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The Rise of the Flash Memory Market: Its Impact on Firm Behavior and Global Semiconductor Trade Patterns

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Abstract

This article addresses three questions about the flash memory market. First, will the growth of the flash memory market be a short- or long-term phenomenon? Second, will the growth of the flash memory market prompt changes in firm behavior and industry structure? Third, what are the implications for global semiconductor trade patterns of flash memory market growth? The analysis concludes that flash memory market growth is a long-term phenomenon to which producers have responded in four distinct ways. It also concludes that the rise in flash memory demand has intensified current semiconductor trade patterns but has not shifted them fundamentally.

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Introduction

The past few years have witnessed rapid growth in a particular segment of the semiconductor market known as flash memory.[2] In each of the past five years, for example, flash memory market growth has either outpaced or equaled that of the total integrated circuit (IC) market[3] (McClean et al 2004-2007, section 5). One observer expects flash memory to have the third-strongest market growth rate over the next six years among all IC product categories (McClean et al 2007, 5-6). As a result, the flash memory share of the total IC market has increased from 5.5 percent in 2002, to 8.1 percent in 2005. As a share of the memory market segment, flash memory has increased from 28.7 percent to 38.2 percent during the same period. In short, the flash memory market has quickly become a significant part of the overall semiconductor market that cannot be ignored; some predict it will soon compete with the dynamic random access memory (DRAM) market for dominance within the memory sector in the not-too-distant future (McClean et al 2007, 5-4).[4]

Given its market size and projected growth, flash memory is likely to have an increased impact on the global semiconductor industry, and the decisions that flash memory producers make are likely to have a significant influence on industry evolution. These decisions have already been as dynamic as the recent performance of the flash memory market. Some firms have shifted production from other products to flash memory. In addition, some other firms have partnered to gain flash memory market share. Also, some firms have aggressively moved to lock in long-term deals with certain flash memory consumers.

This article will address three questions about the flash memory market. First, will the growth of the flash memory market be a short- or long-term phenomenon? Second, will the growth of the flash memory market prompt

[2] Flash memory is a type of nonvolatile memory that can be electrically erased and reprogrammed. Nonvolatile memory is memory that retains data when the power is turned off. Flash memory costs less and includes more functionality than other forms of nonvolatile memory.

[3] The semiconductor market is composed of two main subsets, the integrated circuit (IC) market and the optoelectronics, sensors, and discretes (O-S-D) market. The IC segment of the semiconductor market is by far the biggest (85 percent in 2006) and comprises semiconductors that are harder to manufacture, more advanced, and more expensive. Flash memory is a type of IC.

[4] DRAM is a popular type of volatile memory used mainly in computers. Compared to nonvolatile memory, volatile memory loses data when powered down. DRAM composes the largest share of the memory market, though flash memory has eroded its lead in recent years.

changes in firm behavior and industry structure? Third, what are the implications for global semiconductor trade patterns of flash memory market growth?

The analysis concludes that (1) flash memory market growth is a long-term phenomenon; (2) flash memory producers have responded to flash memory market growth in four distinct ways: choosing to produce flash memory rather than nonvolatile memory, entering into flash memory production, increasing flash memory production and production capacity, and partnering with each other; and (3) increased demand for flash memory and the response of producers to meet this demand have intensified current semiconductor trade patterns but has not shifted them fundamentally.

Flash Memory To Endure

The semiconductor industry has experienced many changes since flash memory first appeared in the early 1980s, one of the most dramatic and long-term of which has been the rise of the consumer electronics market as a demand driver for semiconductors. This rise in the consumer electronics market has fueled flash memory market growth and helped to make flash memory a prominent segment within the semiconductor industry.

Broadly speaking, flash memory ideally suits the consumer electronics market, because it bestows upon electronic devices two qualities that the market demands: mobility and miniaturization. For example, cell phones, a major application for flash memory, require data storage to save and store frequently called numbers and perform other convenient functions for which a traditional hard drive would prove impractical; such information would be erased every time the phone were turned off. Because (1) flash memory is small, reliable, and (2) its memory is nonvolatile, numerous applications not practicable with traditional data storage technology are emerging. Flash memory brings mobility and miniaturization to electronics products, two defining features of most consumer electronics products today.

Given capabilities and attractiveness of flash memory to the consumer market, it is clear why demand for it has rapidly grown. Flash memory allowed existing electronic products to adopt mobile and miniature qualities they did not have before and thus opened them up to new and very large consumer markets. In addition to cell phones, USB flash memory drives function as portable and smaller floppy drives. Flash memory has also prompted the growth of new consumer applications. Flash memory is an important component in popular devices such as DVD players, digital cameras, MP3 players, personal digital assistants (PDAs), and global positioning systems (GPS), all of which could not function without flash memory (McClean et al 2004, 7-2, and 2005, 7-3).

Origins and Early Growth

When flash memory first appeared in the early 1980s, most industry observers hardly took note. The few that did most likely would not have predicted then that the flash memory market would become a major segment of the global semiconductor market (box 1). Once flash memory fully emerged in the early 1990s, the initial industry consensus was that it had growth potential, but certain concerns made its growth trajectory uncertain. First, which markets would drive flash memory market growth? Second, how would flash memory compete against other types of nonvolatile memory technologies? Third, given its high price, how long would sluggish early sales continue?

Box 1 Fujio Masuoka, the Inventor of Flash Memory

The first flash memory device was invented in 1981 by a midlevel factory manager at Toshiba Corp. (Toshiba) named Fujio Masuoka. Masuoka wanted to create a device that would retain its memory after having been powered down. Up until then the main type of memory that existed was volatile memory such as DRAM, which lost its memory when the device was powered down. For example, any data created on a personal computer (PC) using such memory had to be saved to the PC's hard disk drive. Masuoka sought to create a chip that improved upon DRAM and hard disk drives. According to Masuoka,

> "Simply put, I wanted to make a chip that would one day replace all other memory technologies on the market. In the 1980s, the market for data storage on PCs was dominated by magnetic tape and disk drives0.Going after [the memory storage] market was the obvious thing to do for me..."

The industry was initially slow to recognize Masuoka's invention and realize its potential. It was not until 1985, four years after patent filing, that the industry was introduced to the device at a conference, and some firms realized flash memory potential. Intel asked for a sample of the new chip and in 1987-88 announced mass production of its own version of flash memory. Soon thereafter, Toshiba began mass production of flash memory.

Source: *Business Week* 2006a and 2006b.

These concerns proved to be unfounded as the flash memory market began to grow in the early 1990s (table 1). First, the most significant factor in flash memory growth was the emergence of the portable and laptop PC market as a growth driver. Flash memory provided the proper benefits of size, power dissipation, reliability, and speed for this expanding market (ICE 1992, 6-48).

The demand for flash memory created by portable and laptop PCs in the early 1990s hinted at a long-term trend within the semiconductor industry that would fuel flash memory market growth: the emergence of the consumer electronics market as the primary driver of end-use demand in the semiconductor industry. Second, within the nonvolatile memory sector, flash memory competed primarily against two other technologies called EPROM and EEPROM. In terms of price and functionality, flash memory fell somewhere in between these two technologies, effectively competing for space at the start of the 1990s (ICE 1992, 6-47). Third, regarding prices, in 1992 flash memory demand received a boost when Intel, the leader in flash memory production at the time, effectively lowered flash memory price-per-megabit ratio (ICE 1992, 6-49). Understanding the future demand for flash memory, Intel decided in 1991 to focus its nonvolatile memory production on flash memory and away from EPROM (ICE 1992, 6-49).

TABLE 1 The Rise of the Flash Memory Market

	Flash memory market (USD Million)	Flash memory market annual percentage growth	Flash memory as percentage of total semiconductor market	Flash memory as percentage of total memory market
1990	35		0.1	0.3
1991	135	286	0.3	1.0
1992	270	130	0.5	1.8
1993	640	106	0.8	3.0
1994	865	35	0.9	2.7
1995	1,860	115	1.3	3.5
1996	2,611	40	2.0	7.2
1997	2,702	3	2.0	9.2
1998	2,493	-8	2.0	10.8
1999	4,561	83	3.1	14.1
2000	10,637	133	5.2	21.6
2001	7,595	-29	5.5	30.5
2002	7,767	2	5.5	28.7
2003	11,739	51	7.1	36.1
2004	15,611	33	7.3	33.1
2005	18,569	19	8.2	38.3
2006	20,275	9	8.1	34.4

Source: WSTS and IC Insights.

End-use Demand

Scholars have noted that shifts in semiconductor end-use demand have historically fueled the growth and specialization of certain types of semiconductors, thereby benefiting firms or regions or both that specialized in their production (Langlois and Steinmueller 1999, 68). The birth of the semiconductor industry in the United States in the 1950s was fueled by U.S. military demand for high-performance semiconductors. The growth of the PC industry in the late 1980s and early 1990s spurred demand for microprocessors (Langlois and Steinmueller 1999, 23 and 52).

Since the mid-1990s the importance of the consumer electronics market as a source of end-use demand has grown dramatically, and it is predicted to increase. In 1993, consumer markets accounted for a little over 20 percent of the overall semiconductor market (Gartner Dataquest 2004, Tully). Corporate and military demand were the primary market drivers of the semiconductor industry then, and historically in the United States these and other sources had always accounted for a much greater share of semiconductor end-use demand than the consumer market (Langlois and Steinmueller 1999, 37). However, since 1993 the consumer electronics market has increased its share of the overall semiconductor market, leading one market research firm to predict that by 2013, consumer markets will account for more than 50 percent of the overall semiconductor market, roughly a 30 percent increase in the share of the semiconductor market in 20 years (Gartner Dataquest 2004, Tully).

Therefore, flash memory has quickly become an integral component in an end market of growing and sustained significance to the semiconductor industry. The question is how long will its importance last? Is flash memory growth truly a long-term phenomenon? If the prediction is correct that the consumer market will account for over 50 percent of the semiconductor market by 2013, then it is highly likely flash memory demand will continue to grow.[5]

Changes in Firm Behavior and Industry Structure

Semiconductor producers have devised various strategies to meet the increased demand for flash memory and obtain market share. At the beginning of flash

[5] Alternative nonvolatile memory solutions exist and could potentially challenge flash memory, though industry experts believe that these alternatives will not be widely used for many years. Such alternatives include FeRAM, NVRAM, PRAM, and C-RAM. *IC Insights* 2007, 7-15 and 7-16; and industry official, phone interview by Commission staff, April 18, 2007.

memory growth, producers of flash memory had to decide whether to switch production from other nonvolatile devices to flash memory. When flash memory growth exploded in the late 1990s, existing firms increased production and firms producing nonflash memory began production. More recently, firms have partnered to gain a leg up on the competition. The following describes these four firm behaviors and considers their impact on the semiconductor industry.

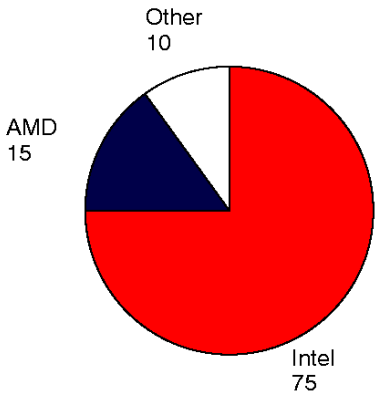
Which Nonvolatile Memory To Produce?

For firms producing nonvolatile memory in the early 1990s, uncertainty existed over which nonvolatile memory technology would take off—flash memory, EEPROM, or EPROM—thus making the decision to produce flash memory difficult. In addition, with flash memory accounting for less than 1 percent of the memory market in 1990, many firms had more immediate priorities than to focus on a technology with little demand. Decisions to produce flash memory fell into three general categories: (1) all in, (2) partially in, and (3) all out. Intel was one of the only nonvolatile memory producers that decided to go "all in" to flash memory production. In 1991, the company made the strategic decision to shift focus from EPROM to flash memory (ICE 1992, 6-49). More firms decided on the "partially in" strategy. Some were motivated by Intel's announced pull out of EPROM production to stay in that market (for example, AMD, SGS-Thomson, Fujitsu, and Texas Instruments), but they also wanted to maintain some flash memory production, especially at higher densities where some believed flash memory was superior to EPROM in terms of its functionality/cost ratio (ICE 1992, 6-49). Finally, some firms were unable to compete in the flash memory market and exited the market, such as Seeq Technology (ICE 1992, 6-49).

Intel's leap into the flash memory market proved critical in a technology that would soon dominate the nonvolatile memory market. By 1992, Intel had captured 75 percent market share of the flash memory market (figure 1) (ICE 1993, 6-52). Once it was obvious that flash memory would be the dominant nonvolatile memory technology, many of the firms "partially in" to flash memory production changed strategies and increased production or jumped into an "all in" strategy. In 1995, AMD, Fujitsu, Atmel, and SGS-Thomson followed this strategy, reclaiming flash memory market share from Intel, which saw its share of the market drop to 42 percent (figure 1) (ICE 1996, 8-20).

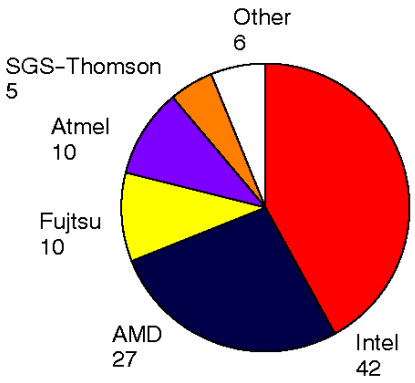
Figure 1 Changing Flash Memory Market Share, selected years *(percentage)*

Flash Memory Market Share, 1992 ($310 million)



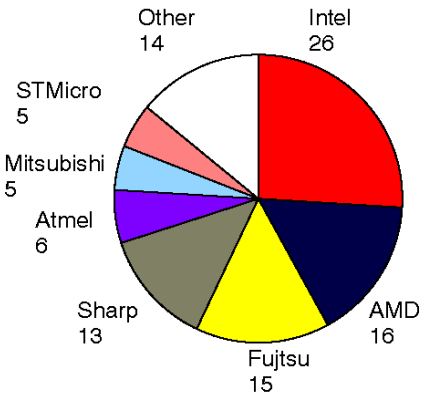
Source: ICE.

Flash Memory Market Share, 1995 ($1.9 billion)



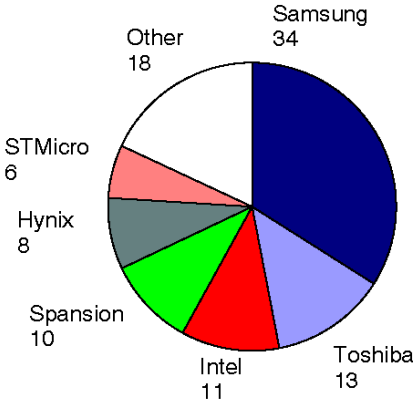
Source: ICE.

Flash Memory Market Share, 1999 ($4.7 billion)



Source: ICE.

Flash Memory Market Share, 2005 ($20.5 billion)



Source: Web-Feet Research.

New Producers Entering Market

The fragmentation of the flash memory industry continued in the late 1990s, as a small number of existing flash memory producers struggled to satisfy the increasing demand for flash memory. Seeing the opportunity to enter a growing market, other semiconductor firms (e.g. Samsung, Toshiba-SanDisk) commenced flash memory production. Thus, the number of flash memory producers went from less than 15 in 1995 to at least 28 in 2005 (ICE 1996, 8-22 and Web-Feet Research 2006, Niebel).

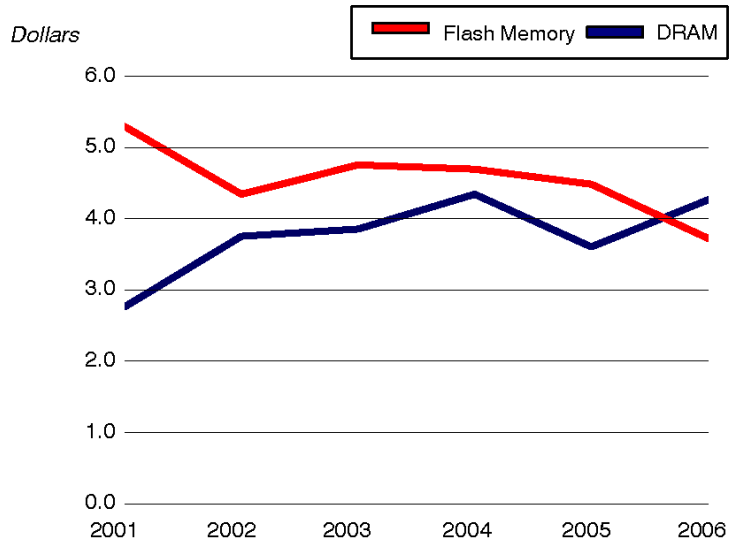
The entrance of new producers has had several effects on the industry. Besides initially helping to supply the exploding demand for flash memory at the end of 1998 and 1999 (though their presence and the increased production of existing producers still did not fully satisfy demand in 1999) and helping to lower Intel's market share from 42 percent in 1995 to 26 percent in 1999 (ICE 1996, 8-20, and 2000, 68), the biggest effect of new flash memory producers has been the disruption of supply-demand balances in the flash memory and DRAM markets. This is because the recent entrants have included a host of DRAM producers who have shifted portions of their DRAM capacity to flash memory, in particular the ever popular NAND flash.[6] Many DRAM producers were lured by the higher average selling price of flash memory from 2001-2005 (figure 2) and the saturation of the DRAM market. For example, Samsung, which is the world's leading supplier of both DRAM and flash memory, has accelerated production of flash memory and delayed its DRAM expansion plans (McClean et al 2006, 7-17).

Ironically, DRAM producers' entrance into flash memory production has actually contributed to defeating their original purpose for entering: flash memory's average selling price dropped below that of DRAM in 2006 due to oversupply and currently DRAM is more profitable (figure 2). It is uncertain if these short-term supply-demand imbalances in flash memory and DRAM will continue (LaPedus and McGrath, 2007) and if producers will continue to shuffle their production in search of higher average selling prices.

Estimating proper supply for the flash memory market is complicated by the unpredictable nature of flash memory demand – it is unclear what consumers will deem the next great gadget to drive the market, and when it will appear.

[6] NAND is a flash memory architecture that provides fast write speeds, a useful feature for storing large amounts of data (often used for digital photos, MP3 files, and other multimedia applications). The other type of popular flash memory architecture is NOR, which provides fast read speeds, a useful feature for quickly pulling data out of memory (cell phones are a major application). Currently, almost all flash memory is based on either NAND or NOR architectures.

Figure 2 Flash memory and DRAM average selling prices



	2001	2002	2003	2004	2005	2006
Flash Memory	5.29	4.34	4.75	4.69	4.48	3.72
DRAM	2.76	3.75	3.85	4.34	3.60	4.26

Source: IC Insights.

One bright note in this supply-demand challenge is that a chronic oversupply or undersupply situation for either flash memory or DRAM is less likely given that now a small group of producers exists that are skilled in switching between flash memory and DRAM production.

Flash Memory Producers Increasing Production and Production Capacity

From 1991 to 2006, the flash memory market grew by 63 percent a year (calculated from various ICE and IC Insights reports) and grew from one-quarter of one percent to over 8 percent of the overall semiconductor market during this period (calculated from various ICE and IC Insights reports). Between 1995 and 2006 capital spending on flash memory grew from 3 percent to 20 percent of overall semiconductor capital spending (McClean et al 2007, 4-15 to 4-16). Because of the long-term growth forecast of flash memory,

positive current producers are likely to continue increasing production and production capacity.

Producers use four primary methods to increase flash memory production and production capacity. One of the fundamental methods firms use to increase production is transitioning to smaller production process geometries. Semiconductors are produced in batches on silicon wafers. Switching to smaller production process geometries allows firms to produce more chips per wafer, thus increasing chip production. Second, firms can increase their flash memory production by shifting existing chip production capacity from other chip production to flash memory production.[7] Shifting existing production capacity allows firms to produce flash memory relatively quickly and cheaply. Recently, one firm has shifted existing production capacity from DRAM to flash memory in months instead of years and for millions of dollars instead of the billions of dollars required to build a new state-of-the-art semiconductor fabrication facility (McClean et al 2007, 8-15).[8] A third option for increasing production is to buy existing semiconductor facilities when available and convert them to flash memory production. Finally, for those firms that have the financial resources, building new flash memory capacity from the ground up is an option, albeit a very expensive and high-risk venture.

These methods of increasing production require different amounts of spending, and it is significant that flash memory producers have used the most costly method of increasing production. Flash memory producers have increased their production *capacity*, which is a strong indication they believe flash memory is a long-term phenomenon; they would not make such an investment otherwise.

Indeed, a clear distinction in spending exists in the semiconductor industry between increasing production and increasing production capacity. Increasing production through R&D investment is a necessary reality in the semiconductor industry. Firms constantly attempt to increase production by increasing the number of good die per wafer, increasing the number of wafers processed per month, and shrinking the size of the die on wafers. The average R&D spending of a semiconductor firm as a percentage of sales is usually between 10 and 20 percent. In 2006 the average was 15.5 percent (McClean et al 2007, 16-5). Though this investment in production is costly,[9] increasing production capacity, by converting existing capacity, buying existing capacity, or building new capacity, is more costly. In 2006, the majority of semiconductor firms invested less than $1 billion in R&D (McClean et al 2007, 16-5). By contrast, the

[7] Samsung, a major producer of DRAM, employed this strategy during the late 1990s to enter the flash memory market. *IC Insights* 2000, 66.

[8] In 2006, the construction of a new state-of-the-art semiconductor fabrication facility was estimated at $2.5 billion. *IC Insights* 2007, 16-6.

[9] The only industry that spends more on R&D as a percentage of sales is the biotechnology industry. *IC Insights* 2007, 16-3.

construction of a new state-of-the-art semiconductor fabrication facility in 2006 cost an estimated $2.5 billion.

It is possible, however, that a continual increase in flash memory production capacity may lead to chronic oversupply as evidenced by the decline in flash memory average selling price in 2006. Downward pricing pressure may lead to competitor consolidation. Historical lessons from the DRAM industry, where regular overspending led to downward pricing pressures and consolidation, are a case in point (McClean et al 2007, 4-15). The nature of end-use demand for flash memory, however, is different than it was for DRAMS when overspending occurred. The future strength and stability of the flash memory market depends largely on development of new and diverse sources of demand from the consumer market coupled with producer sensitivity to creating overcapacity.

Flash Memory Producers Partner

Firms have also sought to increase their share of the growing flash memory market through partnerships (box 2). Partnering has emerged as a way for firms to rapidly increase production without heavily investing in new fabrication facility construction.[10] It has also permitted firms to share R&D and manufacturing resources for mutual advantage in joint technology development, allowing both partners to become more competitive. Intel and Micron created IM Flash Technology to combine "Micron's expertise in developing NAND technology and operating highly efficient manufacturing facilities with Intel's multi-level cell technology and history of innovation in the flash memory business..." and to bring together "the manufacturing technology, assets, experience and scale necessary for Intel and Micron to successfully compete in the NAND flash memory business...." (Intel and Micron, joint press release, November 21, 2005).

Thus far, partnering has occurred between relatively equally matched firms looking to combine resources to gain market share in a rapidly growing market. If supply consistently exceeds demand, the nature of partnering may change to where stronger firms take over struggling firms. However, since most flash memory producers manufacture other semiconductors, the fall in prices for flash memory, even if persistent, will not lead quickly to consolidation.

[10] One industry expert estimates that a quarter to a third of current flash memory production comes from partnered firms. Industry official, phone interview by Commission staff, April 18, 2007.

Box 2 Major Partnerships among Flash Memory Producers

IM Flash Technologies (IMFT) – joint venture between Intel and Micron

- Began operations on January 6, 2006 to manufacture NAND flash memory for the exclusive benefit of its partners.
- Key elements: Intel owns a 49 percent interest while Micron owns 51 percent; companies share output generally in proportion to their investment; costs for product and process development are generally split evenly; product design and other research and development costs are shared equally. Micron contributed land and facilities in Lehi, Utah, a fully paid lease of a portion of its manufacturing facility in Manassas, Virginia, a wafer supply agreement to be supported by its operations located in Boise, Idaho, and $250 million in cash. Intel contributed $1.196 billion in cash and notes.

Hynix and STMicroelectronics – joint venture in China

- Signed and announced a joint venture agreement in 2004 to build a front-end memory manufacturing facility in Wuxi City, China. Construction began in 2005. The fab will employ roughly 1,500 people and will feature a 200-mm wafer production line planned to begin production at the end of 2006 and a 300-mm wafer production line planned to begin production in 2007. Total investment planned for the project is $2 billion. STMicroelectronics will contribute 33 percent of the equity financing, while Hynix will contribute 67 percent.

Flash Partners and FlashVision – joint ventures between Toshiba and SanDisk

- Flash Partners formed in September 2004.
- Key elements: SanDisk owns 49.9 percent while Toshiba owns 50.1 percent; purchases wafers from Toshiba and sells wafers to SanDisk and Toshiba at a price equal to manufacturing cost plus a markup; Toshiba operates its Fab 3 in Japan, and SanDisk has employees assigned to work there; each firm is committed to take 50 percent of Flash Partners' wafer output.
- FlashVision formed in April 2002. Firms agreed to consolidate the NAND wafer fabrication manufacturing operations in Toshiba's Fabs 1 and 2 in Japan.
- Key elements: SanDisk owns 49.9 percent while Toshiba owns 50.1 percent; each company is committed to take 50 percent of FlashVision's wafer output; each firm has a design and development team associated with FlashVision with each paying the cost of its design teams and 50 percent of the wafer processing and similar costs associated with this direct design of the flash memory.

Spansion – joint venture between AMD and Fujitsu

- Formed in 2003 as a manufacturing venture between AMD and Fujitsu.
- Key elements: provides flash memory to AMD and Fujitsu, who resell it to customers; for fiscal 2005, AMD accounted for approximately 56 percent of Spansion's net sales, and Fujitsu accounted for approximately 44 percent; currently, Spansion sells directly to customers previously served by AMD and continues relationship with Fujitsu.

Source: Company annual reports and 10K and 20F filings to the SEC.

Impact on Semiconductor Trade Patterns

Firm and industry changes due to the rise of the flash memory market have intensified current semiconductor trade patterns but has not shifted them fundamentally. Despite the rise in the flash memory market, major importers and exporters of semiconductors (HS 8542) have remained remarkably stable.[11] From 2002-2006, the top 10 semiconductor importers remained constant, and very little change occurred in the top 10 semiconductor exporters (Global Trade Atlas).[12] The following section describes the nature of the change to global semiconductor trade patterns and briefly analyzes possible implications of this outcome.

Changes in Current Semiconductor Trade Patterns

Within the semiconductor industry major trade shifts usually occur when changes develop in one or more of the following three variables: the structure of the semiconductor manufacturing process, the location of front-end chip production, and/or the location of the semiconductor market. Increased flash memory production has not significantly changed these three variables and hence has not shifted current semiconductor trade patterns.

Structure of the Semiconductor-Manufacturing Process

Most semiconductor-manufacturing includes two distinct production processes: the highly capital-intensive front-end fabrication process and the less capital-intensive (though still highly automated) back-end assembly and test process.[13] Historically, firms have physically separated these processes, with the front end taking place in the firm's home country, usually the United States, the EU, or Asia (predominantly Japan), while the back end has occurred mostly in Southeast Asia. Firm response to flash memory market growth has not significantly altered this production process model. By and large, flash memory producers have increased production capacity through construction or conversion of facilities in their own countries while also maintaining back end

[11] Data on flash memory trade patterns is unavailable, because virtually no country breaks down its trade data by flash memory. Only South Korea maintains a subheading in its tariff schedule specifically for flash memory. For most countries flash memory trade data is aggregated into broader semiconductor groupings in their tariff schedules.

[12] Yearly changes in position *among* the top 10 semiconductor importers and exporters did occur from 2002-2006.

[13] Front-end semiconductor processing is the stage of manufacturing in which semiconductors are formed. To reduce semiconductor defects, this process takes place in ultraclean environments known as cleanrooms. Once semiconductors are formed, back-end processing begins in which semiconductors are assembled, tested, and packaged for final sale.

production in their usual locations, mainly in Southeast Asia. Therefore, the increase in flash memory production has actually taken place within the predominant production model, thus perpetuating it and the trade patterns it creates (box 3).

It is unlikely that flash memory producers would switch to an alternative production model that would shift trade patterns. The most viable scenario is one in which flash memory producers outsource production to semiconductor

Box 3 Selected Flash Memory Firms' Plant Locations

With a few exceptions, firms' recent efforts to increase flash memory production capacity show that it is taking place in the usual areas for front-end fab construction (i.e. the United States, the EU, and Japan), thus reinforcing trade patterns.

Current plant locations of significant flash memory firms

Company	**Flash memory fabrication locations**
Samsung	South Korea
Toshiba/SanDisk	Japan
IMFT	United States
Micron	Italy
Spansion	United States and Japan
Hynix	South Korea
STMicro	Italy, France and Singapore
Qimonda	Germany
Hynix/STMicro joint venture	China
Powership	Taiwan

Source: Company annual reports, 10K and 20F filings to the SEC, and the McClean Report. 2007 ed.

Note: Intel, which is a major producer of NOR flash memory, has fabrication facilities in the United States, Ireland, and Israel, but it is unclear which of those three locations is a source of flash memory production.

Two companies bear watching because they buck the location trends of most flash producers: Powership of Taiwan plans to open new flash memory capacity in Taiwan in 2007, and Hynix's and STMicro's joint venture to construct a flash memory fabrication plant in Wuxi, China should be in full operation in 2007.

Back-end production location specifically for flash memory is harder to pinpoint, though most of the companies listed have back end facilities in Southeast Asia as well as in their home countries (many firms also contract out back end work to firms that are predominantly located in Southeast Asia).

pure-play foundries.[14] The majority of pure-play foundry production capacity is in Taiwan, Singapore, and China. Pure-play foundries in these three countries accounted for more than 80 percent of the worldwide pure-play foundry market in 2006 (McClean et al 2007, 3-23). Any significant or measurable switch to pure-play foundries for flash memory production would shift trade patterns, as front-end production would likely move from the United States, South Korea, and Japan to those three countries.

This scenario is unlikely, however, because the flash memory market continues to grow. First, the majority of foundry production is of chips designed by "fabless" semiconductor companies that do not own production facilities. The overwhelming majority of flash memory producers, in fact, own their own production facilities, thus limiting their need for foundry services. Second, memory producers have been using foundry services less and less in recent years (17 percent in 2001 to 5 percent in 2005) (McClean et al 2006, 3-30), and this trend is likely to continue.

The Location of Front-end Semiconductor Production

Regarding front-end production, several scenarios exist outside the context of the manufacturing process that could shift global trade patterns.

One scenario is for flash memory producers to relocate front-end production closer to their principal end market, China. In 2005, China became the largest single country market for integrated circuits, which includes flash memory, due to the increasing concentration of electronic system production in that country (McClean et al 2006, 2-50 to 2-54). Under this scenario, semiconductor producers, including flash memory producers, would benefit from proximity to their largest market, significantly altering current industry trade patterns.

Though some back-end production has shifted to China from other Asian countries, front-end production has remained outside of China, primarily because firms maintain concerns over intellectual property rights (IPR) protection and enforcement in China. China's weak IPR protection and enforcement is recognized by the U.S. Government and U.S. industry. In its 2005 "Special 301" out-of-cycle review of China's implementation of its intellectual property (IP) protection commitments, the Office of the United States Trade Representative (USTR) determined that IP infringement was "unacceptably high" and that China's inadequate IPR enforcement was

[14] Pure-play foundries are semiconductor companies that fabricate semiconductors only. Foundries provide services to "fabless semiconductor companies that only design semiconductors, and to integrated device manufacturers (IDMs) that often outsource production to foundries, especially during business upturns when IDMs may not have sufficient production capacity to meet demand. The pure-play foundry model was pioneered in Taiwan in the late 1980s and has become a very popular production model.

"resulting in infringement levels at 90 percent or above for virtually every form of intellectual property." (USTR 2005, 2). Consequently, USTR elevated China to its "Priority Watch List" as a country that does not provide an adequate level of IPR protection and enforcement where it remains to date. The U.S. semiconductor industry has also voiced concerns over China's lack of IPR protection and enforcement. The Semiconductor Industry Association (SIA) listed improving intellectual property protection in China as a major priority in its 2005 annual Report (SIA 2005, 30-31), and in its comments to USTR for the 2005 National Trade Estimate Report on Foreign Trade Barriers, SIA wrote, "China has the substantive intellectual property laws required under the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS), but enforcement remains an issue" (SIA 2004, 3). Because a significant portion of the value of semiconductor firms rests in their intellectual property, they must guard it vigilantly. Until China's IPR protection and enforcement environment improves, many semiconductor firms will likely remain wary of relocating front-end production facilities there.

Another scenario that could alter trade patterns involves Chinese manufacturers independently designing and producing flash memory. However, while they have made strides in developing semiconductor production technical capabilities, China-based manufacturers are still many years away from being competitive, particularly for flash memory, which embodies the newest process technologies for semiconductors. In 2006, total China-based IC production accounted for less than 2 percent of total worldwide IC production (McClean et al 2007, 1-1). To put this into perspective, each of the top 21 IC producers in 2006 produced more than all China-based IC producers *combined*, and production of the world's leading IC producer, Intel, was more than *10 times* that of all China-based IC producers (McClean et al 2007, 2-49 and 3-8). Even given the Chinese Government's ambitious plans for its domestic semiconductor industry, future production is estimated to remain a very small fraction of total IC production. China's 10th Five-Year Plan calls for domestic semiconductor production to reach $24 billion by 2010 (USTR 2006, 98). If this goal were achieved, China's total domestic semiconductor production would only be able to supply less than 15 percent of the estimated total semiconductor market in 2010 (McClean et al 2007, 2-13).[15]

[15] Since flash memory falls under the subset of semiconductors known as integrated circuits (ICs), a more realistic calculation of China's ability to produce flash memory is its share of total IC production, which is predicted by IC Insights to be less than 3 percent by 2011 (McClean et al 2007, 2-49). The difference between China's share of total semiconductor production and China's share of total IC production includes production of optoelectronics, sensors, and discretes (O-S-D), which are semiconductors that are easier to produce, have much less functionality, and have a much lower average selling price than ICs.

The location of the flash memory market

China is the world's leading semiconductor market and continues to grow as such. Since 2002 China has also been the world's leading annual destination of imports of electronic integrated circuits, HS heading 8542 (Global Trade Atlas).[16] Given flash memory's use in consumer goods, which are manufactured/assembled almost exclusively in China, China looks to continue to be the final destination of flash memory for a long time. Hence, increased flash memory production will perpetuate foreign flash memory exports to China. Flash memory exports to China from two of the world's leading flash memory producing countries, the United States and South Korea, have been strong in recent years. In 2006, China was the leading destination for U.S. exports of nonvolatile EEPROM memory (of which flash memory is the biggest part), and China and Hong Kong combined to be the leading destination for South Korean exports of flash memory.[17]

Conclusion

The growth of flash memory has had a supportive, not disruptive, effect on current semiconductor trade patterns. Producers have scrambled to meet explosive demand for flash memory within, not outside, the context of the prevailing production model, thus helping to maintain existing trade patterns and increasing trade flows within these patterns. China remains the largest market for flash memory, perpetuating overall consumption trends and trade patterns.

While flash memory has experienced phenomenal growth over the last 15 years, it still represents less than 10 percent of the overall semiconductor market. The ability of such a small portion of the market to shift overall semiconductor trade patterns, no matter how rapid its growth, is understandably limited.

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[16] HS 8542, electronic integrated circuits, is the HS code that most closely represents all semiconductors. Since ICs represent the biggest subset of semiconductors (approximately 85 percent in 2006), ICs are often used as a proxy for semiconductors. Also, flash memory is a subset of ICs, making it a subset also of semiconductors.

[17] Because Chinese import statistics categorize semiconductors by process technology instead of product type, it is necessary to examine other countries' export statistics to China to calculate flash memory trade flows to China. Further complicating matters are the facts that (1) of major semiconductor producing countries only South Korea maintains an export subheading for flash memory (the United States maintains a subheading that encompasses flash memory relatively tightly) and (2) the global nature of the semiconductormanufacturing process can distort countries' trade statistics.

However, the impact of flash memory on the semiconductor market and trade patterns will hinge on the sustainability of current high demand over the long term. Much uncertainty exists whether flash memory's influence will reinforce current semiconductor trade patterns or will eventually shift them. No matter how big the flash memory market grows, it is likely only to reinforce semiconductor trade patterns, not shift them. Shifts in semiconductor trade patterns are based on changes in three variables: the production process structure, the location of production, and the location of consumption, and thus far flash memory growth has demonstrated little direct influence on these variables.

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