5 THE FLASH MEMORY MARKET

<u>1996 FACTS</u>		**<u>1997 FORECAST</u>**	
Market Size:	**$2,610 million**	**Market Size:**	**$3,000 million**
Shipments:	**359 million**	**Shipments:**	**554 million**
ASP:	**$7.27**	**ASP:**	**$5.41**

OVERVIEW

In the semiconductor hierarchy, flash is a member of the non-volatile family (Figure 5-1). Expanding the non-volatile memory family (Figure 5-2), flash memory represents a middle-of-the-road alternative in terms of cost and functionality. Figure 5-3 looks more closely at how flash memory compares with other non-volatile devices, specifically, the EPROM and EEPROM.

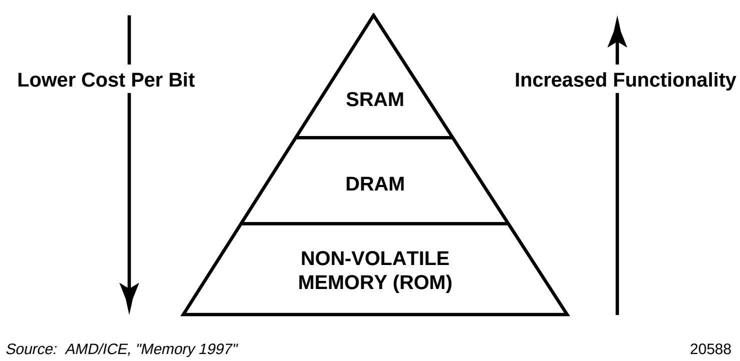
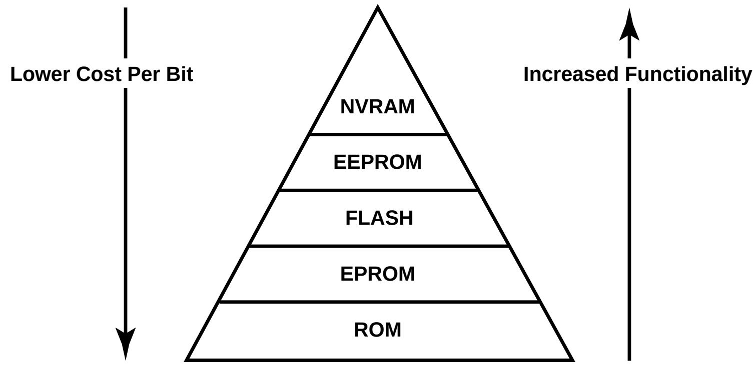


Figure 5-1. Semiconductor Memory Hierarchy

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

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



Source: AMD/ICE, "Memory 1997" 20589

Figure 5-2. Non-Volatile Memory Hierarchy

	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/ICE, "Memory 1997" 20411B

Figure 5-3. Flash Finds Its Non-Volatile Niche

Growth in the flash memory market is forecast to continue at an impressive rate as flash memory devices are designed into many high-growth product segments including networking equipment, wireless communication devices, and PC-related products (Figure 5-4). Other emerging markets, such as digital cameras, represent additional growth opportunities.

While the flash market seems golden, a closer look reveals some wrinkles that still need to be ironed out. For instance, among flash memory suppliers and customers, there exists a push for change, but at the same time, a demand for stability. Vendors continue to juggle combinations of new architectures, cell structures, and manufacturing processes to achieve the best in low power, high density, easy programming, and cost-effectiveness. All are vying for domination or are aiming their devices at specific application niches.

Source: SanDisk/ICE, "Memory 1997" 20616A

Figure 5-4. Flash Data Targets Growing Markets

The lack of uniformity in the market has not stopped the excitement, however. Moving ahead to the year 2002 will only witness the ongoing rise in complexity and greater risks for success or failure. The promise of many new applications awaits flash memory. The next five-year period will be an interesting time for suppliers and users alike.

THE FLASH MEMORY MARKET

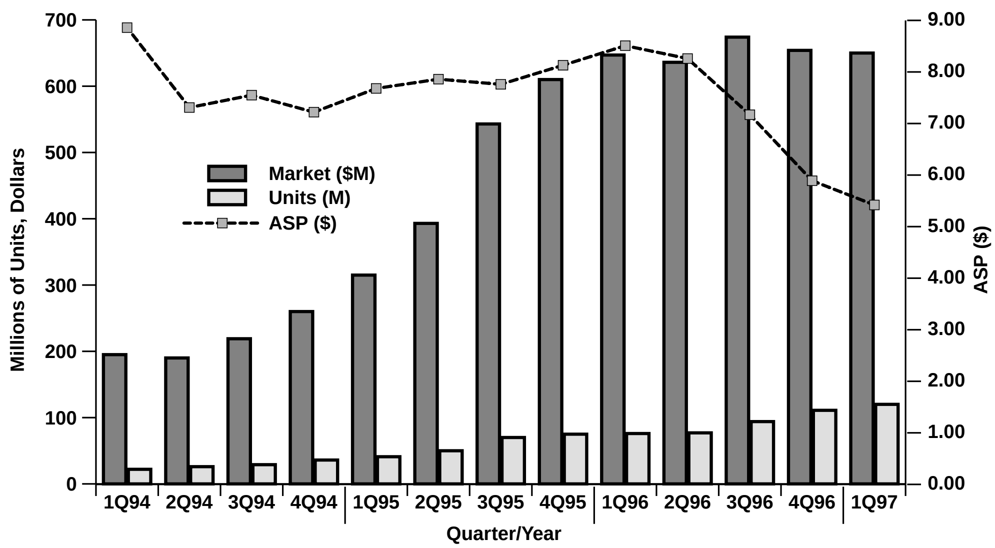
Listed in Figure 5-5 is ICE's complete flash memory market forecast for the 1992-2002 time period. Displayed are the market size, unit shipments, ASPs, and price per megabit for several densities. The 1996 flash memory market was very good to most suppliers through most of the year. However, several companies moved production capacity to flash memory from other not-so-profitable memory lines and by the end of the year, flash memory average selling prices took quite a tumble.

A look at the quarterly flash memory market during the past three years (Figure 5-6) shows how the market grew rapidly and how average selling prices started their steep decline in 2H96. Through 1997, ICE believes that reasonable supply and demand conditions will prevail, which should contribute to relative calm in the market.

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
256Kbit Units (M)	9	15	20	25	30	19	12	5	—	—	—
ASP ($)	5.75	4.35	3.20	2.75	2.50	1.93	1.75	1.65	—	—	—
Price Per Mbit ($)	21.93	16.59	12.21	10.49	9.54	7.36	6.68	6.29	—	—	—
Market ($M)	52	65	64	69	75	37	21	8	—	—	—
512Kbit Units (M)	5	10	12	22	34	25	15	10	—	—	—
ASP ($)	6.80	4.80	3.60	3.00	2.65	1.75	1.40	1.15	—	—	—
Price Per Mbit ($)	12.97	9.16	6.87	5.72	5.05	3.34	2.67	2.19	—	—	—
Market ($M)	34	48	43	66	90	44	21	12	—	—	—
1Mbit Units (M)	9	32	45	82	105	125	115	95	80	50	30
ASP ($)	11.35	7.65	5.40	4.35	3.55	2.00	1.60	1.40	1.25	1.15	1.10
Price Per Mbit ($)	10.82	7.30	5.15	4.15	3.39	1.91	1.53	1.34	1.19	1.10	1.05
Market ($M)	102	245	243	357	373	250	184	133	100	58	33
2Mbit Units (M)	2	9	12	33	55	80	75	55	40	25	15
ASP ($)	23.50	12.00	8.40	6.75	5.75	2.90	2.25	1.80	1.50	1.25	1.10
Price Per Mbit ($)	11.21	5.72	4.01	3.22	2.74	1.38	1.07	0.86	0.72	0.60	0.52
Market ($M)	47	106	102	223	316	232	169	99	60	31	17
4Mbit Units (M)	1	7	18	50	85	145	195	230	215	200	170
ASP ($)	49.00	25.50	14.45	11.00	8.75	4.15	3.15	2.50	1.90	1.60	1.40
Price Per Mbit ($)	11.68	6.08	3.45	2.62	2.09	0.99	0.75	0.60	0.45	0.38	0.33
Market ($M)	25	166	253	550	744	602	614	575	409	320	238
8Mbit Units (M)	0.1	0.2	5	20	40	118	150	190	180	165	150
ASP ($)	105.00	50.00	30.00	19.50	15.00	8.25	5.95	4.40	3.25	2.60	2.20
Price Per Mbit ($)	12.52	5.96	3.58	2.32	1.79	0.98	0.71	0.52	0.39	0.31	0.26
Market ($M)	11	10	149	390	600	972	893	836	585	429	330
16Mbit Units (M)	—	—	0.1	3	9	38	85	155	240	255	235
ASP ($)	—	—	120.00	59.00	36.25	18.00	11.00	8.00	5.80	4.50	3.80
Price Per Mbit ($)	—	—	7.15	3.52	2.16	1.07	0.66	0.48	0.35	0.27	0.23
Market ($M)	—	—	12	177	334	689	935	1,240	1,392	1,148	893
32Mbit Units (M)	—	—	—	0.1	0.6	3	12	27	80	150	250
ASP ($)	—	—	—	290.00	95.00	38.00	18.00	14.10	11.00	9.00	8.00
Price Per Mbit ($)	—	—	—	8.64	2.83	1.13	0.54	0.42	0.33	0.27	0.24
Market ($M)	—	—	—	29	59	114	216	381	880	1,350	2,000
64Mbit Units (M)	—	—	—	—	0.1	1	12	35	90	200	360
ASP ($)	—	—	—	—	200.00	61.00	44.40	35.00	25.83	20.00	17.00
Price Per Mbit ($)	—	—	—	—	2.98	0.91	0.66	0.52	0.38	0.30	0.25
Market ($M)	—	—	—	—	20	61	533	1,225	2,325	4,000	6,120
128Mbit Units (M)	—	—	—	—	—	—	—	0.1	5	20	55
ASP ($)	—	—	—	—	—	—	—	220.00	60.00	42.00	30.00
Price Per Mbit ($)	—	—	—	—	—	—	—	1.64	0.45	0.31	0.22
Market ($M)	—	—	—	—	—	—	—	22	300	840	1,650
Total Market ($M)	270	640	865	1,860	2,610	3,000	3,585	4,530	6,050	8,175	11,280
Total Units (M)	26	73	112	235	359	554	671	802	930	1,065	1,265
ASP ($)	10.54	8.82	7.75	7.91	7.27	5.41	5.34	5.65	6.51	7.68	8.92

Source: ICE, "Memory 1997" 20590B

Figure 5-5. Flash Memory Market Forecast



	1Q94	2Q94	3Q94	4Q94	1Q95	2Q95	3Q95	4Q95	1Q96	2Q96	3Q96	4Q96	1Q97
Market ($M)	195	190	219	260	315	393	543	610	647	636	674	654	650
Units (M)	22	26	29	36	41	50	70	75	76	77	94	111	120
ASP ($)	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

Source: ICE, "Memory 1997" 20597A

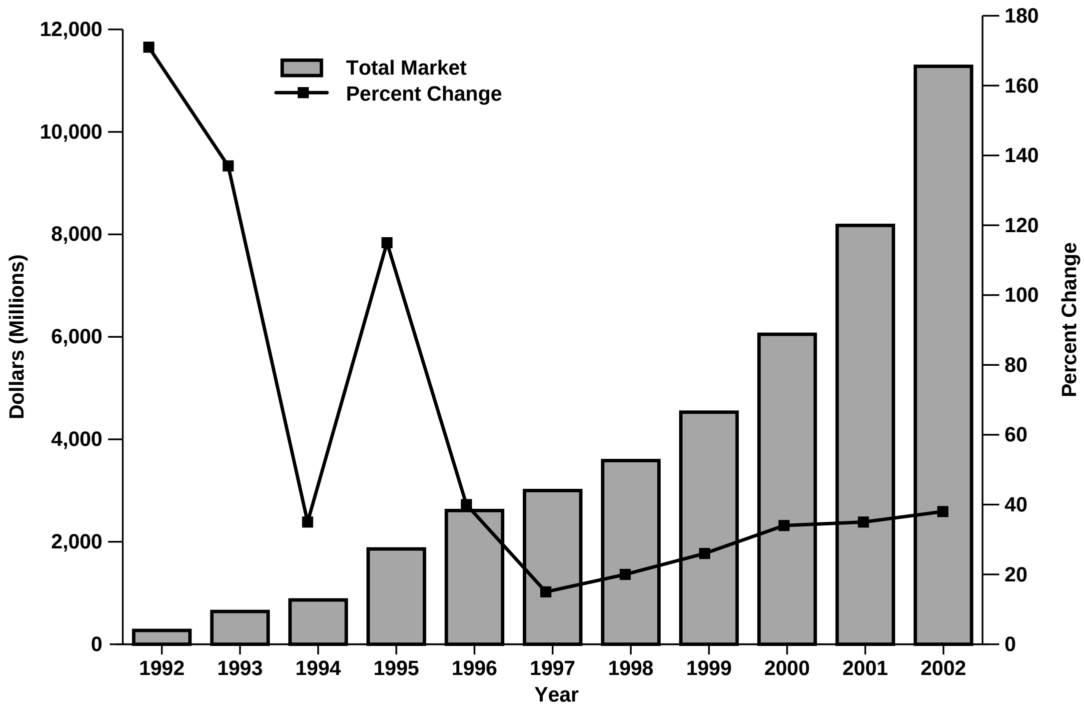
Figure 5-6. Quarterly Flash Memory Market

The flash memory market finished 1996 at $2.6 billion. Growth in 1996 (40 percent over 1995) was a continuation of the good times in the flash memory market. Although growth rates are projected to moderate in the next five years, ICE nevertheless projects a cumulative average annual growth rate of 30 percent for the flash memory market from 1997 through the year 2002, when the market size is forecast to be $11.3 billion (Figure 5-7). Further, ICE believes flash dollar volume, as a percent of the total MOS memory market, will increase slightly through 2002, while other memory segments (excluding DRAMs) decline in their share of the memory market.

Figure 5-8 displays the flash memory market by density. In terms of dollar size, the 4Mbit and 8Mbit densities represented the “sweet spot” of the flash market in 1996. ICE anticipates a strong move to higher density devices in 1997. For this reason ICE forecasts the 8Mbit and 16Mbit markets to be the largest of all flash densities in 1997.

FLASH MEMORY UNIT SHIPMENTS

Shown in Figure 5-9 is ICE’s forecast of total flash memory unit shipments for the 1992-2002 time period. Much like the dollars portion of the flash market, unit shipment growth exploded during the first half of the decade. Naturally, as the volume of shipments increases, the growth rate will tend to diminish. Still, the unit growth forecast from 1997 through the year 2002 calls for steady growth that averages a healthy 18 percent.



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

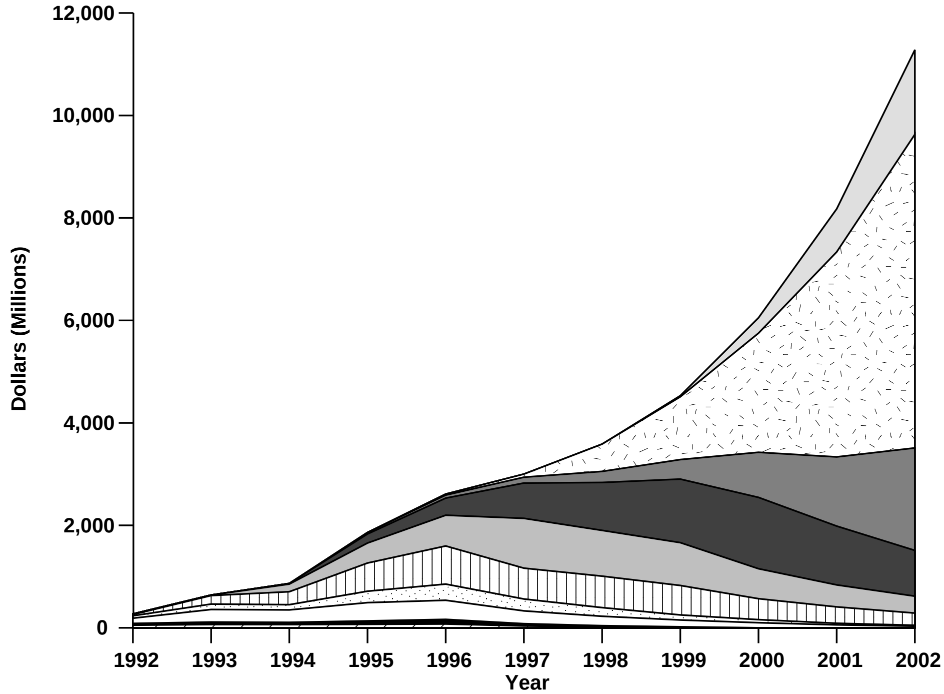
Source: ICE, "Memory 1997" 20587A

Figure 5-7. Flash Memory Market Growth

In 1996, flash memories at the 1Mbit density shipped the most, followed by 4Mbit devices (Figure 5-10). Driven by lower prices, shipments at the 1Mbit, 2Mbit, and 4Mbit level should remain robust in 1997. By 1998, a definite swing to 8Mbit and 16Mbit devices will be under way. Although offered in a wide variety of densities (including 2Mbit, 8Mbit, and 32Mbit) ICE believes that flash memory devices will sell best at densities that mirror those found in the DRAM market (i.e., 1Mbit, 4Mbit, 16Mbit, etc.).

FLASH MEMORY AVERAGE SELLING PRICES

The overall flash memory average selling price decreased eight percent in 1996 (Figure 5-11), largely due to additional suppliers providing more production capacity. In 1997, ICE forecasts that additional suppliers and additional capacity will lead to a drastic reduction in flash ASPs. Memory suppliers, looking for a profitable market, will flood to the flash market. This will likely lead to reduced ASPs and very little profitability from the devices. Later in the decade and into the year 2002, ICE believes that increased demand and the transition to higher density devices will result in average selling prices increasing.



	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
256Kbit	52	65	64	69	75	37	21	8	—	—	—
512Kbit	34	48	43	66	90	44	21	12	—	—	—
1Mbit	102	245	243	357	373	250	184	133	100	58	33
2Mbit	47	106	102	223	316	232	169	99	60	31	17
4Mbit	25	166	253	550	744	602	614	575	409	320	238
8Mbit	11	10	149	390	600	972	893	836	585	429	330
16Mbit	—	—	12	177	334	689	935	1,240	1,392	1,148	893
32Mbit	—	—	—	29	59	114	216	381	880	1,350	2,000
64Mbit	—	—	—	—	20	61	533	1,225	2,325	4,000	6,120
128Mbit	—	—	—	—	—	—	—	22	300	840	1,650
Total Market ($M)	270	640	865	1,860	2,610	3,000	3,585	4,530	6,050	8,175	11,280

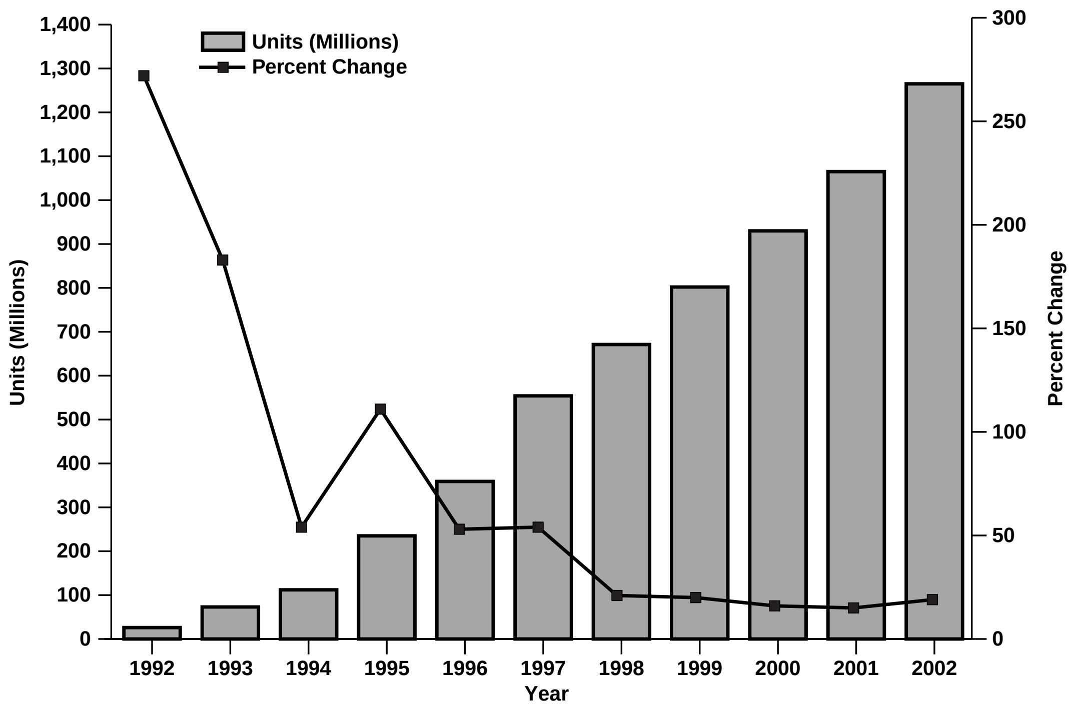
Source: ICE, "Memory 1997" 20591B

Figure 5-8. Dollar Volume of Select Flash Memory Densities

Figure 5-12 plots the ASPs of several flash memory densities through the year 2002. Later in the decade, ASPs for each generation will decline, generating more applications that incorporate flash memory chips. This, in turn, will help increase unit sales and create a larger flash memory market.

FLASH MEMORY BIT VOLUME

Flash memory bit volume for the complete market and for specific densities is provided in Figures 5-13 and 5-14, respectively. Total bit volume growth appears to rise exponentially in the second half of the time period shown. Even though growing at a more "relaxed" rate through 2002, the bit volume numbers show explosive growth. This pace of growth is almost identical to that experienced in the DRAM market when it was this size.



Total Units (M)	26	73	112	235	359	554	671	802	930	1,065	1,265
Percent Change	272	183	54	111	53	54	21	20	16	15	19

Source: ICE, "Memory 1997" 20592B

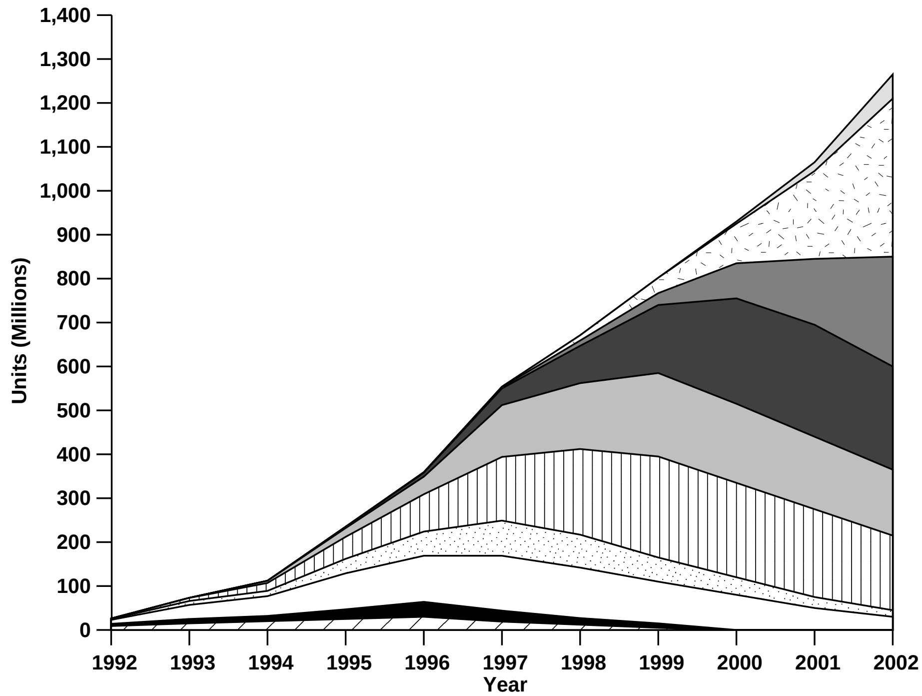
Figure 5-9. Flash Memory Unit Shipments

FLASH MEMORY PRICE PER MEGABIT

Figure 5-15 compares price per megabit values for several densities of flash memory. One issue that is often raised when considering how quickly and how large the flash memory market will grow is the price per megabit compared to a DRAM part of an equivalent density. The thought in some circles is that flash memory devices will eventually replace DRAM main memory in PC applications. The logic driving this thought is that flash memory devices will be cheaper on a per megabit basis than DRAMs beginning with the 16Mbit generation.

FLASH MEMORY CONSUMPTION AND PRODUCTION

Flash memory consumption (Figure 5-16) was dominated by the North American region during 1995 and 1996. In the course of one short year, however, Japan's consumption of flash memory devices increased greatly. That region's thirst for portability and consumer applications led to the dramatic increase in flash consumption during 1996. With its emphasis on smart cards and telecommunications, the European and ROW regions will likely increase their share of the 1997 flash memory market.



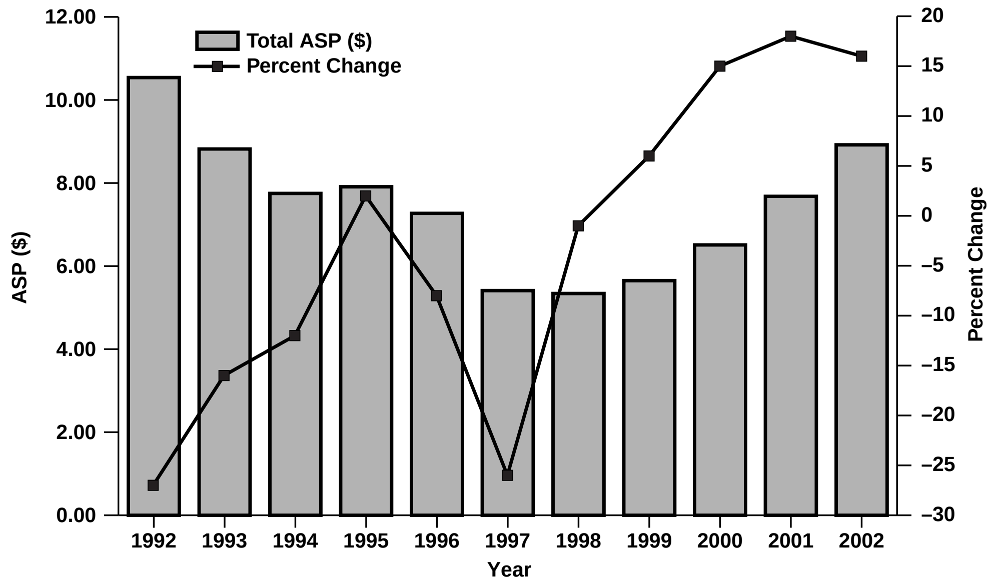
256Kbit	9	15	20	25	30	19	12	5	—	—	—
512Kbit	5	10	12	22	34	25	15	10	—	—	—
1Mbit	9	32	45	82	105	125	115	95	80	50	30
2Mbit	2	9	12	33	55	80	75	55	40	25	15
4Mbit	1	7	18	50	85	145	195	230	215	200	170
8Mbit	0.1	0.2	5	20	40	118	150	190	180	165	150
16Mbit	—	—	0.1	3	9	38	85	155	240	255	235
32Mbit	—	—	—	0.1	1	3	12	27	80	150	250
64Mbit	—	—	—	—	0.1	1	12	35	90	200	360
128Mbit	—	—	—	—	—	—	—	0.1	5	20	55
Total Units (M)	26	73	112	235	359	554	671	802	930	1,065	1,265

Source: ICE, "Memory 1997" 20593B

Figure 5-10. Flash Memory Unit Shipments by Density

Meanwhile, North American firms produced 74 percent of the world's flash memory devices in 1996 (Figure 5-17). This was down by 11 percentage points from the previous year, but still represents a very sizable portion.

Most production was due to the efforts of Intel and AMD. Products that were announced from these firms were typically quickly available to their customers (albeit on a constrained basis). Although Japanese, Korean, and European companies announced increased flash production capacity, their efforts will be no match compared to what Intel and AMD will produce during 1997.



	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Total ASP ($)	10.54	8.82	7.75	7.91	7.27	5.41	5.34	5.65	6.51	7.68	8.92
Percent Change	–27	–16	–12	2	–8	–26	–1	6	15	18	16

Source: ICE, "Memory 1997" 20595B

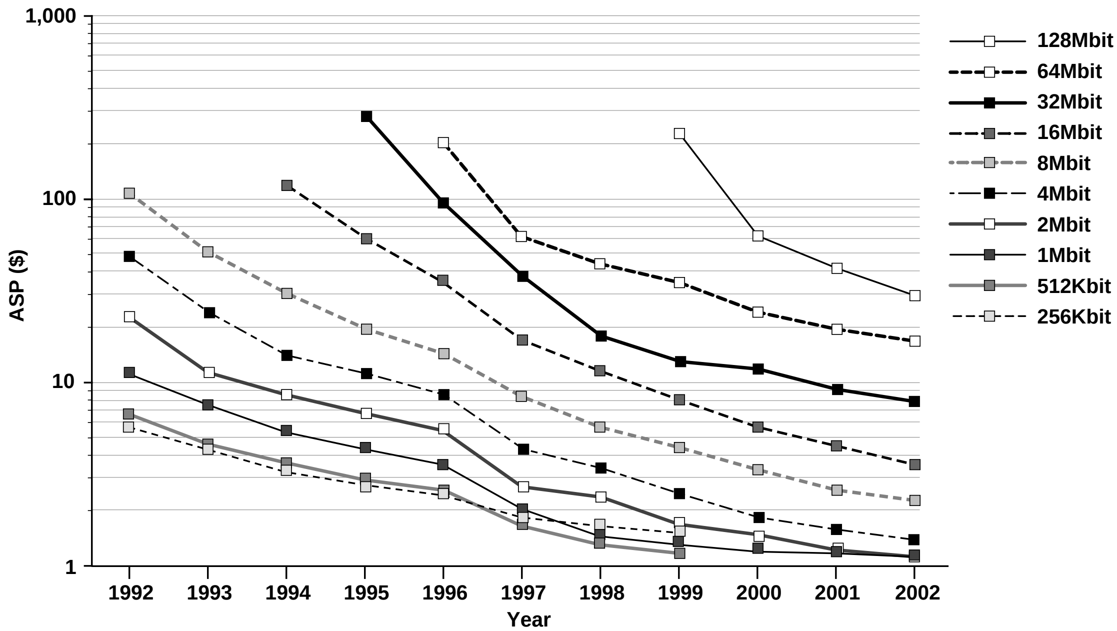
Figure 5-11. Flash Memory Average Selling Price

FLASH MEMORY SALES LEADERS

The leading flash memory suppliers for 1995 and 1996 are shown in Figure 5-18. In 1996, several additional players entered the flash market and competition between suppliers heated up. As a result, Intel's flash memory business, which sailed along through the first half of 1996, dropped sharply in 3Q96 due to pricing pressures. Nevertheless, Intel managed to increase its flash business 22 percent during the year. 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 likely be the front-runners in the flash memory business again in 1997.

Atmel, Solid State Technology (SST), and Sharp each enjoyed large percentage gains in their flash IC business in 1996. Atmel was one of the first suppliers to offer low-voltage flash IC devices and Sharp ramped production of its internally designed flash ICs in 1996. The sales figures shown for Sharp reflect only that revenue generated from sales of its in-house-designed flash memory devices.

Other companies, including several Taiwanese suppliers (see Figure 5-19), became more active in the flash market during 1996 and anticipate another year of solid flash memory sales in 1997. Additional flash highlights on a company by company basis are provided below.



256Kbit	5.75	4.35	3.20	2.75	2.50	1.93	1.75	1.65	—	—	—
512Kbit	6.80	4.80	3.60	3.00	2.65	1.75	1.40	1.15	—	—	—
1Mbit	11.35	7.65	5.40	4.35	3.55	2.00	1.60	1.40	1.25	1.15	1.10
2Mbit	23.50	12.00	8.40	6.75	5.75	2.90	2.25	1.80	1.50	1.25	1.10
4Mbit	49.00	25.50	14.45	11.00	8.75	4.15	3.15	2.50	1.90	1.60	1.40
8Mbit	105.00	50.00	30.00	19.50	15.00	8.25	5.95	4.40	3.25	2.60	2.20
16Mbit	—	—	120.00	59.00	36.25	18.00	11.00	8.00	5.80	4.50	3.80
32Mbit	—	—	—	290.00	95.00	38.00	18.00	14.10	11.00	9.00	8.00
64Mbit	—	—	—	—	200.00	61.00	44.40	35.00	25.83	20.00	17.00
128Mbit	—	—	—	—	—	—	—	220.00	60.00	42.00	30.00
Total ASP ($)	10.54	8.82	7.75	7.91	7.27	5.41	5.34	5.65	6.51	7.68	8.92

Source: ICE, "Memory 1997"

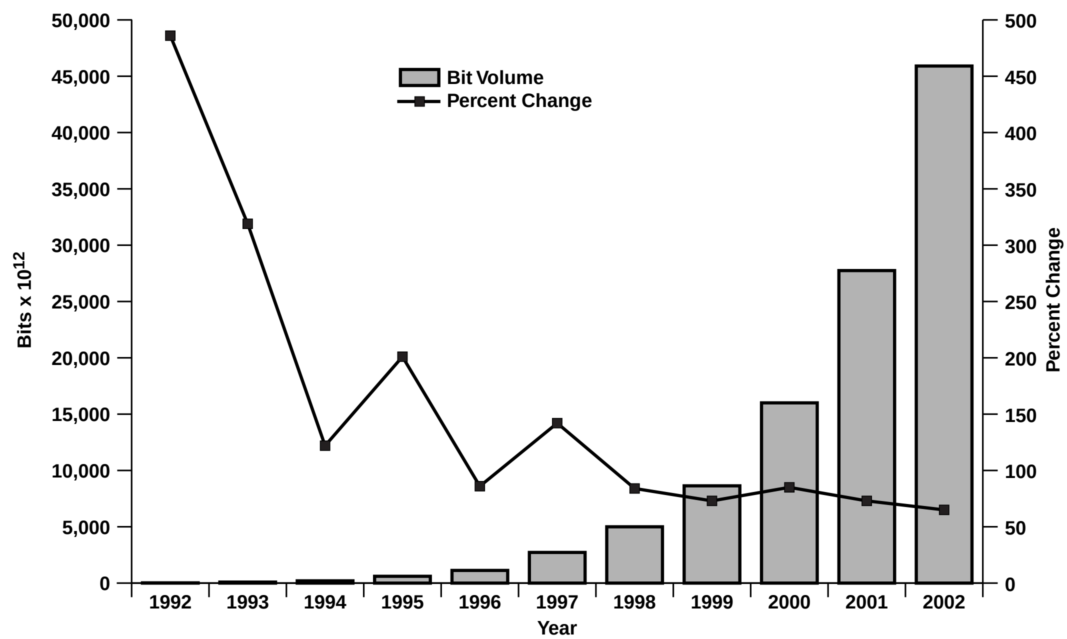
20596B

Figure 5-12. Flash Memory ASPs By Density

Advanced Micro Devices (AMD)

Amid very weak MPU sales, AMD experienced a rough year financially. However, flash memory sales provided one of the few bright spots. Although revenue growth was slower than anticipated in 1996, demand and shipments remained very solid and the company remained optimistic about its future in this product segment. In fact, in 1Q97, AMD witnessed a 20 percent increase in sales of its flash memory devices.

Architecturally, AMD's flash devices 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 OEMs a simpler solution and believes that the single-power-supply flash memory (i.e., read/program voltages of 5V/5V, 3V/3V, etc.), will be the approach that wins out in the marketplace.



	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Annual Bit Volume (10^{12})	21.5	90.2	200.7	604.5	1,125.1	2,722.8	4,999.1	8,635.3	16,001.3	27,745.3	45,905.3
Percent Change	486	319	122	201	86	142	84	73	85	73	65

Source: ICE, "Memory 1997" 20599B

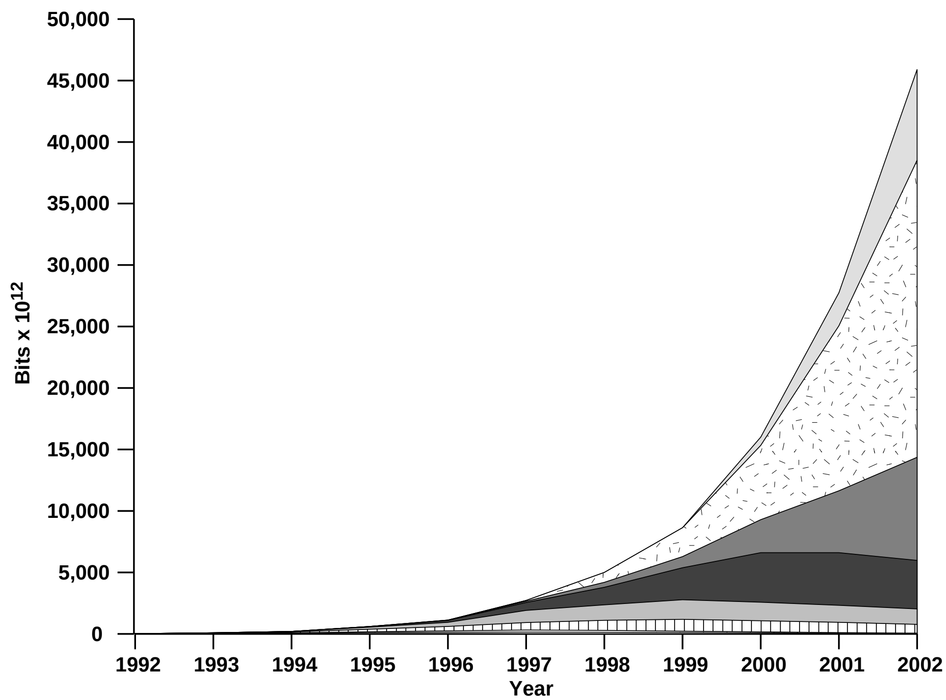
Figure 5-13. Flash Memory Bit Volume

To that end, AMD announced the first parts in a series of 3V-only and 2.7V-only flash memory families in 1996. The 3V-only devices range in density from 2Mbits to 8Mbits. The 2.7V devices—two 4Mbit and one 8Mbit—feature access times as fast as 100ns and are targeted for emerging and existing battery-powered applications including digital cellular phones, flash memory cards, and digital cameras.

AMD also announced a family of flash devices that operates at 2.2V. The new family, named the Am29LLXXX, debuted about one year after the company rolled out its 2.7V Am29LVXXX flash products and represents another step on the road to 1.8V and eventually, 0.9V parts. First out of the chute will be an 8Mbit device. For AMD, 1997 will be the year that it quickly ramps up volume production of its low-voltage devices.

In 2Q97, AMD unveiled the first device in a family that incorporates its new simultaneous read / write flash architecture. The 8Mbit AM29DL800 allows read operations to occur during program and erase operations.

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



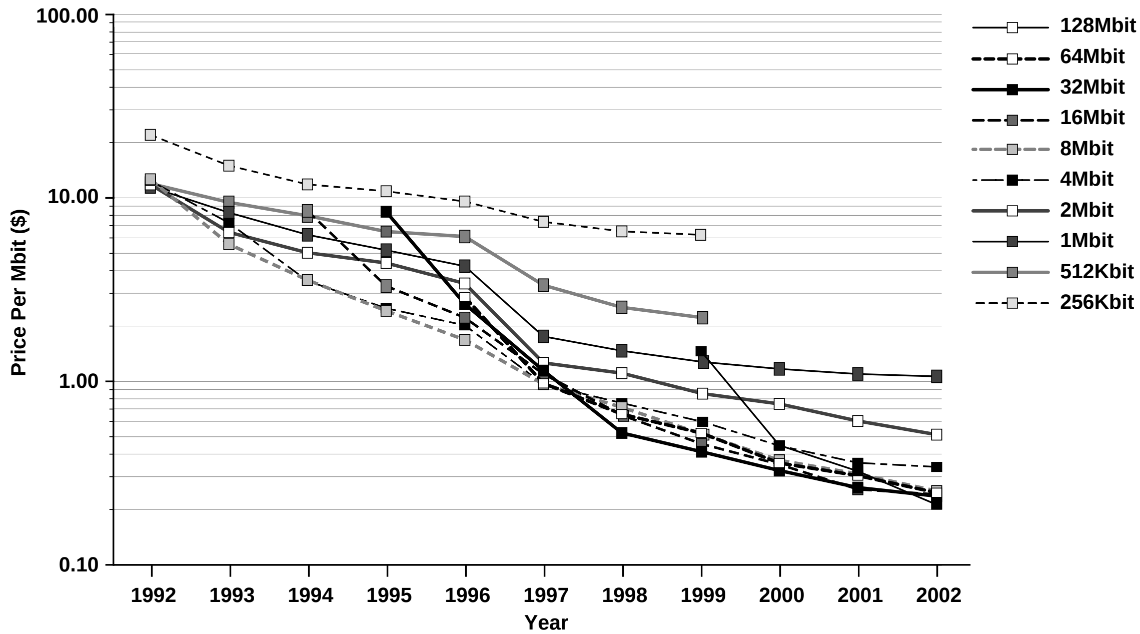
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
256Kbit	2.4	3.9	5.2	6.6	7.9	5.0	3.1	1.3	—	—	—
512Kbit	2.6	5.2	6.3	11.5	17.8	13.1	7.9	5.2	—	—	—
1Mbit	9.4	33.6	47.2	86.0	110.1	131.1	120.6	99.6	83.9	52.4	31.5
2Mbit	4.2	18.6	25.4	69.2	115.3	167.8	157.3	115.3	83.9	52.4	31.5
4Mbit	2.1	27.3	73.4	209.7	356.5	608.2	817.9	964.7	901.8	838.9	713.0
8Mbit	0.8	1.7	41.5	167.8	335.5	988.2	1,258.3	1,593.8	1,509.9	1,384.1	1,258.3
16Mbit	—	—	1.7	50.3	154.4	641.7	1,426.1	2,600.5	4,026.5	4,278.2	3,942.6
32Mbit	—	—	—	3.4	20.8	100.7	402.7	906.0	2,684.4	5,033.2	8,388.6
64Mbit	—	—	—	—	6.7	67.1	805.3	2,348.8	6,039.8	13,421.8	24,159.2
128Mbit	—	—	—	—	—	—	—	—	671.1	2,684.4	7,380.6
Total Bit Volume (10^{12})	21.5	90.2	200.7	604.5	1,125.1	2,722.8	4,999.1	8,635.3	16,001.3	27,745.3	45,905.3

Source: ICE, "Memory 1997"   20598B

Figure 5-14. Flash Memory Bit Volume By Density

In another move, AMD began selling bare-die versions of its flash chips in response to requests from its non-volatile-memory customers for a known-good-dice program. Over the long term, about 10 percent of AMD’s flash sales will be in die format. How quickly the company reaches that level depends on customers’ willingness to use the die.

The joint manufacturing venture that AMD shares with Fujitsu was set to switch to 0.35µm process technology from its current 0.5µm line at its No.1 facility in 2Q97, effectively doubling the line’s production capacity to 20 million 4Mbit equivalent units per month. The companies also planned to begin installation of 0.35µm equipment at their No. 2 facility in 2Q97 and launch pilot production there in mid-1997. FASL produces 2Mbit through 16Mbit flash chips that operate on 5V and 2Mbit through 8Mbit chips that operate on 2.7V-3V. Figure 5-20 provides a glimpse of AMD’s scheduled increase of production capacity for flash memory devices.



	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
256Kbit	21.93	16.59	12.21	10.49	9.54	7.36	6.68	6.29	—	—	—
512Kbit	12.97	9.16	6.87	5.72	5.05	3.34	2.67	2.19	—	—	—
1Mbit	10.82	7.30	5.15	4.15	3.39	1.91	1.53	1.34	1.19	1.10	1.05
2Mbit	11.21	5.72	4.01	3.22	2.74	1.38	1.07	0.86	0.72	0.60	0.52
4Mbit	11.68	6.08	3.45	2.62	2.09	0.99	0.75	0.60	0.45	0.38	0.33
8Mbit	12.52	5.96	3.58	2.32	1.79	0.98	0.71	0.52	0.39	0.31	0.26
16Mbit	—	—	7.15	3.52	2.16	1.07	0.66	0.48	0.35	0.27	0.23
32Mbit	—	—	—	8.64	2.83	1.13	0.54	0.42	0.33	0.27	0.24
64Mbit	—	—	—	—	2.98	0.91	0.66	0.52	0.38	0.30	0.25
128Mbit	—	—	—	—	—	—	—	1.64	0.45	0.31	0.22

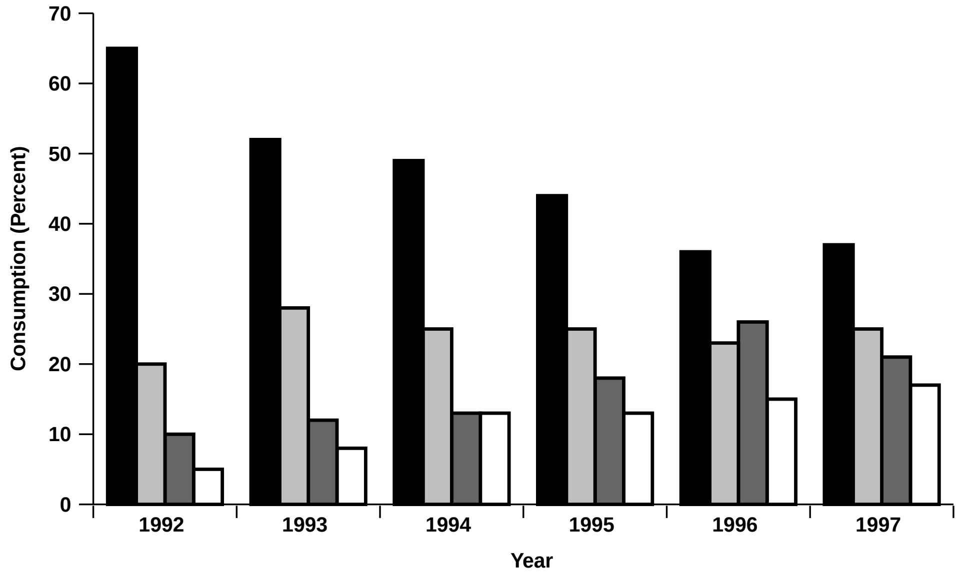
Source: ICE, "Memory 1997" 20602B

Figure 5-15. Flash Memory Price Per Mbit By Density

The partnership between AMD and Fujitsu continues to work well for both companies. The FASL (Fujitsu-AMD Semiconductor Ltd.) agreement initially gave each company exclusive rights to sell flash chips in specific regions of the world—AMD in North America, Taiwan, and most of Europe, while Fujitsu claimed Japan and the United Kingdom. However, due to eroding prices and dwindling market share in 1996, the two companies modified their agreement late in the year. Now, both companies can sell their flash devices anywhere in the world without regard to geographic region. Together, the firms are aiming for a 40 percent share of the world market.

Atmel

Atmel has been a leader in the flash memory business as well. Its flash memory devices afford the user the ability to erase information in small, bit increments rather than in large blocks or sectors offered from most other vendors.



	1992	1993	1994	1995	1996	1997
North America	65	52	49	44	36	37
Europe	20	28	25	25	23	25
Japan	10	12	13	18	26	21
ROW	5	8	13	13	15	17

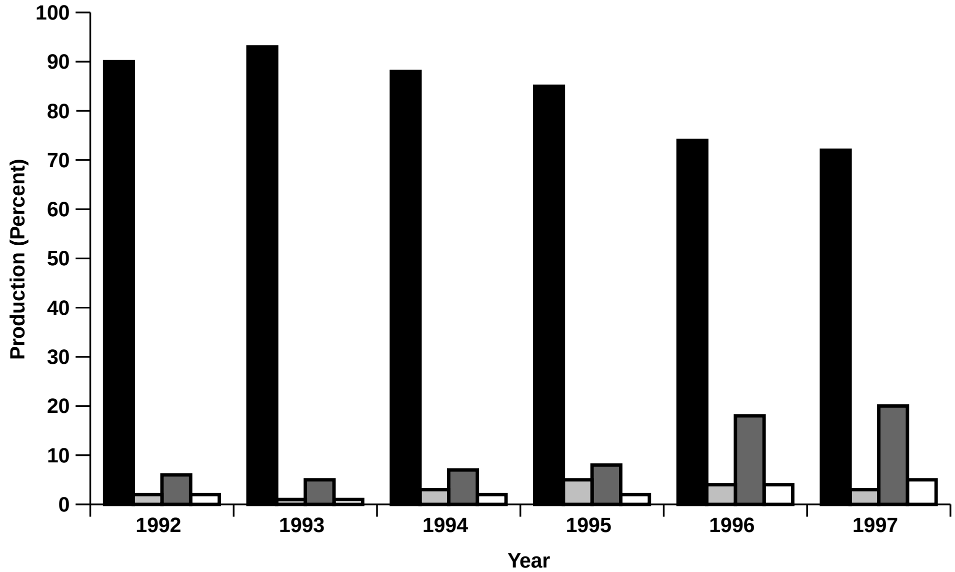
Source: ICE, "Memory 1997" 20603B

Figure 5-16. Regional Flash Memory Consumption (Percent)

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 device. Besides 3V parts, it also developed a 2.5V, single-voltage read/write flash family in 4Q96. The new flash family will eventually range in density from 1Mbit to 8Mbit. Additionally, the company is working feverishly on a 1.8V part that is slated to be released in 1997.

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

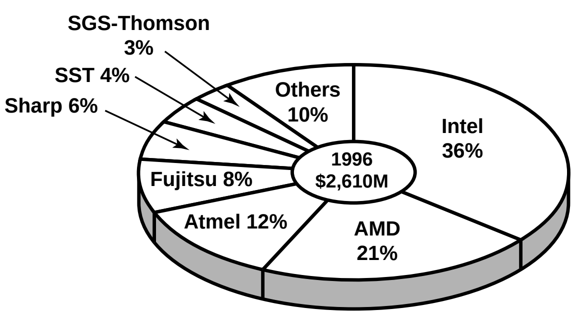
Taking advantage of its EEPROM expertise, Atmel also developed a memory device that incorporates both flash memory and EEPROM. The company's ConcurrentFlash chip packs 4Mbit of flash along with 256Kbit of EEPROM. It is clearly targeted for cell phone designs where, for example, program storage of various worldwide digital cell phone protocols (GSM, etc.) can be changed frequently in flash. Meanwhile, names and numbers can be updated in EEPROM.



	1992	1993	1994	1995	1996	1997
North America	90	93	88	85	74	72
Europe	2	1	3	5	4	3
Japan	6	5	7	8	18	20
ROW	2	1	2	2	4	5

Source: ICE, "Memory 1997" 20604A

Figure 5-17. Regional Flash Memory Production (Percent)



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%

20614D

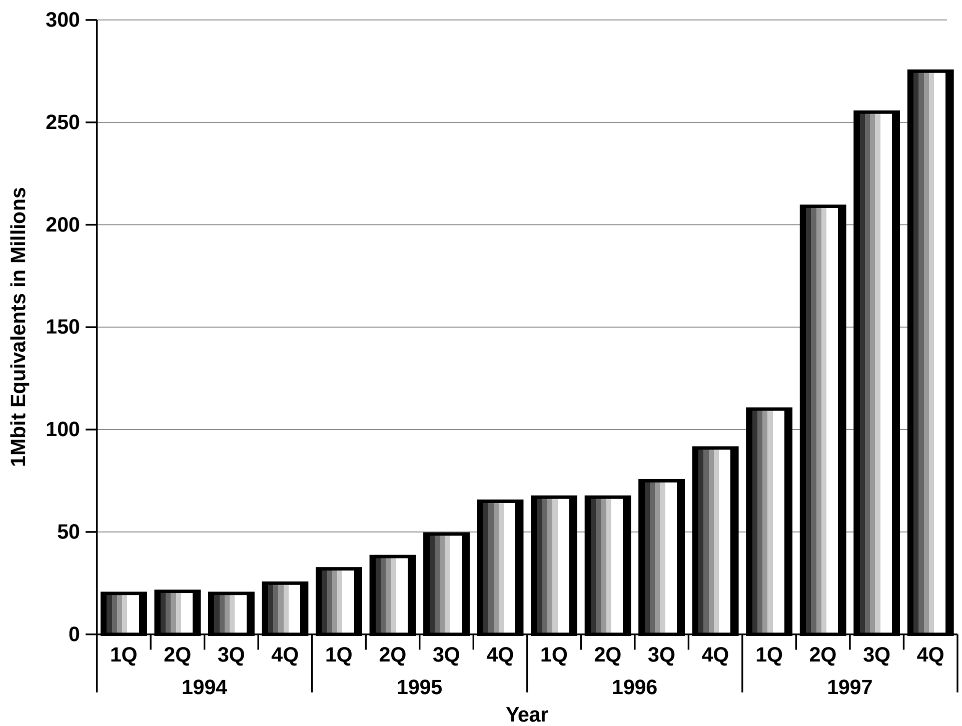
Source: ICE, "Memory 1997"

Figure 5-18. Flash Memory Sales Leaders

Company	Flash Plans
Macronix	Has sold 1Mbit and 4Mbit flash parts for several years. Designing products around a single-voltage architecture developed by AMD. Rapidly ramping 5V, 16Mbit, and 8Mbit flash devices.
UMC	Exploratory phase.
Winbond	Offers 256Kbit and 1Mbit flash devices based on its proprietary EEPROM-like "split-gate" architecture licensed from Silicon Storage Technology. Winbond is increasing production of its 5V, 2Mbit devices with 70ns access time.

Source: ICE, "Memory 1997" 20419A

Figure 5-19. Taiwan Joining Flash Bandwagon



Source: AMD/ICE, "Memory 1997" 20605

Figure 5-20. Total AMD Flash Capacity

Catalyst

At Catalyst, low density flash products are an important element of its long-term strategy. To that end, the company targeted its flash memory product line specifically at disk drives and other storage applications with a BIOS flash family of products. The family, which debuted in 1Q97, was initially offered in 1Mbit and 2Mbit book block versions. A 1.5Mbit device was scheduled to be introduced in the first half 1997. According to Catalyst, 1Mbit and 2Mbit flash devices account for more than 90 percent of the volume in PC applications.

To build the devices Catalyst engaged in a foundry agreement with United Microelectronics Corporation (UMC) and also has manufacturing ties with Oki Electric.

Fujitsu

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

Fujitsu announced in 4Q96 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 chips because it believes they are better suited for file applications. Additionally, Fujitsu thinks it is essential to have a broader product lineup.

Hitachi/Mitsubishi

Hitachi stressed development of its DINOR technology in 1996 and offered end users several densities built upon this body of knowledge. In 2H96, it introduced two 3V-only 8Mbit devices that were co-designed with Mitsubishi. The memories, built on 0.5µm technology, feature 80ns access times and 40 percent less power dissipation than equivalent 5V memories. The two companies believe that with the 8Mbit DINOR devices, they will be able to quickly catch up to leaders Intel and AMD in the flash memory market.

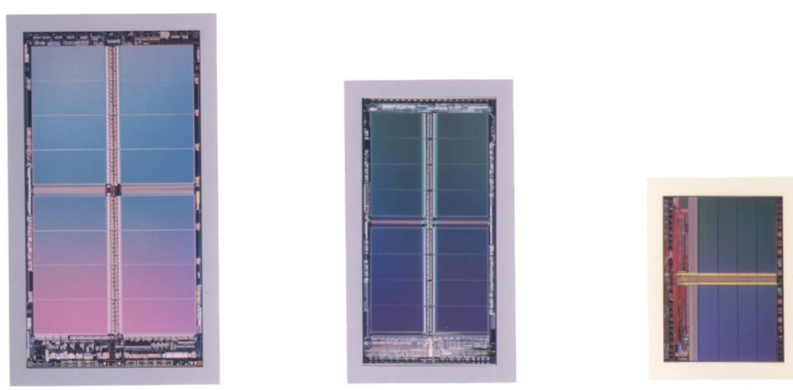
In 4Q96, Hitachi and Mitsubishi rolled out a 64Mbit flash device that initially served as the storage centerpiece in Hitachi's 75MB ATA-standard PC cards. The chips were manufactured using 0.4µm AND-flash process technology. A second-generation 64Mbit AND flash memory device built using sub-0.4µm technology is set to debut in 4Q97. The new device will be 30 percent smaller than the first generation device. Hitachi plans to increase output of its 64Mbit flash devices to 500,000 units per month by the end of 1997.

Mitsubishi plans to raise output of its 8Mbit DINOR-type flash memories to two million units per month by the end of 1997. The company plans to increase its flash memory offerings in 1997 and will focus its product line on low-voltage (2.7V) offerings. Additionally, it plans 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 devices. Instead, it will focus on producing DINOR- and AND-based flash devices.

Intel

The flash memory market leader is Intel. It, along with AMD, is the dominant supplier of flash memory for code-storage applications. Intel offers its SmartVoltage flash parts that provide read and write voltages ranging from 3V to 12V. Intel maintains that this feature gives its customers more choices of programming speed (higher voltage means higher programming speed).

SmartVoltage flash devices are manufactured using a 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 for an 8Mbit flash memory (Figure 5-21).



1992	1994	1996
0.8µ	0.6µ	0.4µ
8Mbit (28F008SA)	8Mbit (28F008SA)	8Mbit (28F008SC)
104mm^2	63mm^2	35mm^2

Courtesy of Intel/ICE, "Memory 1997" 22583

Figure 5-21. Intel's Flash Memory Die Size Reduction

In 4Q96, Intel expanded its SmartVoltage lineup with the Smart3 and Smart5 families that provide embedded system designers with 3V or 5V read/write capabilities, while enabling fast 12V programming. The devices are available in densities up to 16Mbit.

A new generation of SmartVoltage devices was sampled by Intel in 2Q97 that stored both code and data in a single component without using special on-chip circuitry. By utilizing a software innovation, the new Smart3 Advanced Boot Block flash devices eliminate the need for EEPROM-based data storage in many embedded systems. The devices are targeted for space-constrained applications such as new, streamlined digital cellular phones.

As shown in Figure 5-22, portable and wireless applications were the main end-use markets that Intel served in 1996. Wireless applications included products such as pagers, handsets, cellular phone base stations. “Emerging” markets include digital cameras, voice recorders, and automotive (navigation / map information) applications. The company believes its Smart3 Advanced Boot Block technology will broaden its influence in these market during 1997. Volume production, beginning with a 16Mbit device, is slated to begin in 3Q97.

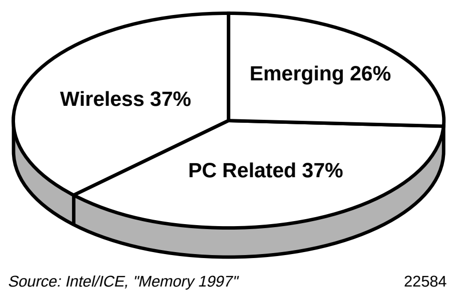


Figure 5-22. Intel’s 1996 Flash Business by Market Segment

Intel introduced the first of its long-awaited multi-level cell (MLC) flash devices in 1H97. A 64Mbit device was slated to be the initial product in this line. MLC stores two bit of data on one flash cell (compared to one bit of data per cell now), effectively doubling the storage density without increasing die size. Intel believes four bits of data per cell are very possible and hopes to eventually store 16 bits of data in a single cell. If yields are satisfactory, Intel could quickly move several steps ahead of its competition in bringing down the cost per bit of flash memory.

Despite the many new flash product introductions, Intel claimed that its popular, higher-density flash memory devices were “sold out” through 1997. As a result of the heavy demand, Intel had to defer orders for its 4Mbit, 8Mbit, and 16Mbit devices. The tightening supply through 1997 stems from especially high demand in the communications market.

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-dedicated fabs (Figure 5-23). It is now positioned, along with its flash manufacturing partner Sharp, to capture additional worldwide business in this field.

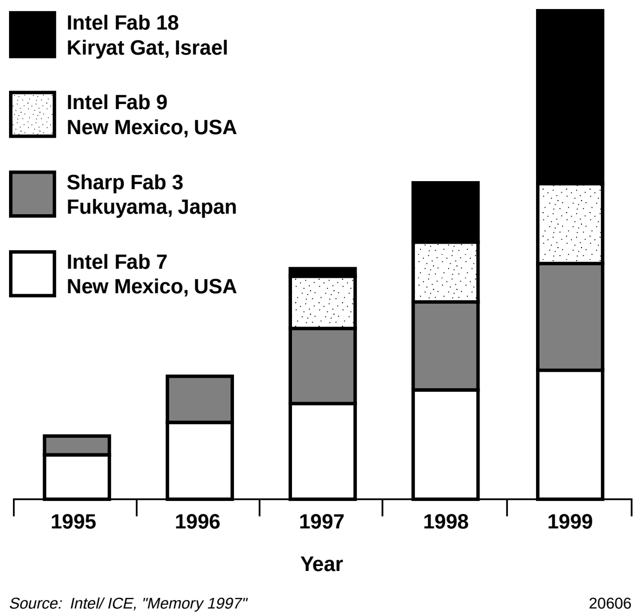


Figure 5-23. Intel's Flash Memory Capacity Projection

Intel also started construction of 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.

Macronix

Macronix is Taiwan's largest flash memory supplier, providing parts ranging from 1Mbit and 2Mbit, to 5V 16Mbit densities. It turned up the production of its flash products to meet growing demand in Taiwan and throughout the world. It sampled an 8Mbit product line in 1Q97. Through its new 200mm wafer fab that came on-line in 2Q97, the company hopes to triple its flash revenue in 1997.

Micron

After converting most of its fab capacity to 200mm wafers and hoping to shelter itself from a limp DRAM market, Micron announced that it started production of 2Mbit and 4Mbit SmartVoltage boot block (i.e., Intel compatible) flash memory devices. Although the company has bet on the multiple-voltage approach for now, it expects to eventually move to single-voltage parts.

Motorola

Motorola said that it would begin to second-source Mitsubishi's divided bit line NOR (DINOR) flash memory devices. Motorola joins Hitachi, which previously signed a joint-development agreement with Mitsubishi, as alternate sources for the DINOR technology.

Initially, the agreement calls for Motorola to purchase Mitsubishi's finished products for resale under the Motorola brand name. By 2H97, however, Motorola plans to purchase bare die from Mitsubishi to package, assemble, and test to its own specifications. First products from Motorola are expected to be 8Mbit devices.

Nexcom Technology

Flash designer-turned-vendor Nexcom Technology introduced the first two members (4Mbit and 8Mbit) of its high-density flash family in 4Q96. Nexcom's flash products combine NOR-and NAND-based flash structures. The result is a single-cell device that offers the high density of NOR and the quick write times of NAND. The devices include on-chip serial SRAM, which can be used either with or independently of the flash memory. The new memories are expected to appear in portable applications where audio and images, as well as data, require low-power memory for storage and transfer.

Samsung

Samsung is a relatively minor player in flash memory, but the manufacturing giant has big ambitions. As the largest DRAM manufacturer in the world, it has the ability to pursue flash as vigorously as it does the DRAM market.

With big plans in mind, Samsung hoped to break into new markets with its 64Mbit NAND flash device that became available in 1Q97. Samsung thinks it can beat its competitors in the emerging mass-storage market by undercutting them in cost and offering better reliability.

Samsung's initial foray in the flash market, however, has been a rocky one. An ongoing patent infringement case with SanDisk kept Samsung from developing its flash market. SanDisk claims that Samsung copied at least two of its patents. The U.S. International Trade Commission (ITC) may rule to bar Samsung from the U.S. flash memory market if SanDisk's complaint is verified.

Sanyo

In 1Q97, Sanyo began sample shipments of its 8Mbit flash memory chips that operate from a 3.3V or 5V single supply. The company, which started operations at its 0.35µm line at Niigata, plans to produce 80 million flash memory chips in fiscal 1997 (ending March 1998).

SGS-Thomson

Amid reports of a possible shortage of flash memory capacity, SGS-Thomson joined a growing list of companies that made announcements of expanded fabrication capacity for flash ICs. In 1H97, it increased production capacity for flash memories with particular emphasis on 2Mbit and 4Mbit devices. Moreover, the company was working quickly to qualify its 200mm fab in Catania, Sicily, to gain additional flash fab capacity in 1997. ST expects its Catania fab to begin volume production of flash devices in 2H97.

SGS-Thomson offers both multiple-voltage and single-voltage only flash parts to its customers. ST intended to sample Intel-compatible 8Mbit flash devices in 2Q97, ramp production of the devices in 3Q97, and come to market with 16Mbit flash chips in 1998.

Sharp

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

In building nearly half of the flash devices 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 16Mbit products, dual-works flash (affording simultaneous read and write / erase functions), and chip-size packages (CSP).

Also, Sharp increased flash 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 fab in Hiroshima.

Siemens

The European memory IC giant outlined a plan to move into flash-memory manufacturing as the next step necessary to balance its product portfolio and reduce risk in its memory business. Siemens desires to go at flash production alone rather than in a joint venture. The company currently embeds flash memory in its logic chips and microcontrollers.

Silicon Storage Technology (SST)

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

Texas Instruments

TI introduced a series of, 1Mbit, 2Mbit, and 4Mbit flash devices with separate versions that conform to both Intel (dual supply / autoselect) and AMD (single supply) standards (Figure 5-24). By 2H97, the company hopes to develop a basic 8Mbit design that can be tailored for either standard by changing the metal mask, a step TI claims is a relatively simple manufacturing adjustment.

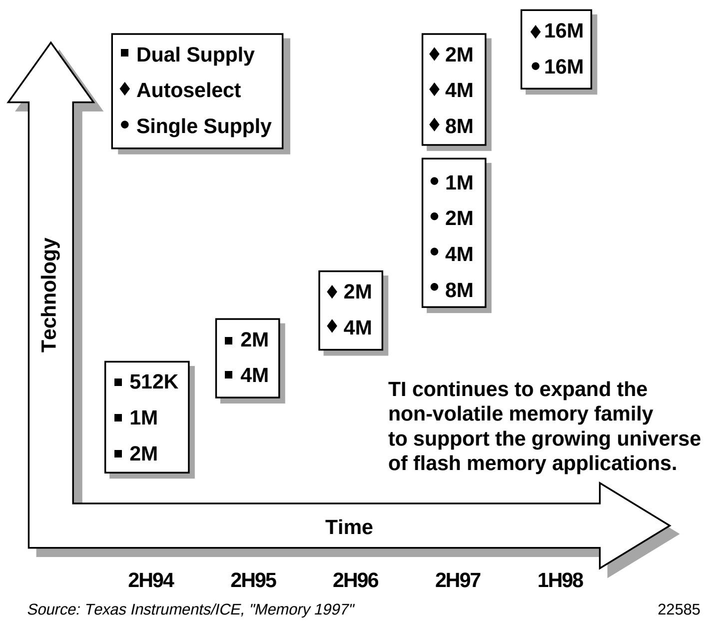
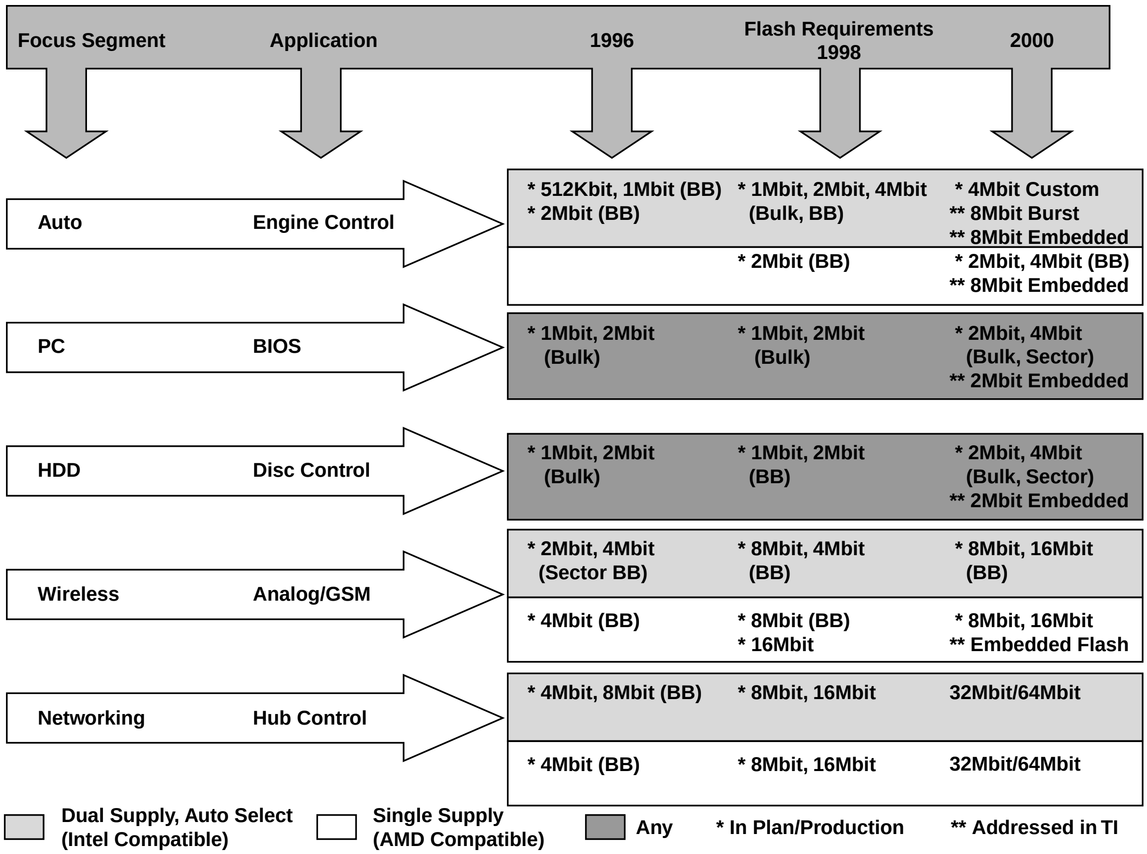


Figure 5-24. TI's Flash Memory Evolution

TI also revealed its plans to move to 4Mbit custom, 8Mbit burst, and 8Mbit embedded flash for the auto and engine control markets by the year 2000 (Figure 5-25). At the high end, the firm plans to offer 8Mbit and 16Mbit flash for networking and hub control applications by 1998, and 32Mbit and 64Mbit devices by the year 2000.

To build all these devices, TI announced that it signed a $1.2 billion agreement with the Italian government to build a 300mm (12-inch) wafer fab in Avezzano, Italy, to manufacture its flash products. Dubbed AMOS 3, the fab will initially use a 0.28µm process that is scaleable to 0.18µm and below. Volume production at the facility is currently slated for sometime in 1Q99.



Source: Texas Instruments/ICE, "Memory 1997"

22586

Figure 5-25. TI's Flash Target Segments

Toshiba

Toshiba supplies flash devices with densities ranging from 1Mbit through 64Mbit. It commercialized both 3.3V NAND (16Mbit, 32Mbit, and 64Mbit) and NOR (1Mbit, 4Mbit, and 8Mbit) flash devices that are targeted for a wide variety of end uses. The 64Mbit NAND devices, built using 0.4µm technology, were expected to sample in mid-1997 with volume production reaching 600,000 units by the end of 1997. Prices were set at $65 in 1,000 piece quantities.

Toshiba teamed with Samsung to create an alliance to build compatible NAND-type flash devices that exclusively target the mass-storage market. The two companies initially conceded the NOR market to Intel and AMD, but by 4Q96, each feared losing out on the booming wireless phone market and emerging PC boot-up market, where NOR devices hold a distinct market lead. As a result, both companies introduced NOR-based flash devices in 1Q97.

Responding to the needs of cellular phones and other small, mobile products, Toshiba and Fujitsu jointly agreed on a common specification for a 48-pin ball-grid-array (BGA) package that will house many different memory chips, including flash memory devices, in a single package. The BGA configuration is aimed at encasing flash and SRAM in a multichip package that occupies 70 percent less space than conventional methods of using TSOPs.

Winbond

Taiwan's largest SRAM maker, Winbond, offers a line of "split-gate" architecture flash memories licensed from Silicon Storage Technology. The company's latest offering is a 5V 2Mbit device with 70ns access time. It plans to increase production of this and all its flash devices during 1997.

Xicor

Xicor offers parts ranging in density from 1Kbit to 16Kbit. Unlike other vendors, Xicor is interested solely in code storage for embedded portable applications. Small sector sizes, low pin count, and low voltages are the technology's strengths.

TRENDS IN FLASH MEMORY

Applications

To date, the main applications for flash memory have been small, portable, and/or mobile electronic products. Some estimates show that as much as 90 percent of all flash devices eventually end up in some embedded application such as memory cards, pagers, or cellular phones. Telecom, including hubs, network switches, and routers are large end-use segments as well. In other words, the communications market dominates flash applications (Figure 5-26).

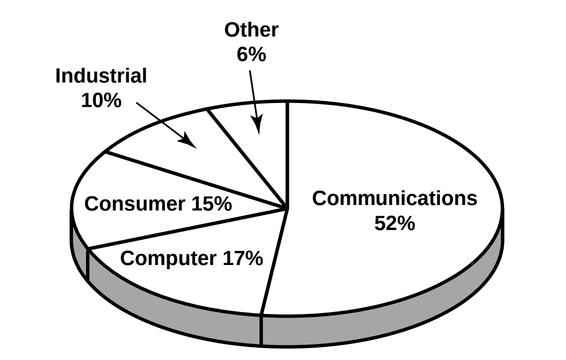


Figure 5-26. 1997 Flash Memory Applications

The automotive segment is also a significant end-use market. Nearly all U.S. engine control systems use flash memory. PC BIOS also ranks among the leading applications of flash devices.

In the coming years, 128Mbit flash memories will form the building blocks for many new applications such as improved digital cameras, program carriers for personal digital assistants (PDAs) and personal computers, and speech storage mediums for solid-state memo takers. Other applications include telephone answering systems and tape recorders.

Architecture

All flash devices are not created equally. What differentiates flash products the most is the architecture used to design them. There are four significant flash architectures that are available (Figure 5-27) to OEMs. The two most prominent architectures are NOR and NAND. Both are based on technology from flash's predecessors, the EPROM and EEPROM, respectively. Of these two styles, the most ubiquitous type is the NOR architecture.

Rivalry exists among vendors as to which 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.

Beyond NOR and NAND are emerging architectures such as Mitsubishi's DINOR architecture. DINOR is an attempt to combine the speed and random access of conventional NOR-type flash chips with the small cell size of NAND flash. Hitachi is promoting its AND structure, and a technology called NexFlash (from Nexcom Technology) promotes high density and low cost per bit.

All of the NOR- and DINOR-style parts are full random-access devices that operate similarly to an SRAM. They allow for fast access. They have address and data buses that provide users with the ability to access any location and read data in just one cycle. NAND- and AND-styles, on the other hand, typically feature a byte-serial access scheme. They are better oriented to file-storage operations as disk-drive replacements. Figure 5-28 provides a sampling of flash devices.

A standard architecture for all flash memory devices will not likely occur within the next five years. Each architecture appears to have advantages depending on the application. In order to hedge their bets and to support the needs of a growing customer base, several suppliers 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 a specific architecture for specific applications.

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)				
1Mbit to 4Mbit	BIOS, EPROM replacement, communications, low-density XIP cards	Not suitable	BIOS, EPROM replacement, communications, low-density XIP cards	Not suitable
8Mbit to 16Mbit	PDA, cellular, networking, low-density ATA cards	PDA, cellular, networking, low-density ATA cards	PDA, cellular, networking, low-density ATA cards	Not suitable
32Mbit to 256Mbit	Not suitable	Not suitable	High-density ATA cards (10-100Mbytes)	High-density ATA cards (10-100Mbytes)

Source: Computer Design/Mitsubishi/ICE, "Memory 1997" 20418B

Figure 5-27. Flash Architectures Stretch to Fit Memory Requirements

	Cell Architecture	Transistors Per Bit	Maximum Density Available*	Main Applications
AMD	NOR	1	16Mbit	Embedded Code
Atmel	NOR	2	4Mbit	Embedded Code
Intel	NOR	1	16Mbit	Embedded Code
Hitachi, Mitsubishi	DINOR	1	16Mbit	Audio, Data, Images, Embedded Code
Nexcom	NOR	1	8Mbit	Audio, Data, Images, Embedded Code
SST, Winbond	Split-Gate NOR	1.5	4Mbit	Embedded Code
Toshiba, Samsung	NAND	1**	16Mbit	Audio, Data, Images
Hitachi, Mitsubishi	AND	1	32Mbit	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/ICE, "Memory 1997" 21773A

Figure 5-28. A Sampling of Flash Products

Capacity

Capacity—whether too much or not enough—was, and continues to be, an issue in the flash memory market much like it has been in other memory segments during the past several years. In early 1997, Intel claimed its flash 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 to the contrary. Although Intel's capacity may be tight, ICE forecasts that overall flash supply and demand will be fairly well balanced during the year. If the industry is to be wary of anything in 1997, it would be the potential for excess flash memory capacity and the resulting 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 fab capacity due to come on-line in 1997.

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

For its part, Sharp intends to make flash product revenue second only to that of flat-panel displays at the company. To do so the company plans to build a $1 billion wafer fab (Fab 4) near Hiroshima, Japan dedicated to flash memory devices. Initially (beginning in 1998), the plant will produce 10,000 200mm wafers a month, but eventually will ramp 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 firm.

AMD and Fujitsu formed a flash alliance that competes directly with Intel and Sharp. AMD/Fujitsu announced the second phase of their joint-venture flash fab in Japan. The phase two is on schedule to be completed in mid-1997 with initial production slated to come on-line in 1998. These leading companies also reduced process feature size in order 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 2Mbit and 4Mbit devices. The capacity increase resulted from ST's yield improvements, technology upgrading resulting in reduced chip size, and in the introduction of new fab capacity in Agrate, Italy. The company is also qualifying a new 200mm fab in Catania, Sicily, as quickly as possible. Flash memory production is slated to begin in 2H97.

Meanwhile, Macronix, Taiwan's largest flash memory supplier began volume production of flash devices in 2Q97 from its new 200mm wafer fab. The company plans to triple its flash 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 fab in Avezzano, Italy, for the manufacture of flash memory devices (although volume production is not expected until 1Q99).

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.

Strangely, Intel is the only company to have mentioned anything about a flash memory capacity shortage even as all these new fab facilities are due to come on-line.

Is it possible for the market to absorb a doubling of flash manufacturing capacity in each of the next few years? Chip makers must think so as the spending for and building of flash facilities is set to increase dramatically. The additional fab capacity could lead to a further decline in average selling prices, even as demand increases, which is contrary to what Intel has mentioned.

A review of flash wafer fab capacity plans from several leading vendors is shown in Figure 5-29.

Small Form-Factor Flash Memory Cards

With the promise of huge potential markets for handheld 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 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 devices, there is not a "one size fits all" standard for miniature flash cards. However, end users have begun to understand which formats are best matched with specific applications.

SanDisk Corporation (formerly SunDisk) remains the front-runner in the miniature card market with its CompactFlash series of products. It first had working prototypes in 1994. In only a few short years, its format won the support of over 40 companies who are participants in the CompactFlash Association (CFA), the largest forum.

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 8Mbit, 16Mbit parts for Intel. Also builds its own line of 2Mbit, 4Mbit, 8Mbit, and 16Mbit 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, "Memory 1997" 20079D

Figure 5-29. New Flash Capacity to Meet Demand

The company claims its product is the smallest removable data-storage system. CompactFlash is a matchbook-sized ATA-compatible card, but is less than one-fourth the size of a standard Type II PCMCIA card. Another of its attractions is its built-in controller, interchangeability regardless of flash-memory architecture, and dynamic 3.3V/5V support.

At higher densities, momentum has grown for CompactFlash, especially as "film" for digital cameras. It boasts an impressive list of design wins in this arena. It has been selected as the "film" for Canon's PowerShot 600 digital camera. In 1996, Canon had the largest share of the worldwide digital camera market. Kodak's DC50 also uses CompactFlash cards as its storage medium as do Polaroid's digital cameras. For digital cameras and other uses, SanDisk has planned for densities of up to 100Mbits in 1997 and up to 500Mbits by the end of the decade.

Photographic film manufacturers believe it will be difficult for "digital film" to replace conventional film in 10-20 years, but do acknowledge that digital cameras will impact the market. While digital cameras still have a long way to go in terms of good resolution at an affordable price, it may be only a matter of time before consumers desire—even demand—digital photography technology.

Other announced products that use SanDisk CompactFlash include IBM's Palmtop PC-110 computer and an audio recorder from Matsushita. In other markets, CompactFlash has been selected for factory-floor computers, network hubs, telecommunications systems, medical monitors, global positioning systems, and security systems.

Meanwhile, support for the Miniature Card is formidable. It includes the two largest flash memory suppliers—Intel and Advanced Micro Devices, as well as Microsoft, Compaq Computer, Sharp, Philips, and Fujitsu.

The Miniature Card is slightly smaller than SanDisk's CompactFlash card. Unlike CompactFlash, the Miniature Card requires a software driver and does not offer plug-and-play compatibility across products from several vendors. Instead, the host computer requires flash translation layer software (FTL) to control the flash memory. Such software is readily available. Microsoft (an MCIF supporter) is one supplier. Additionally, since the Miniature Card does not include a controller chip, its price should be lower than that for CompactFlash and will therefore play a major role in cost-sensitive consumer applications.

Again, as in the flash memory market, each of the leading proponents of CompactFlash and Miniature Card have hedged their bets against future developments of the memory card market. SanDisk and Intel signed a cross-licensing agreement in which each licensed the other's patents covering the design and manufacture of flash-memory products.

The SSFDC, developed and championed by Toshiba, is the thinnest of the three competing flash-card packages. It measures 45mm x 37mm x 0.76mm—about half the area and the same thickness as a credit card. Despite being the last of the three competing miniature flash cards to be brought to the market, support for the SSFDC appears to be building. This is especially evident in Japan, where the device has been used in many low-cost consumer applications. The basic, controller-less, stamp-sized card—no more than a single chip in an overmolded package less than one millimeter thick—is attracting the attention of those OEMs who need low density and low cost for their applications. Some manufacturers believe SSFDC devices will sell in off-the-shelf retail outlets for as little as $1 / Mbyte in the year 2000.

As with the competing organizations, vendors in the SSFDC Forum include both OEMs and chip suppliers. Among the companies are Fuji, Sega, Cirrus Logic, Samsung, and National Semiconductor.

A brief review of the three miniature flash memory card formats is shown in Figure 5-30.

	CompactFlash	Miniature Card	SSFDC
Original Developer	SanDisk	Intel/AMD	Toshiba
Industry Alliance	CompactFlash Association (CFA)	Miniature Card Implementers Forum (MCIF)	SSFDC Forum
Forum Members	Apple, Canon, HP, LG Semicon Motorola, NEC, Panasonic, Polaroid, others, (40 Total as of 1Q97)	Microsoft, Compaq Computer, Sharp, Philips, Fujitsu, others (38 Total as of 1Q97)	Fuji, Sega, Samsung, National Semiconductor, and others
Module Dimensions	43 x 36 x 3.3mm	38 x 33 x 3.5mm	45 x 37 x 0.76mm
Contacts	Circular Pins 50-Pin Subset of PCMCIA 68-Pin Slot	Flat-Edge Contacts, Uses rubberized connector with 40 embedded silver conductors or pads	Flat Surface Contacts
Software Interface	ATA	Host-Base File System	Host-Based Controller
Built-In-Controller?	Yes	No	No

Source: Computer Design/ICE, "Memory 1997" 22588

Figure 5-30. Small Form-Factor Flash Memory Card Comparison

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 vendors now embed flash memory onto their microcontroller or other logic device. Typical embedded code applications include smart sensors, rolling code remote-keyless-entry, home security systems, and space-constrained applications such as pagers.

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, flash memory on-chip significantly lowers the system power consumption, and on-chip flash provides higher reliability. On-chip flash also accelerates product testing, allowing easy substitution of test vectors for operating code during the final assembly stages. Additionally, product scrapping due to misprogramming or bugs is no longer an issue as every device is reprogrammable. In summary, on-chip flash helps reduce time-to-market for many systems at only a marginally higher cost.

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

Microchip Technology features a 2V 8-bit flash microcontroller. Also, Toshiba introduced a 16-bit MCU with 64Kbit of flash memory and NEC, in 4Q96, sampled its 3V 16-bit MCU with 128Kbit of built-in flash memory.

Hitachi developed a 32-bit RISC MCU that is offered with 128Kbit or 256Kbit of built-in flash memory and began sampling the part in 1Q97. Sanyo teamed with Silicon Storage Technology to offer 8-bit and 16-bit MCUs with flash memory. And, Lucent Technology provides flash memory built into its DSP devices (FlashDSP).

Multi-Level Cell Technology

Currently, flash devices store one bit of data in each memory cell. However, for some time, engineers have envisioned storing more than one bit of data in each memory cell. The process focuses on peripheral circuitry that can sense the two different voltage levels used in MLC cells. That concept is not far away. Multi-state flash (Intel calls it multi-level cell—MLC—flash, SanDisk calls it "Double Density" or "D2") is a great way to boost density in memory cells without greatly increasing the size of the die.

Two leaders in implementing this technology are SanDisk and Intel. 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, has used the technology in flash memory devices to boost single-chip capacity to 64Mbit. The SanDisk implementation can store four discrete voltage levels in each NOR cell, thereby representing two bits per cell. SanDisk claims that the 64Mbit die is only 10 percent larger than the company's 32Mbit die. It hoped to offer samples of its device in 1Q97. Meanwhile, the company is also working on a 256Mbit "Double Density" flash device.

Intel planned to unveil its long-awaited MLC-based 64Mbit flash device in 2Q97. With its MLC product, Intel plans to target the market for NAND-flash by offering comparable (or better) performance at a lower price.

Voltage

Another trend being addressed in the flash market is that of single- versus dual-supply voltage, and the implementation of low-voltage parts. Growth of the flash memory market is due in large part to the fact that flash devices are used in mobile and portable devices. Accordingly, the market for low-voltage flash devices is forecast to grow to match demand for low-voltage operating systems.

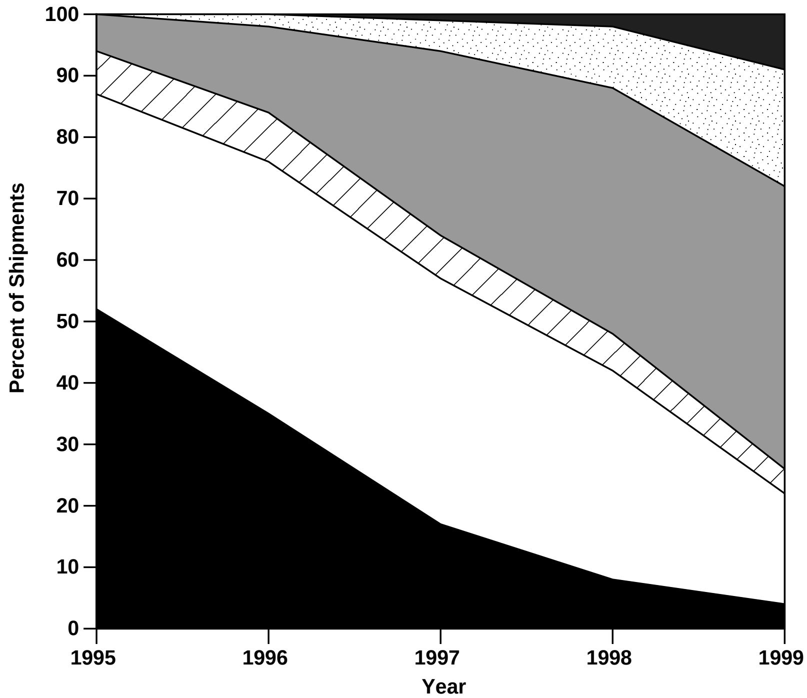
Early bulk erase flash memory, requiring external 12V supplies and manual program/erase control, have been largely overtaken by second, third, and even fourth generation single-voltage devices. Low-voltage is now the name of the game in the flash memory market.

It is no secret that these mobile/portable devices often mandate low-voltage ICs to function within the system. Besides these battery-powered portable applications, demand has escalated as embedded systems designers of set-top boxes and network interface cards have opted for 3.3V flash devices rather than use a 5V device and a voltage translator.

Intel offers its SmartVoltage devices, which provide several voltages for reading and erasing data from storage. AMD, on the other hand, is among the leading proponents of single-voltage flash devices. Currently, both dual and single-voltage parts have advantages. Again, the end user usually determines the best device to implement into the design.

Besides these, a new generation of 3.3V-and-lower-voltage devices emerged in 1996 to meet growing demand. These single power supply parts operate over an extended voltage range and feature very low standby and sleep-mode power requirements without compromising access speed or functionality.

Long-term, ICE believes that users will design single-voltage devices into their systems. Flash unit shipments quickly shifted to single, low-voltage (5V/5V and 3V/3V, read/erase-program) parts in 1996 and are forecast to continue migrating to lower voltages (Figure 5-31).



	1995	1996	1997	1998	1999
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/ICE, "Memory 1997" 20594B

Figure 5-31. Percentage of Flash Unit Shipments By Read/Erase-Program Voltage