns access time, were among the fastest offered in the first quarter of 1997. Unlike its competitors who use a BiCMOS process for their fast SRAMs, IBM used a pure CMOS process to manufacture its ICs. The 1M IC is built using 0.45μm technology while the 4M IC is built on a 0.4μm process.

Integrated Device Technology

IDT, a company that derives nearly half of its revenue from the SRAM market, was hit hard by the drop in SRAM ASPs in 1996. Pricing on several of its best selling commodity SRAMs dropped by more than 80 percent during 1996 and showed little sign of recovery into 1997.

Adding to IDT's financial strain was the significant increase in operating costs due to its new wafer fabrication plant in Hillsboro, Oregon, that came on-line in mid-1996. As a result of these financial strains, IDT adjusted its production schedules and staffing at each of its manufacturing facilities. In fact, citing a huge oversupply of product, IDT reduced its output of 256K SRAM in the second quarter of 1997 and announced it would not accept orders for its 32K-by-8 ICs until the second half of 1997.

To lessen its dependence on SRAM sales and to shift away from its reliance on the PC market, IDT announced it would aggressively target the networking and communications markets with its specialty memory products. The company introduced an SRAM architecture called zero bus turn-around (ZBT) that it claims will double the current switching speed of telecommunications and data communications operations. In the first quarter of 1997, it introduced a true dual-port SRAM that offers synchronous interfaces in both pipelined and flow-through styles. Further, the company said it would push to increase sales of its RISC microprocessor products for embedded control applications.

Mitsubishi

Mitsubishi began sample shipments of its 2M SRAM in an ultra-small, 8.0mm by 13.4mm, thin small outline package (TSOP) early in 1997. Designed for use as buffer memory in mobile phones and other portable applications, the device occupies the same size on a circuit board as a conventional 256K SRAM. The 2M SRAM operates at 3V and features an access time of 70ns.

Mosel-Vitelic

Mosel-Vitelic announced the first three members of its new SRAM family early in 1997 and several additional SRAM products through the year. Available in speeds ranging from 35ns to 70ns, the first three family members are 1M, 256K, and 64K ICs that operate at 5V and are targeted for PC and peripheral, networking, instrument, and telecommunication applications.

Motorola

Rather than sell ICs at a loss, Motorola revealed that in the second quarter of 1997, it deliberately limited the output of 256K SRAMs, due to a huge oversupply throughout the industry. Motorola stopped shipping the 32K-by-8 parts at the price customers were willing to pay, essentially removing itself from the market.

Nevertheless, to improve its competitive position, Motorola plans to introduce several new SRAM products that take advantage of the company's strength in digital signal processing and communications technologies. One of those ICs is the company's late-write fast SRAM that started shipping in 1M and 4M densities. These ICs are designed to operate at the same clock speeds as high-end microprocessors, initially running between 143MHz and 200MHz with a road map to 500MHz.

NEC

NEC developed a new 4M high-speed cache SRAM chip that was designed using a 0.25μm CMOS process. The 500MHz chip is based on an architecture known as the pre-fetch burst system, which boosts the chip's overall operating frequency while setting the internal SRAM frequency at 125MHz. The chip also incorporates circuitry that will cut in half the noise generated during high-speed data transfer between a central processing unit and secondary cache memory, and cuts power consumption to about one-eighth the level of conventional chips.

Paradigm

Paradigm is another supplier that was hit hard by the drop in SRAM prices. To return to profitability, the company revealed a plan to change its business model by becoming a fabless high-speed SRAM supplier. It sold its San Jose, California, wafer fabrication facility late in 1996 for $20 million. The company hopes that by being a fabless supplier, it will better withstand fluctuations in the market, reduce fixed manufacturing costs, and be provided with additional working capital.

Sharp

Although Sharp has been involved in the SRAM business for many years, it made it known that too much dependence on SRAM was not the best road to profits and sought ways to diversify its product line. In the short term, the company placed a greater emphasis on its flash memory technology and is engaged more in customer-specific products.

Toshiba

Toshiba continued to pursue the high-speed and low-voltage SRAM business when many others slowed or halted development efforts. Hoping to get a jump on its competition, the company announced several new high-speed cache SRAM chips in late in 1996 that will keep pace with next-generation microprocessors, including Intel's P6 with MMX technology.

Figure 7-50 summarizes the major SRAM applications through 1996 and into 2002. Though the SRAM market was soft in 1996 and 1997, bright spots for standard-speed SRAMs still exist. They include cellular and portable products, switches, routers, and hubs in telecommunications. DSP suppliers will ignite the demand for very fast asynchronous SRAM in modems. Phone handsets is another good market.

	1993 $3,295M	1996 $4,745M	2002 $6,916M (FCST)
PC/Office Automation	41%	48%	53%
Other Computer	20%	26%	28%
Industrial/Other	15%	11%	7%
Military	7%	3%	1%
Telecom	10%	7%	8%
Consumer	7%	5%	3%
Total	100%	100%	100%

Source: ICE 18785H

Figure 7-50. SRAM Applications by Percent Dollars

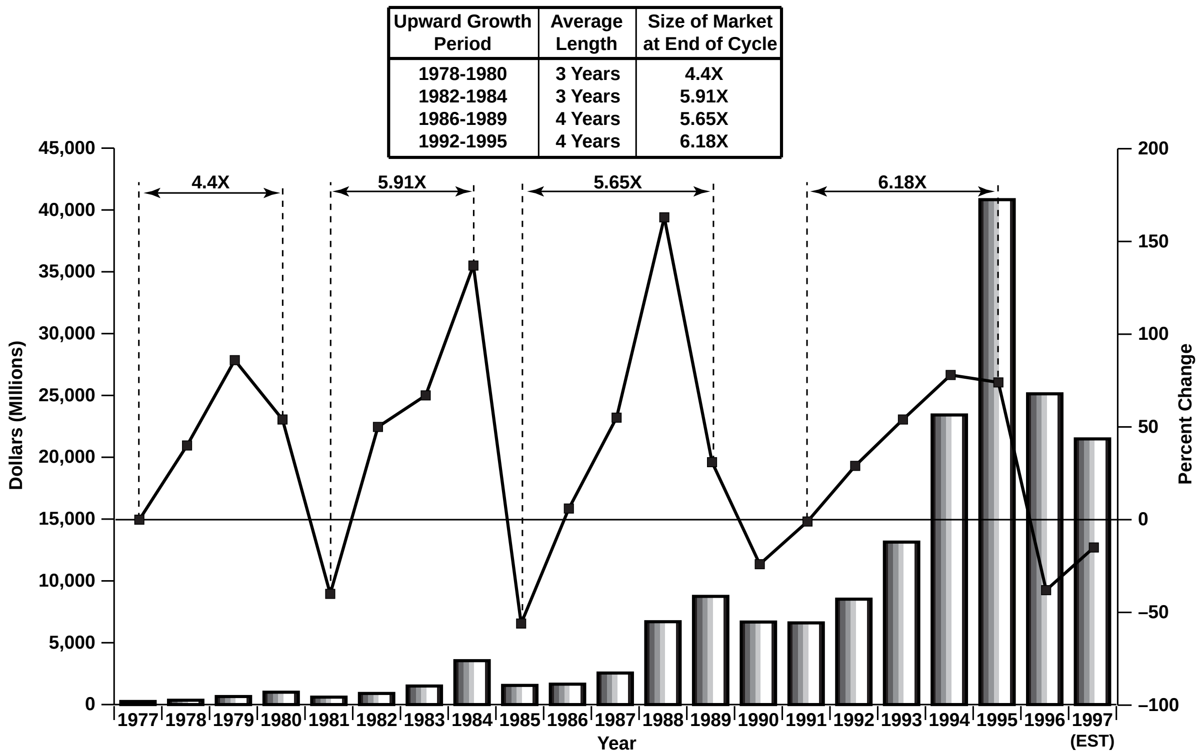
As higher-speed Pentium microprocessors migrate into the laptop environment, the market for low-power, high-speed cache SRAM should also grow. Already, several suppliers have positioned their product lines to meet the anticipated demand for this market.

The DRAM Market

The DRAM market has been through many up and down cycles as shown in Figure 7-51, but few suppliers recalled demand ever being as strong over such a long period as it was from 1992 through 1995. For the huge DRAM market to grow by such large percentages over a several year period was quite remarkable.

As the graph shows, good markets don't last forever; certainly, 1996 was evidence of that. Excess capacity and plunging average selling prices resulted in a 38 percent decline in the DRAM market. Fortunately, recent DRAM market results show that negative growth has lasted one or, at the most, two years, while positive growth periods have been three or four-plus years.

ICE estimates that the final data for 1997 will show another decline for the DRAM market. Although unit demand remained strong and bit volume continued to grow, excess capacity still played a large role in further eroding the average selling price. Rapid growth that the market experienced just a few years ago will be put off for another year.



Total Market ($M)	250	350	650	1,000	600	900	1,500	3,550	1,550	1,650	2,550	6,700	8,750	6,675	6,605	8,525	13,140	23,420	40,835	25,130	21,485
Percent Change	—	40%	86%	54%	−40%	50%	67%	137%	−56%	6%	55%	163%	31%	−24%	−1%	29%	54%	78%	74%	−38%	−15%

Source: ICE

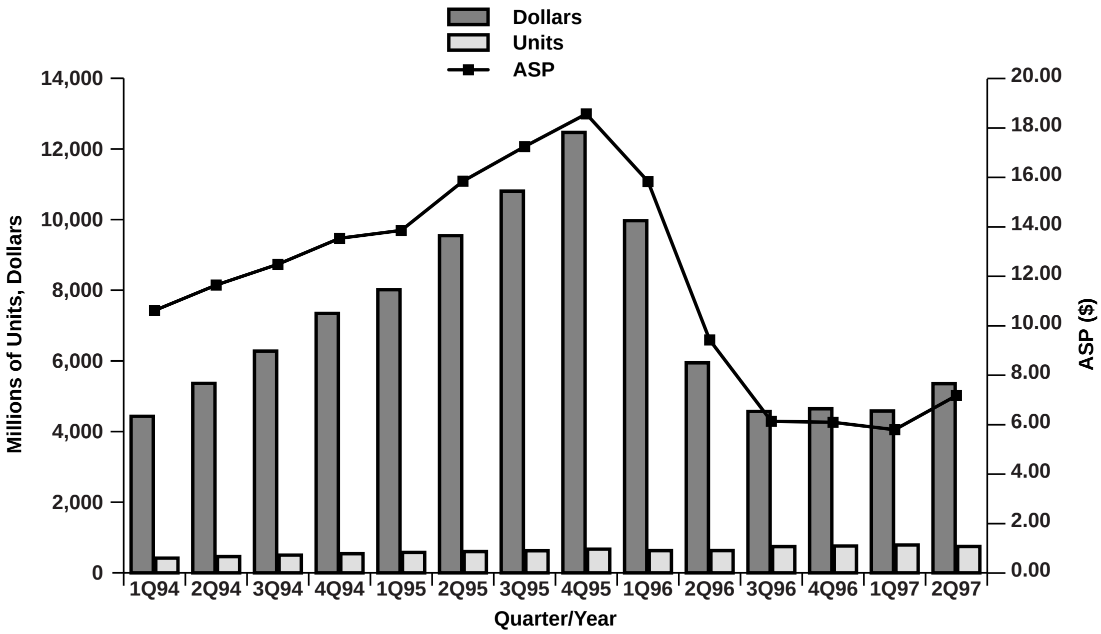
20870E

Figure 7-51. DRAM Market History

The recent DRAM market is detailed through mid-1997 by quarter in Figure 7-52. As shown in the chart, average selling prices fell steeply and quickly from their 1995 highs. As of mid-1997, however, it appeared that the worst of the decline was over and that the market was beginning to stabilize.

In the first quarter of 1992, the DRAM market accounted for 17 percent of the total IC market. By the fourth quarter of 1995, that percentage climbed to 35 percent of the total IC market (Figure 7-53). In that quarter, ASPs for 4M and 16M DRAMs peaked. Amazingly, in the span of just one year, the DRAM market declined to represent only 16 percent of the total IC market.

The total DRAM market for the period 1992 through 2002 is shown in Figure 7-54. ICE forecasts that it will take the DRAM market a few more years, until 2000, to be at least the size it was in 1995. From 1998 to 2002, ICE forecasts the DRAM market to have a cumulative average annual growth rate of 31 percent.



	1Q94	2Q94	3Q94	4Q94	1Q95	2Q95	3Q95	4Q95	1Q96	2Q96	3Q96	4Q96	1Q97	2Q97
Market ($M)	4,432	5,365	6,277	7,346	8,015	9,545	10,805	12,468	9,969	5,946	4,570	4,645	4,582	5,355
Units (M)	417	460	502	542	578	602	626	671	629	630	743	760	789	746
ASP ($)	10.63	11.66	12.50	13.55	13.87	15.86	17.26	18.58	15.85	9.44	6.15	6.11	5.81	7.19

Source: ICE 20881C

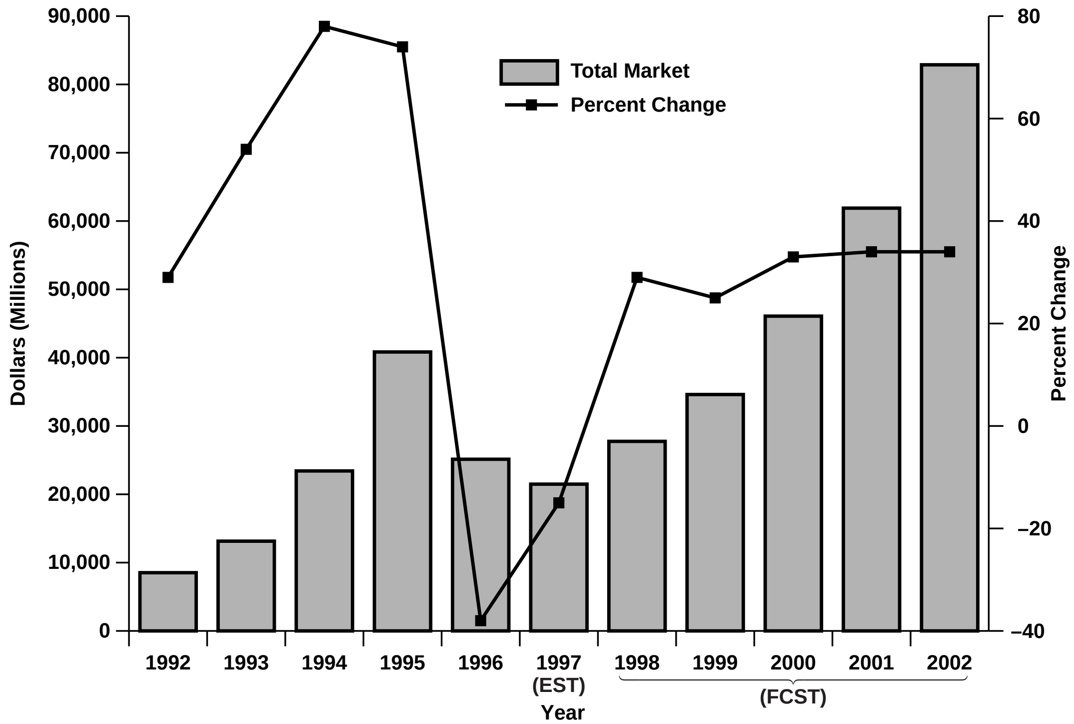
Figure 7-52. Quarterly DRAM Market Summary

SEGMENT	1992				1993				1994				1995				1996				1997	
	1Q	2Q	3Q	4Q	1Q	2Q	3Q	4Q	1Q	2Q	3Q	4Q	1Q	2Q	3Q	4Q	1Q	2Q	3Q	4Q	1Q	2Q
DRAM Market ($B)	1.9	2.0	2.2	2.4	2.6	3.0	3.6	4.0	4.4	5.4	6.3	7.3	8.0	9.6	10.8	12.4	10.1	6.0	4.4	4.6	4.6	5.4
DRAM Percent of IC Market (Dollars)	17%	17%	17%	17%	18%	19%	20%	22%	23%	25%	27%	29%	29%	31%	33%	35%	32%	22%	17%	16%	16%	18%

Source: WSTS 14520U

Figure 7-53. Quarterly DRAM Market Share (1992-1H97)

Figure 7-55 looks at unit shipments for key DRAM densities from 1991 through 1997. The 1M density followed a long, slow decline on its way out of the market spotlight after peaking in 1991. 4M shipments topped out in 1995. Despite the fact that PC manufacturers are moving to 16M ICs, huge numbers of 4M ICs were again shipped during 1996. Higher-density, 16M ICs are forecast to out-ship all other densities in 1997. ICE anticipates that 16M DRAM shipments will peak in 1998.



Total Market ($M)	8,525	13,140	23,420	40,833	25,130	21,485	27,750	34,605	46,080	61,890	82,870
Percent Change	29	54	74	74	–38	–15	29	25	33	34	34

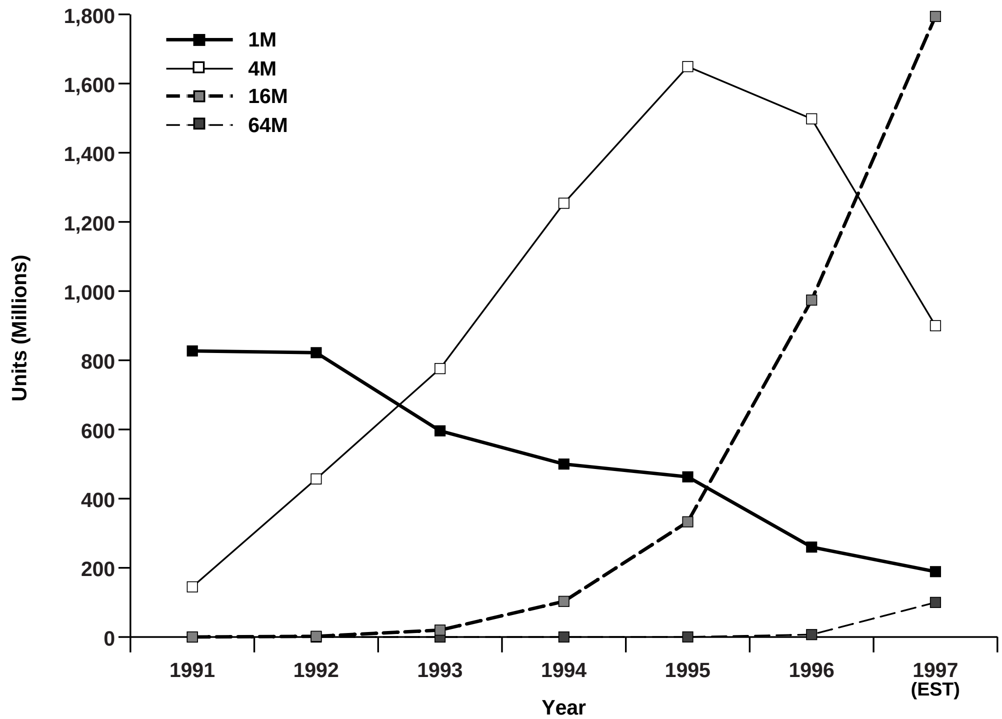
Source: ICE 18857F

Figure 7-54. DRAM Market Growth and Forecast

ASP trends for several DRAM densities are provided in Figure 7-56. It is interesting to note that demand at the 4M level kept ASPs elevated and essentially flat for four years, from 1992 through 1995. As witnessed in the 1M generation during 1989 through 1990, the 4M generation during 1995 through 1996, and the 16M generation from 1996 through 1997, when ASPs fall, they fall fast and far.

As Figure 7-57 shows, the decrease in 4M and 16M average selling prices during 1996 and into 1997 was anything but gradual. 4M DRAM ASPs fell 78 percent and 16M DRAM ASPs 81 percent during 1996.

64M DRAM ASPs followed the same path as 4M and 16M generations: At the beginning of 1996, 64M DRAMs sold for $250. By the end of the year, they sold for $90. In the first quarter of 1997, these ICs were offered for $60, and by mid-1997 the price had dropped to less than $40. In the second quarter of 1997, there were more 64M DRAMs than the niche market of high-performance workstations could absorb.



1M	827	822	596	500	463	260	189
4M	145	457	776	1,254	1,649	1,498	900
16M	0.1	2	20	103	333	974	1,794
64M	—	—	—	0.11	0.25	7	100

Source: ICE 20009F

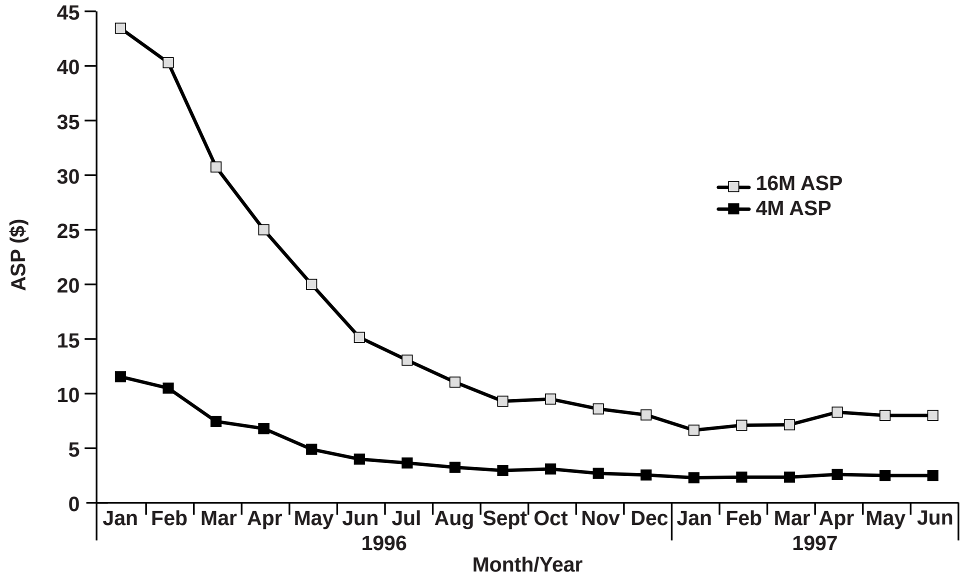
Figure 7-55. DRAM Unit Shipments by IC Density

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997 (EST)
64K	3.84	1.92	1.28	0.90	1.09	1.47	1.59	1.25	1.33	1.45	—	—	—	—	—
256K	51.20	21.76	3.58	2.25	2.41	3.84	3.58	2.69	1.80	1.70	1.80	2.15	2.00	1.95	2.00
1M	—	—	100.00	35.00	25.00	17.00	12.00	5.54	4.50	3.01	3.10	3.60	3.00	2.85	2.56
4M	—	—	—	—	—	—	124.00	36.43	16.05	11.72	11.91	12.00	12.85	5.31	2.42
16M	—	—	—	—	—	—	—	—	275.00	205.00	93.00	61.85	54.41	16.11	7.60
64M	—	—	—	—	—	—	—	—	—	—	—	575.00	225.00	100.35	51.54

Source: ICE 16876N

Figure 7-56. DRAM ASP Trends in Dollars

Additional fab capacity and continued demand will keep pricing pressure on all densities of DRAM well into 1998. The DRAM buyers' market will continue at least until mid year.



4M ASP ($)	11.55	10.5	7.45	6.80	4.90	4.00	3.65	3.25	2.96	3.10	2.70	2.55	2.30	2.35	2.35	2.60	2.50	2.50
16M ASP ($)	43.45	40.30	30.75	25.00	20.00	15.15	13.06	11.05	9.03	9.50	8.60	8.05	6.65	7.10	7.15	8.30	8.00	8.00

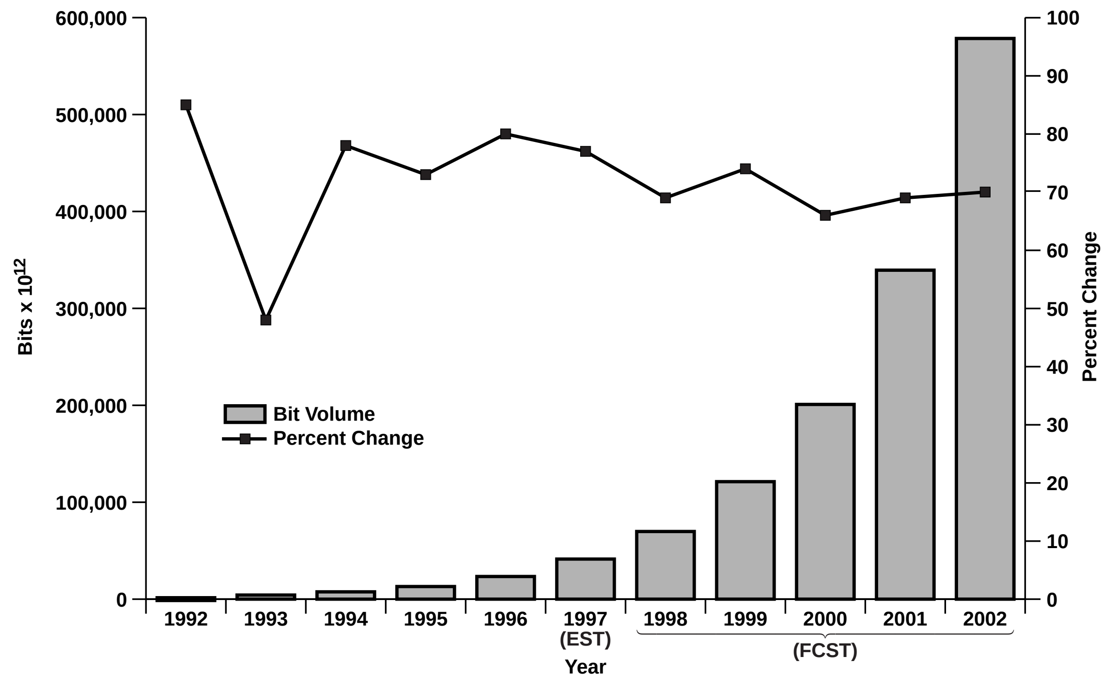
Source: ICE 22768A

Figure 7-57. DRAM ASPs Plummet: 1996-1997

DRAM bit volume is provided in Figure 7-58. The DRAM bit volume forecast provides a clear indication that the DRAM market will remain vibrant through 2002. There will be demand for more bits. Annual bit volume growth from 1997 through 2002 is forecast to average 69 percent, with 64M DRAMs serving as the backbone for that growth.

A comparison of annual DRAM bit volume and market growth (Figure 7-59) shows that DRAM pricing is very dependent on wafer fabrication capacity. DRAM bit volume increased more than 70 percent each year from 1994 through 1997. While bit volume remained strong, market growth fluctuated greatly. Overcapacity in 1996 forced ASPs downward and the market collapsed. In 1997, bit volume remained strong, but ICE believes there will continue to be an excess supply of DRAM fab capacity, which, in turn, will keep ASPs from rising and result in the 1997 market showing a final decline of another -15 percent.

Figure 7-60 summarizes the DRAM market size, unit shipments, and ASPs for five of the most popular DRAM densities. Although it shipped many more units than any other density, 4M DRAMs lost their market dominance to the 16M density in 1996. Despite the fact that DRAM unit shipments increased 12 percent in 1996, DRAM ASPs declined 45 percent and the overall market slid 38 percent. ICE estimates that 1997 has repeated this scenario: unit shipments up an estimated nine percent, overall ASP down 21 percent, and overall market off 15 percent.



Total Bit Volume	2,864	4,243	7,536	13,019	23,370	41,363	69,797	121,219	200,896	339,411	578,476
Percent Change	85	48	78	73	80	77	69	74	66	69	70

Source: ICE

20894D

Figure 7-58. DRAM Bit Volume Growth and Forecast

As was the case through the first years of the 1990s, DRAM consumption continues to be led by the North American region (Figure 7-61) with an estimated 37 percent of the 1997 market. Consumption of DRAMs in the ROW region, which is mostly Asia-Pacific countries excluding Japan, first surpassed Japan's consumption in 1992. Strong consumer electronic consumption in the developing economies of this region along with PC-related work will continue to increase consumption.

Although their market share has dropped considerably since 1991, DRAM production remained firmly in the hands of Japanese companies (Figure 7-62). In 1997, market share of U.S. DRAM suppliers, namely Micron, Texas Instruments, and IBM, is estimated to have increased as they produce more 16M ICs. This market was left to them after Japanese and Korean suppliers cut back production and switched over to what they believed would be more profitable 64M chips.

The gain in market share by U.S. suppliers can also be attributed to the aggressive transition made to 0.35μm wafer processing. Not counting Motorola, which said it was exiting the DRAM market, the three big U.S. DRAM suppliers could see their market share rise to 20 percent or more of the global market by the end of 1997.

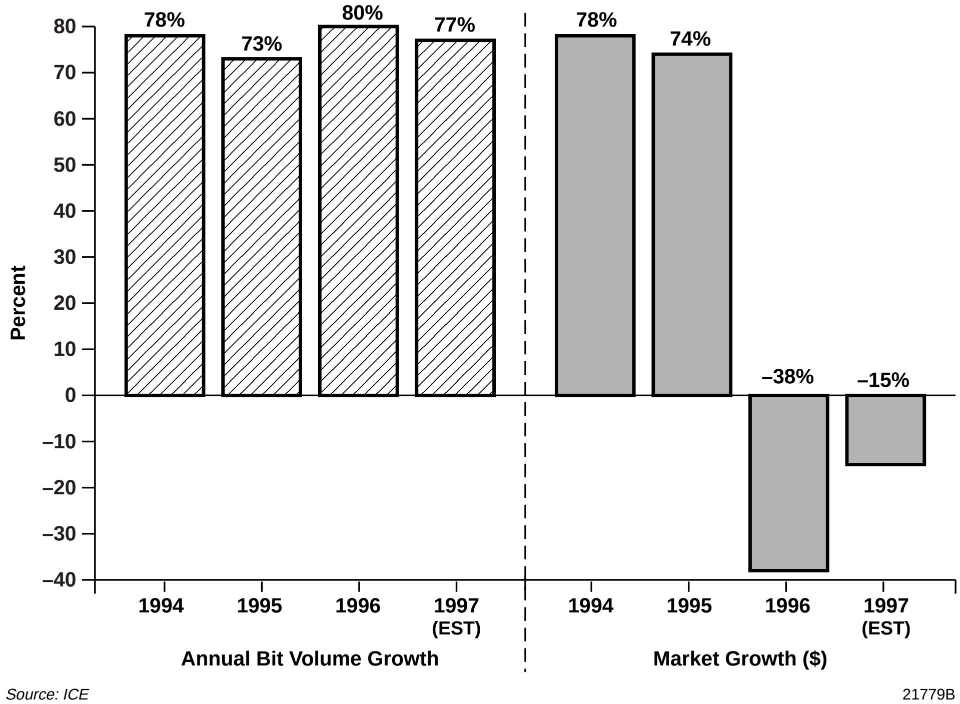


Figure 7-59. DRAMs – A Supply-Driven Industry

	1994			1995			1996			1997 (EST)		
	ASP ($)	UNITS (M)	MARKET ($M)	ASP ($)	UNITS (M)	MARKET ($M)	ASP ($)	UNITS (M)	MARKET ($M)	ASP ($)	UNITS (M)	MARKET ($M)
256K	2.15	64	139	2.00	32	65	1.95	23	44	2.00	15	30
1M	3.60	500	1,800	3.00	463	1,388	2.85	260	740	2.56	189	484
4M	12.00	1,254	15,048	12.85	1,649	21,190	5.31	1,498	7,955	2.42	900	2,181
16M	61.85	103	6,371	54.41	333	18,135	16.11	974	15,691	7.60	1,794	13,630
64M	575.00	0.1	62	225.00	0.25	57	100.35	7	700	51.54	100	5,160
TOTAL	12.19	1,921	23,420	16.48	2,477	40,835	9.10	2,762	25,130	7.16	2,998	21,485

Source: ICE 14749Q

Figure 7-60. DRAM Market Summary

Shown in Figure 7-63 are the leading DRAM suppliers for 1996. As noted in the chart, no supplier was spared from a huge decline in DRAM revenue. Texas Instruments' DRAM sales were down 50 percent in 1996, while Samsung managed to control its lose to a 26 percent decline in its DRAM sales for 1996. For most, the decline in DRAM revenue nearly matched that of the DRAM market itself, a –38 percent.

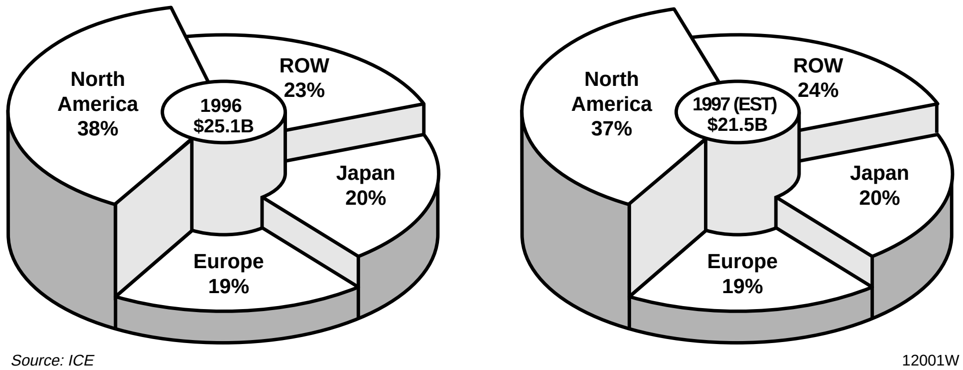


Figure 7-61. Worldwide DRAM Consumption by Region

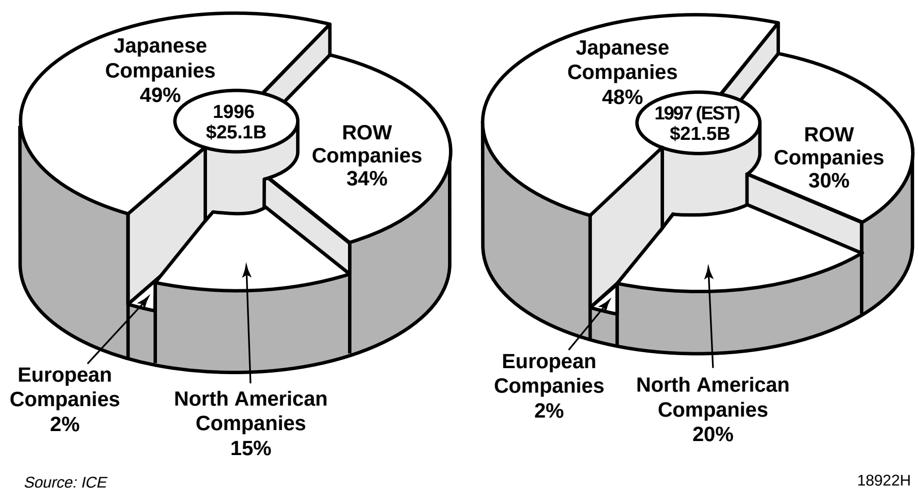


Figure 7-62. Worldwide DRAM Production by Regional Companies

Topping the list of DRAM suppliers was Samsung. Although its DRAM sales were down 26 percent in 1996, it easily remained the world's leading supplier of DRAMs.

One reason why the top ten players accounted for the overwhelming 93 percent of sales in 1996 was that many marginal suppliers fled the market or switched to producing other ICs once DRAM profit margins became extremely lean. While this might have been a difficult decision for some suppliers, large DRAM suppliers could afford to ship more DRAM units in 1996, yet come up with about one to two billion dollars less in revenue. For the small or marginal DRAM supplier, a proportionate reduction in revenue would have been much more devastating.

Company	1996 Sales ($M)	1995 Sales ($M)	1996/1995 Percent Change
Samsung	4,805	6,462	–26
NEC	3,175	4,740	–33
Hitachi	2,805	4,439	–37
Hyundai	2,300	3,500	–34
Toshiba	2,235	3,725	–40
LG Semicon	2,005	3,005	–33
TI	1,600	3,200	–50
Micron	1,575	2,485	–37
Mitsubishi	1,400	2,215	–37
Fujitsu	1,350	2,065	–35
Others	1,880	4,999	–62
Total	25,130	40,835	–38

Source: ICE 20875E

Figure 7-63. 1996 DRAM Manufacturing Sales Leaders

The top 4M DRAM suppliers in 1996 are shown in Figure 7-64. Revenue generated by 4M DRAM suppliers dropped sharply in 1996. Though the luster faded from the 4M market, PC OEMs and consumers wanting to upgrade their system memory took advantage of the long-overdue low prices and filled their computers with additional memory, which helped extend the demand for 4M ICs through 1996.

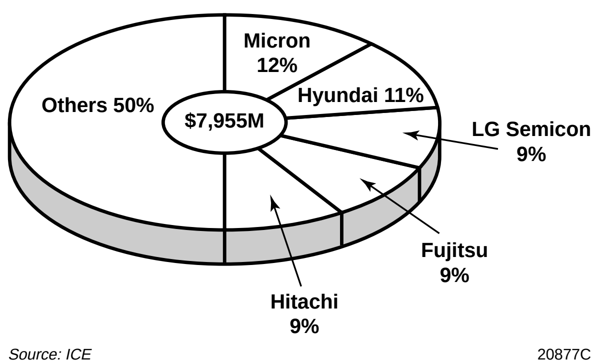


Figure 7-64. 1996 Leading 4M DRAM Suppliers by Percent Dollars

Figure 7-65 shows the leading 16M DRAM suppliers for 1996. Samsung established an early lead in this market category and maintained its leadership as the market matured. However, a rapid decline in 16M ASPs led several Korean and Japanese suppliers away from this market in search of more lucrative profits in the 64M market.

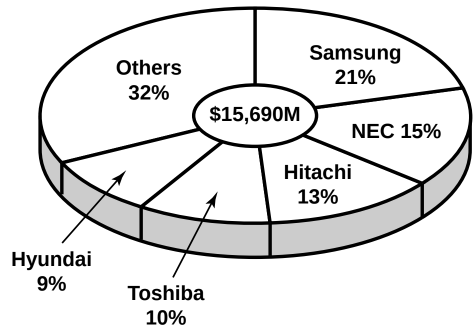


Figure 7-65. 1996 Leading 16M DRAM Suppliers by Percent Dollars

Due to the rapid decline in ASPs, Korean DRAM suppliers elected to stop production of 16M ICs on their manufacturing lines for one week beginning the last week of July, cutting monthly output by 20 percent. No Japanese supplier committed to the same policy. Through the first half of 1997, 16M prices fell so far that the business was only marginally profitable to most suppliers and threatened their ability to invest in next-generation products.

To cut production costs, several Taiwan-based DRAM suppliers shifted their 16M production lines to 0.35μm process technology in the second quarter of 1997. Among the companies moving to finer process geometry were TI-Acer, Vanguard International, United Semiconductor, Mosel-Vitelic, and Powerchip Semiconductor.

In another cost-cutting move, Fujitsu accelerated its drive to shrink 16M DRAM size to lower its production costs. The company currently manufactures 60mm-square chips using a 0.36μm process. It hopes to reduce that to a 40mm-square chip using a 0.28μm process by early 1998.

Company and product highlights surrounding the 16M DRAM market are listed below and in Figure 7-66.

Fujitsu

Fujitsu announced that it would rely on Taiwan Semiconductor Manufacturing Company (TSMC in Hsinchi, Taiwan) for as much as 40 percent of its 16M DRAM production. Fujitsu plans to lower its own 16M production by 15 percent and concentrate its own resources on 64M production.

- Samsung, Hyundai, and LG Semicon decided to trim their output of 16M DRAMs. Beginning with the last week of July 1997, they halted their production lines for one week to cut monthly output by 20 percent. Japanese rivals did not announce any plans to follow the Koreans, but may feel increased pressure to do so.
- Three U.S. DRAM makers—Micron, Texas Instruments, and IBM snapped up 16M business at the same time that South Korean and Japanese suppliers cut back production in order to produce more profitable 64M chips. The result was that Asian DRAM suppliers lost significant market share—if only temporarily.
- Micron manufactured 16M DRAMs at the rate of 30 million per month in 3Q97.
- Volume pricing of 16M DRAMs fell to less than $7.00 in late 2Q97. Spot pricing moved close to $6.00.

Source: ICE 22769

Figure 7-66. 16M DRAM Highlights Through 1997

Hitachi

In response to the glut in the DRAM market, Hitachi underwent one of the most aggressive product restructurings of any Japanese semiconductor maker. It shifted its production of 16M DRAMs in Kofu, Japan, to flash memory ICs. That move followed the news early in 1997 that Hitachi canceled a joint-venture DRAM fab with LG Semicon in Malaysia and an announcement in December, 1996 that it would re-open a closed 16M DRAM fab to make microprocessors instead.

Of the 16M DRAM ICs Hitachi offers, approximately 40 percent are supplied by LG Semicon of Korea.

Intel

Intel announced in first quarter of 1997 that it took an equity position in a $1.3 billion memory fabrication facility being built in Austin, Texas, by Samsung. In exchange for its equity position, Intel will be guaranteed an undisclosed number of wafers from the facility, which is expected to produce 16M and 64M DRAMs using sub-0.5μm technology.

Mitsubishi

Mitsubishi officials displayed a 16M IC fabricated using silicon-on-insulator (SOI) wafers. The company claims that its new 16M DRAM on SOI, slated for sampling in 1998, has the access speed of a 64M device built on a standard silicon wafer. It should be noted that SOI starting wafers are three to five times more costly than standard silicon wafers.

NEC

Although unit demand is strong, NEC believes the market for 16M DRAMs will have a hard time recovering from its level in the first half of 1997. As a result, NEC announced it would trim 16M DRAM output 20 percent by March 1998.

Oki

Oki invested $700 million to build a 16M and 64M DRAM production facility in the U.S. The 0.35μm 200mm wafer processing line will be located in Oregon.

Toshiba

Toshiba off-loaded a small portion of its 16M DRAM production to Taiwan-based Winbond, which also expects to make 64M DRAM for Toshiba. Additionally, the company lowered its own 16M DRAM output by 15 percent in the first quarter of 1997.

64M DRAM

64M DRAMs arrived on the market in volume in the first half of 1996, at a time when overall DRAM prices were dropping quickly. With hopes of capturing some of the hefty profits that eluded the 16M generation, several, mostly Asian, companies disclosed plans to ramp up 64M DRAM production.

However, because so many companies jumped into the lucrative 64M DRAM market, an oversupply situation was created, which defeated DRAM manufacturers' goals of producing chips with higher profit margins. Once again, DRAM suppliers deprived each other of the high margins they came to expect in the growth stage of a new DRAM product.

The rapid drop in average selling price is premature for this relatively new-generation of DRAM. From a pricing standpoint, 64M ICs should continue to decline through the end of 1997. However, a surge in Christmas orders may send prices for these ICs back up. In third quarter of 1997, prices for 64M ICs had dropped below the $40 level. Looking forward, the price-per-bit crossover point for 64M ICs with 16M ICs is on track to occur by early 1998.

Through the first half of 1997, the highest-volume applications for 64M DRAM remained PC servers and workstations. By the end of 1997, there may be a transition to some very high-end PCs. Despite this rather limited market, 64M ICs keep coming. Figure 6-67 shows a sample of 64M DRAM suppliers and their 1997 year-end production targets.

Company	2Q97	1997 Year End Target
Fujitsu	100,000	1,500,000
Hitachi	500,000	1,500,000
Hyundai	300,000	1,000,000
LG Semicon	300,000	1,000,000
Mitsubishi	700,000	2,000,000
NEC	2,000,000	3,500,000
Oki	100,000	600,000
Samsung	2,000,000	4,000,000
Toshiba	100,000	1,000,000

Source: ICE 22683A

Figure 7-67. 64M DRAM Manufacturing Monthly Output Targets

Additional highlights from the 64M DRAM market are shown below:

Fujitsu

Fujitsu moved its 64M DRAM production schedule forward. It decided to boost output to 1.5 million units per month by the end of 1997. It plans to cancel 16M DRAM production at its Gresham, Oregon, plant and instead launch 64M fabrication there.

Hitachi

Hitachi and the Singapore government formed a joint venture that will invest nearly $1 billion to build a 64M DRAM fab in Singapore. The facility will have the capacity to produce 20,000 200mm wafers per month using 0.35µm process technology. Production is slated to begin in the second half of 1998.

Mitsubishi

Mitsubishi developed its 64M synchronous DRAM chip that operates at a clock speed of 125MHz. It made the device available in the second half of 1997. Designed using a 0.3µm process, the low-power chip reduces 3.3V supplied externally to 2.5V internally.

Samsung

Samsung began volume production of 64M SDRAMs early in 1997. The company, a leader in next-generation DRAM development and manufacture, had difficulty accelerating the market for 64M DRAM due to overcapacity (and very low prices) for 16M ICs. It hopes to achieve a crossover point with 16M DRAM in late-1997, but realizes that this could be a difficult goal to achieve.

Taiwan Semiconductor Manufacturing

TSMC, Taiwan's largest chip maker, launched production of 64M DRAM in the second half of 1997, and planned to expand its wafer fabrication facility for additional production capacity.

Toshiba

On the heels of Intel's equity investment announcement with Samsung, Toshiba started negotiations with Samsung about acquiring a 20 percent stake in the Korean company's new Austin, Texas, DRAM wafer fabrication facility. If the deal goes through, Toshiba would get 20 percent of the 64M DRAMs produced at the Samsung fab.

Additionally, Toshiba began shipments of its second-generation 64M SDRAM in the third quarter of 1997. The 3.3V part measures 79.4mm^2, less than half the size of first-generation chips. Volume production is slated to begin in the forth quarter of 1997.

United Microelectronics

UMC, the second largest IC producer in Taiwan, planned to enter the 64M DRAM market in late in 1997.

Winbond

Winbond, plans to enter the 64M DRAM market in early 1998 with technology licensed from Toshiba.

A 128M DRAM

In the second quarter of 1997, at least five DRAM suppliers declared their intentions to manufacturer 128M DRAMs in order to delay the heavy costs associated with developing 256M ICs. Further, this group believes they can provide customers with a cost-effective means to meet growing system memory requirements.

Rather than jumping from the 64M generation straight to 256M ICs, Samsung, NEC, Texas Instruments, Fujitsu, Hyundai, and a handful of other leading DRAM suppliers planned a generational half-step with the 128M DRAM. Driving the move to the 128M density is industry concern over having to invest in 256M DRAM technology after suffering through tremendous DRAM price declines during the past year. Also, computer manufacturers, including IBM and Compaq, called for a transitional density to satisfy memory granularity issues as PC main memory swells to 64Mbytes.

NEC, Hitachi, Toshiba, and Fujitsu announced their intentions to launch volume production of 128M DRAMs in 1998. Hitachi intends to initially offer a stacked ICs, which puts two 64M chips together. If demand picks up, the company will commercialize a 128M chip.

THE 256M DRAM

256M DRAMs have been developed by a few manufacturers. NEC shipped samples of its 256M DRAM in 1996. The company initially forecasted that commercial production of the IC would begin in 1998. That date has since been pushed out to late 1999 or 2000.

Samsung sampled its 256M DRAM in 1996. Meanwhile, Fujitsu announced that it developed a 256M SDRAM and plans to start sample shipments in 1998. Its chip was designed using a 0.28μm process.

Toshiba also plans to launch 256M DRAM production in 1998. It plans to make its ICs at its new facility in Oita using 0.25μm process technology.

Gigabit DRAM

It will be several years before they can be purchased, but for memory manufacturers, the era of the gigabit DRAM is at hand. In the fourth quarter of 1996, Samsung announced it fabricated a one gigabit (1G) DRAM on laboratory silicon, claiming to be the first company to do so. Then, in the second quarter of 1997, it announced the first fully working 1G DRAM at the annual VLSI Technology Symposium. The company invested more than $250 million to develop this IC. Built using 0.18μm technology, the chip is 569mm^2. Critical layers of commercial 1G DRAM are expected to be fabricated with 0.13μm technology, eventually reducing the chip size to 400mm^2. Samsung's gigabit-scale DRAM roadmap through the 16G generation is shown in Figure 7-68.

	1G	4G	16G
First Production	2001	2004	2007
First Working Die	1998	1999	2002
Design Rule (Microns)	0.18	0.13	0.10
Required Overlay (nm)	50	40	20
Die Size (sq. mm)	780	938	1,144
Stepper Field Size (mm)	26 x 30	26 x 36	26 x 44

Source: Samsung/1996 Crymer Seminar 22685

Figure 7-68. Samsung's Gigabit DRAM Roadmap

NEC is also planning to bring 1G DRAM to market. The Japanese company stated it developed a prototype and was expected to ship evaluation ICs to customers in 1997.

Memory powerhouses Hitachi, Mitsubishi, and Texas Instruments announced in the first quarter of 1997 that they would cooperate in the development of 1G DRAM. The immediate purpose of the venture was to share technology, research and development of process and design capabilities, and the production of prototype chips.

The venture will compete with a joint-development team involving four of the world's leading IC manufacturers—IBM, Motorola, Siemens, and Toshiba. Together, the companies pooled their considerable resources in an effort to design, develop, and bring 1G DRAM to market, if only in sample form, by 2000.

It should be noted that Toshiba, in the second quarter of 1997, reviewed its role in the venture and recalled to Japan 70 engineers working on the project. The company claimed there was no break in the relationship, but that it had to re-examine its 1G DRAM effort before further committing to the venture.

At the next level, NEC reportedly built a prototype 4G DRAM IC that measured 986mm^2, approximately one-and-a-quarter inches on a side. For comparison, a 1995 or 1996 generation 16M DRAM measured about 100mm^2. NEC adopted an advanced 0.15μm CMOS process to build its 4G device.

The 4G DRAM can store 47 minutes of full-motion video, six hours of audio data, or the complete works of William Shakespeare 64 times over. NEC, which spent more than $160 million on development, plans to invest another $645 million before mass production is launched. Sample shipments are slated for 2000.

Also, Hyundai started on the long road to 4G DRAM output. It signed a joint development agreement with Eaton Semiconductor Equipment Operations to develop the tools needed to make 4G DRAM ICs. The company stated that it did not expect 4G DRAMs to be available until 2010 when it will implement 0.07μm process technology.

DRAM Price-Per-Bit Trends

Figure 7-69 lists the overall DRAM price-per-bit values for 1985 through estimated 1997. Increased competition, excess capacity, and a slowing market, which results in lower DRAM ASPs, may easily cause price-per-bit drops near 50 percent or more as they did in 1985, 1990, 1996 and 1997. On the other hand, when demand outstrips supply, the average price-per-bit remains flat or even increases as it did in 1987, 1988 and 1993 through 1995. The drop in 4M and 16M DRAM ASPs due to overcapacity was the biggest contributing factor that lowered the total DRAM price per bit in 1996. The drop in 64M ASPs continued to contribute to the significantly lower DRAM price per bit in 1997.

Year	Price Per Bit (Millicents)	Percent Change From Previous Year
1985	1.61	–70
1986	1.00	–38
1987	1.08	8*
1988	1.57	40
1989	1.24	–21
1990	0.66	–47
1991	0.43	–35
1992	0.30	–30
1993	0.31	3
1994	0.31	—
1995	0.31	—
1996	0.11	–65
1997(EST)	0.052	–53

*First time ever increase

Source: ICE

13346U

Figure 7-69. DRAM Price-Per-Bit Comparison

DRAM price-per-bit trends are plotted in Figure 7-70 for densities ranging from 64K to 64M. 4M DRAMs became price competitive with 1M DRAMs in 1991 and enjoyed a long period of being the best value for the money. However, as history showed in the 256K and 1M, and now in the 4M and 16M, generations, when the market moves on to the next density, the price per bit drops sharply.

A pricing curve for DRAM memory is shown in Figure 7-71. The traditional IC learning curve with a 68 percent slope is plotted along with the historical and forecasted annual DRAM price-per-bit figures. Following three years above the slope indicating strong demand and weak supply, the DRAM price-per-bit corrected itself and started moving toward the slope due to excess capacity and price erosion in 1996. ICE estimates that 1997's results will end below the slope.

DRAM Architectures

Early microprocessor-based systems were introduced with clock speeds of one million cycles per second or 1MHz. Today, microprocessors in desktop PCs are 200MHz and faster, at least a 200-times improvement. Early DRAMs had access cycle times, the time required for the DRAM to supply data back to the microprocessor, of 250ns. The fastest DRAM units today are about 50ns, a five-fold improvement.

To face this speed discrepancy, DRAMs have branched into many subcategories. Each features a variation of system interface circuitry with the intent of enhancing performance. Furthermore, each design attempts to answer needs of specific applications. Several current DRAM offerings are shown in Figure 7-72.

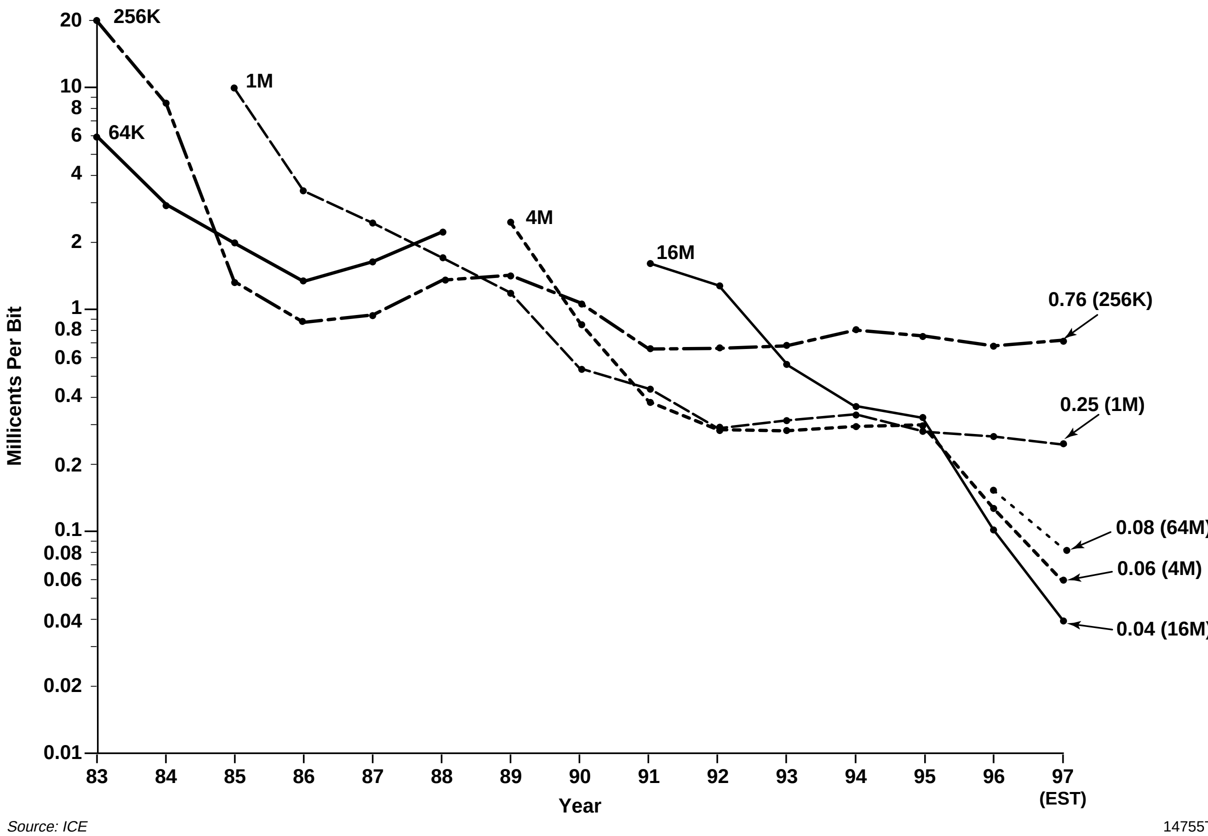


Figure 7-70. DRAM Price-Per-Bit Trends

Figure 7-73 lists many suppliers and the DRAM architectures they provide. Three trends stand out as creating the most interest in the market. These include synchronous DRAM, Rambus DRAM, and SyncLink DRAM.

Synchronous DRAM

As the name implies, synchronous DRAM (SDRAM) work in synch with the microprocessor clock to retrieve data stored in memory more quickly than an asynchronous, fast-page mode DRAM. Manufacturers, including Hitachi, Texas Instruments, and several other leading DRAM suppliers began producing SDRAM ICs late in 1996.

The transition from extended data out (EDO) DRAM to SDRAM may be a bumpy one for suppliers and buyers alike. For suppliers, converting today's DRAM fabs to manufacture SDRAMs has not been smooth, which may delay the supply of parts just as demand is increasing. Meanwhile, some memory IC buyers indicated that initial qualification of SDRAM suppliers was difficult, apparently since specifications varied from supplier to supplier. These are problems that will undoubtedly be resolved with time, but which initially made for a less-than-ideal transition to SDRAM.

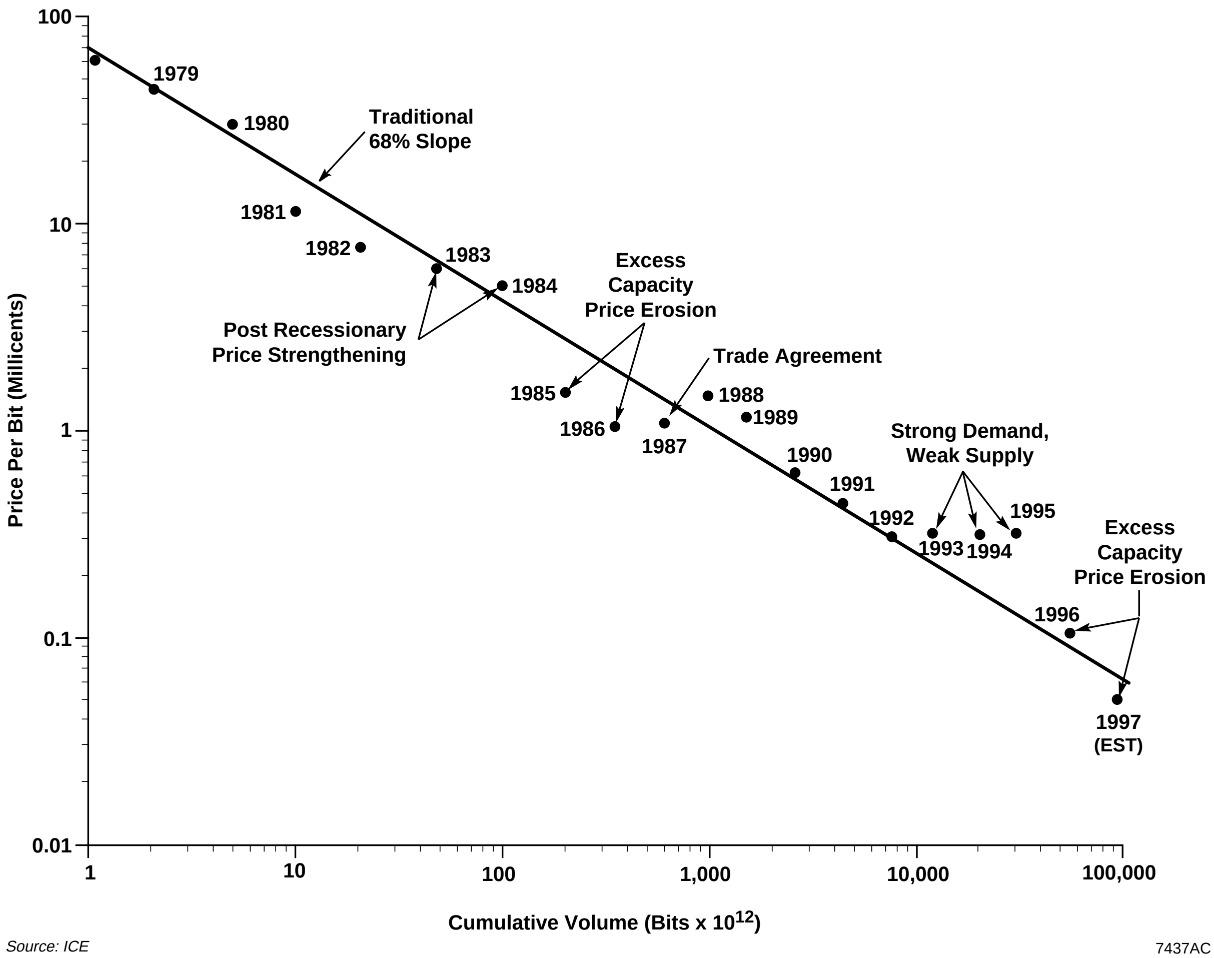


Figure 7-71. Historic Price Curve for DRAM

Toshiba's schedule to increase SDRAM production is shown in Figure 7-74. The company, in the second quarter of 1997, introduced a 64M SDRAM family that featured three organizations and speeds to 125MHz. Meanwhile, Hitachi will have shipped 50 percent of its DRAMs in synchronous form by the end of 1997. Fujitsu and NEC expect 70 percent of all their DRAMs will be synchronous by March 1998.

Samsung, the world's leading memory IC supplier, is another company that aggressively moved into SDRAM production. Its outlook of the PC memory technology transition is shown in Figure 7-75. Samsung noted that U.S. OEMs consumed an equal value of its 16M and 64M SDRAMs in the second quarter of 1997.

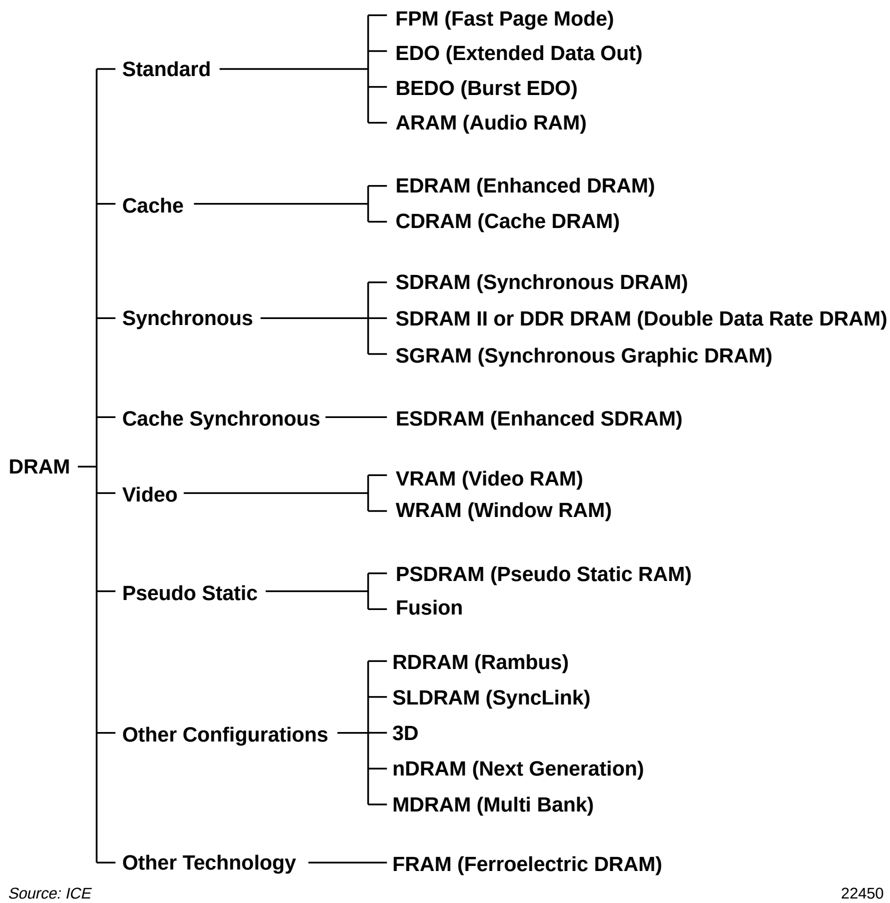


Figure 7-72. Current DRAM Varieties

Rambus DRAM

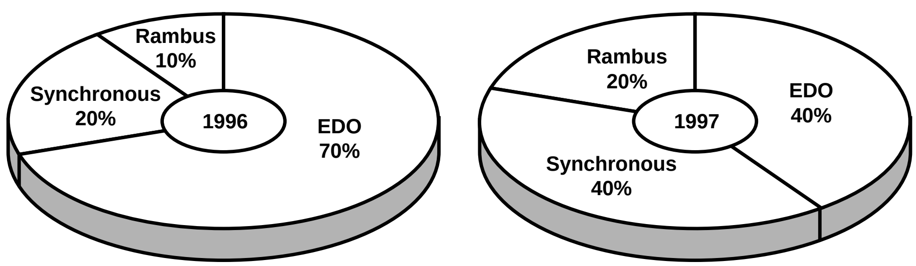
It has become obvious that standard SDRAM will not be able to perform to the 1.5Gbit to 3.0Gbit per second system bandwidth necessary to provide realistic 3D graphics and DVD processing. But the Rambus DRAM (RDRAM) provides that solution. This technology provides a wide path for fast data transfer between the memory and the processing segments of a system.

RDRAM uses conventional DRAM processes and manufacturing technology. The RDRAM is divided into two parts: interface logic and DRAM core. The interface logic includes a high-speed input and output (I/O) interface, clock circuitry, and protocol control logic. Due to the Rambus interface, an RDRAM consumes 14 percent more silicon than a conventional DRAM. Like standard DRAM, the RDRAM cells have to be refreshed; RDRAM has self-refresh capability built in. Figure 7-76 shows the physical layout of a Rambus-based system.

Vendor	DRAM Architectures Offered	Rambus Licensee	SyncLink Consortium Member
Fujitsu	SGRAM, SDRAM	•	•
Hitachi	SGRAM, SDRAM, EDO DRAM	•	•
Hyundai	EDO DRAM	•	•
IBM	SRAM, SDRAM, EDO DRAM	—	•
LG Semicon	—	•	•
Micron	SGRAM, EDO DRAM	—	•
Mitsubishi	3-D RAM, cache DRAM, SDRAM, EDO DRAM	—	•
Mosel-Vitelic	EDO DRAM	—	•
NEC	SGRAM, SDRAM, Rambus DRAM, EDO DRAM	•	•
Oki	EDO DRAM, VRAM	•	•
Ramtron	Enhanced DRAM	—	—
Silicon Magic	EDO DRAM	—	—
Samsung	SGRAM, SDRAM, Windows RAM, EDO DRAM	•	•
Texas Instruments	SDRAM, VRAM, EDO DRAM	•	•
Toshiba	EDO DRAM, SDRAM, Rambus DRAM, VRAM	•	•

Source: ICE 22681B

Figure 7-73. DRAM Suppliers Support Many Architectures



Source: ICE 20889A

Figure 7-74. Toshiba's DRAM Shipments by IC Architecture

Rambus has licensed the top DRAM manufacturers to use its technology. The company charges a flat engineering fee to customize its interface to a memory vendor's existing product. Suppliers then pay royalties based on the actual selling price of the Rambus DRAM.

Rambus scored a major win when it announced in the first quarter of 1997 that Intel would adopt the Rambus DRAM architecture as its next-generation main-memory technology for PCs. If all goes according to Intel's plan, Rambus DRAM will begin to appear in high-end PCs in 1999.

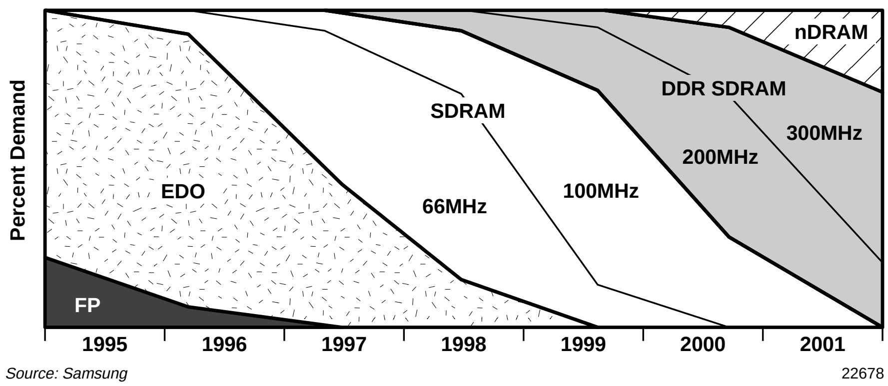


Figure 7-75. Samsung DRAM Technology Roadmap for Main Memory

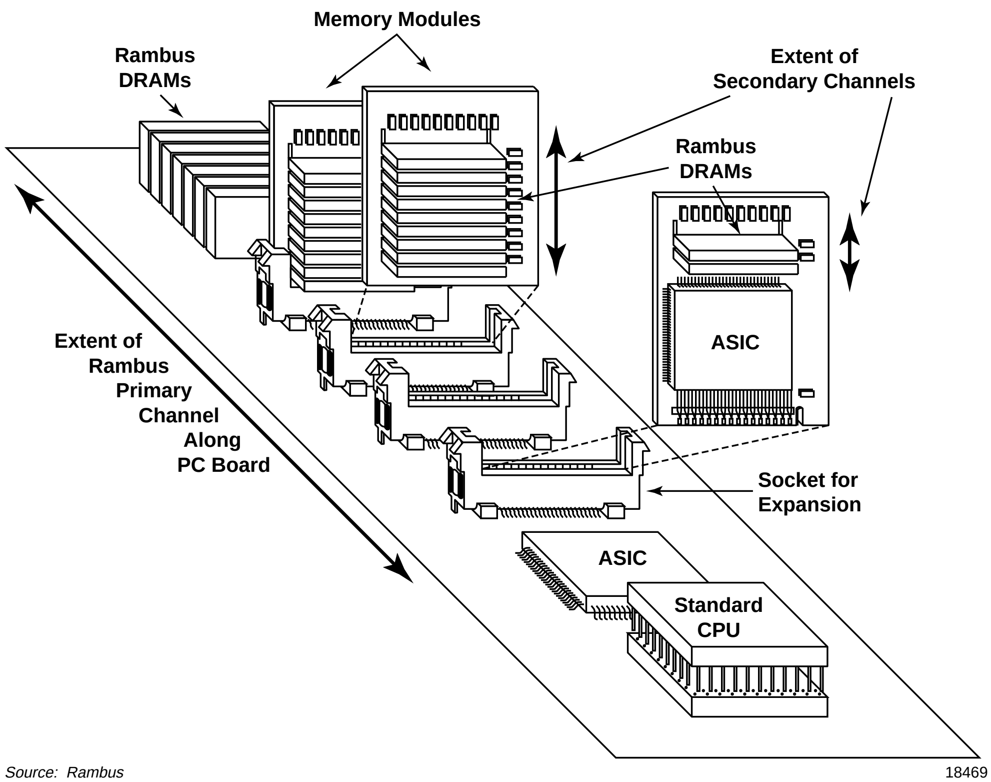


Figure 7-76. Physical Organization of a Rambus-Based System

Intel and Rambus also agreed to collaborate on a new DRAM based on the RDRAM architecture. This new DRAM, called next generation DRAM (nDRAM), will not be available before 1999. Figure 7-77 shows the Intel and Rambus relationship roadmap. Currently, the RDRAM gets its speed by using a narrow 8-bit channel. The nDRAM may use two parallel 8-bit channels and reach a speed of 1.6Gbytes per second.

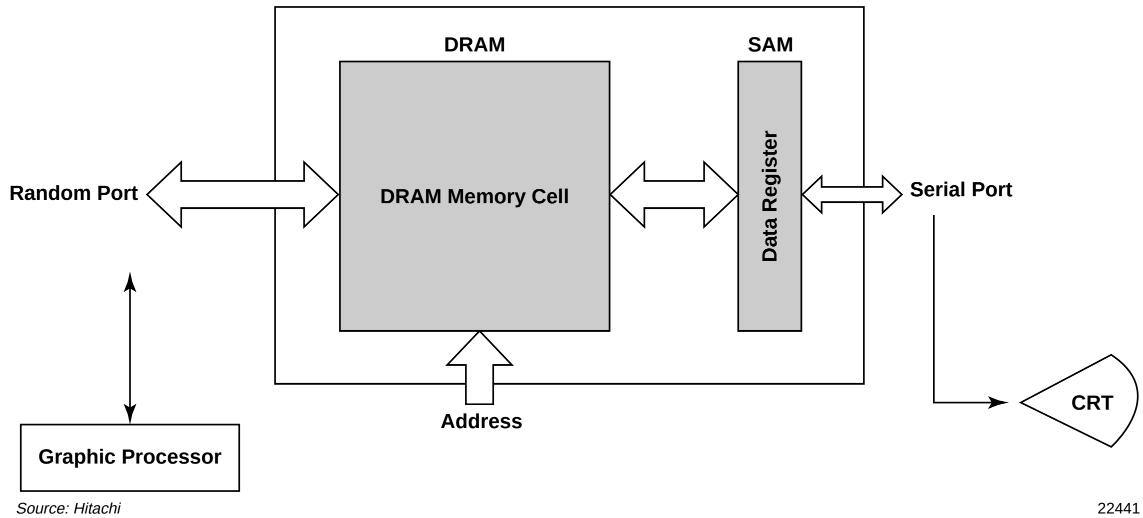


Figure 7-77. A General Concept of Video RAM

SyncLink DRAM

An alternative to Rambus DRAM is SyncLink technology. SyncLink (SL) provides many of the same benefits as Rambus technology, providing a high bandwidth for speedy data transfer. However, SyncLink does not require a license or royalty payment. Many of the same companies that signed on with Rambus also promote SyncLink. Siemens, which does not support Rambus, signed on with SyncLink late in 1996.

The SLDRAM Consortium, formerly known as the SyncLink coalition, plans to present a functioning prototype of a 64M SLDRAM by the second quarter of 1998, and a PC platform supporting the technology at the 1998 Fall Comdex show. Figure 7-78 shows the SLDRAM architecture.

Embedded DRAM

Today's IC industry is experiencing many changes dictated by performance demands as well as customization requirements for specific applications. To meet those needs, suppliers have introduced many new ICs with embedded memory, with a particularly high interest in embedded DRAM.

Several DRAM suppliers worldwide have already staked out their claim in this emerging market. Many announced second-generation DRAM-with-logic processes and produced standard ICs based on the new technologies. Figure 7-79 lists several companies and their recent embedded DRAM products. However, suppliers are trying to take the next step—from embedding DRAM in standard products, to offering it in a cell-based ASIC.

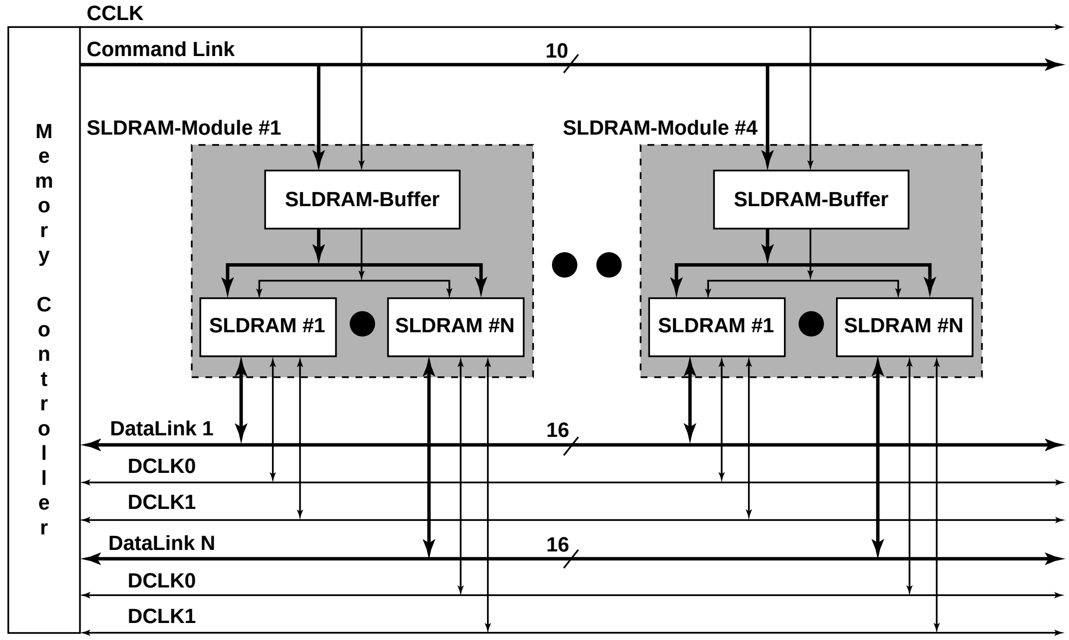


Figure 7-78. SynkLink DRAM Architecture

Company	Product	Comments
NeoMagic	MagicGraph	Graphics controller chip for notebook computers that has 1M of embedded DRAM. Available now.
Silicon Magic	Max-H	IC that couples 1.25M of DRAM with VGA graphics acceleration, audio, and MPEG-1 decompression fuctions. Available now.
Mitsubishi	M32R/D	32-bit RISC processor (54MIPS at 66MHz) and 16M DRAM. Device is built using 0.45µm, two-layer metal technology. Die size: 153.7mm^2. Available now.
NEC	PIP-RAM	Parallel-image processing (PIP) RAM for real-time image processing applications. PIP-RAM integrates 16M DRAM and 128 8-bit processors. In development stage.
Hitachi	"Media Chip"	Prototype optimized for 3-D graphics. The device integrates four 2M DRAM macros and four pixel processors.
SGS-Thomson	Omega	The chip integrates DRAM, ST-20 microprocessor core, an MPEG Audio and video recorder, and SRAM cache memory.

Source: ICE 21211B

Figure 7-79. Companies Exploring DRAM and Logic on Same Chip

Some of the benefits of embedded DRAM include improved performance, board space and pin-count reduction, reduced power and flexible configuration. Figure 7-80 provides some examples of power savings achieved with embedded DRAM when compared to discrete DRAM solutions with equivalent bandwidth configurations.

	Embedded DRAM	Discrete DRAM	Discrete DRAM
DRAM (Mbits)	32M	16M SDRAM	16M RDRAM
Bandwidth (GB/sec)	4.26	4.4	4.5
Operational Frequency (MHz)	133MHz	100MHz	500MHz
Word Width	256	16	8
Number of Chips	1	22 (352M Total)	9 (144M Total)
Power (Watts)	0.86	11.616	11.88

Source: Toshiba 22771

Figure 7-80. Comparison of Embedded DRAM Versus Discrete DRAM Power Dissipation