Can the U.S. Semiconductor Industry be Helped?

A Research Paper by Lawrence J. Arena

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BY

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SUMMARY

This research project explores the decline of the U.S. semiconductor industry and presents an approach for helping the industry. The loss of U.S. competitiveness in semiconductors is illustrated by the 1986 figures for world market share which show Japanese firms dominating the industry. The future trend is not bright either, and this paper explores the implications of a weakened U.S. semiconductor market. A look at the history of the industry gives an insight into some of the reasons why the U.S. industry is in its current straits.

However, regardless of past mistakes, the U.S. semiconductor industry is vital and must be revived. While unfair trading practices and market barriers are strong stumbling blocks to U.S. competitiveness in semiconductors, the primary problem lies in the manufacturing weakness of the U.S. semiconductor industry. With declining revenues, however, individual companies are finding it near impossible to rectify the problem. A new approach, based on cooperation and collaboration among U.S. firms rather than competition, is needed. Such an approach is getting wide attention in the industry. In addition, the Defense Science Board recently endorsed a manufacturing consortium, called the Semiconductor Manufacturing Technology Institute (Sematech), and recommended that the Department of Defense provide financing for it. While there are many hurdles to overcome, Sematech offers the most prominent hope of revitalizing the manufacturing capability of the U.S. semiconductor industry.

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INTRODUCTION

A current theme receiving much attention in this country is U.S. competitiveness in a high technology world. Semiconductor chips, which form the brains of virtually every advanced electronic product from video games to mainframe computers, are at the center of this world. The American semiconductor industry, which provided most of the initial innovations and was once clearly the world leader, is rapidly falling behind the Japanese competition. Since the late 1970's, Japanese companies with strong backing from their government have banded together and have led Japan to world prominence in semiconductors. They have been phenomenally successful not only in providing for their own semiconductor needs, but also in taking over from the U.S. as the major world supplier. U.S. users of semiconductors are increasingly buying from Japan. This has not only economic consequences, but also defense ramifications. This project will consider those factors, examine the history of the industry, explore the nature of the problem, and present an approach to helping the U.S. semiconductor industry.

IMPORTANCE OF THE SEMICONDUCTOR INDUSTRY TO THE U.S.

A fair question is whether we need a U.S. controlled semiconductor industry; the answer lies in exploring the implications of its loss. First, there would be the direct loss of the chip business to the U.S. economy. World semiconductor sales, $27.6 billion for 1986, are expected to reach $200 billion by the year 2000.[1] If the current trend continues, few of these future sales would be attributable to U.S. companies. According to Dataquest, a leading market analysis firm, 1986 closed with three Japanese companies, NEC, Hitachi, and Toshiba, taking the top spots in world semiconductor sales. Of the nine companies in the world reporting 1986 sales of over $1 billion, six are Japanese. The only U.S. companies among the nine are Motorola and Texas Instruments. For 1986, Japan has captured approximately 46 percent of the world market while the United States captured approximately 38 percent. The percentage change in sales from 1985 to 1986 for the leading companies in Japan and the United States shows even more dramatic contrasts as indicated in Table 1.

TABLE 1

Japanese vs. U.S. Semiconductor Producers for 1986

JAPAN			UNITED STATES		
1986 Rank	Company	Per Cent Change in Sales 1985 to 1986	1986 Rank	Company	Per Cent Change in Sales 1985 to 1986
1	NEC	33.0%	4	Motorola	10.7%
2	Hitachi	37.9%	5	Texas Instruments	4.5%
3	Toshiba	54.0%	10	Intel	-2.8%
7	Fujitsu	28.4%	11	National Semiconductor	7.0%
8	Matsushita	36.1%	12	Advanced Micro Devices	2.3%
9	Mitsubishi	83.3%			

Source: Dataquest

Annual sales increases for the leading Japanese companies range from 28.4% to 83.3%; the corresponding figures for leading U.S. companies range from -2.8% to 10.7%. In addition to the semiconductor industry, there is an associated "upstream" industry which provides the sophisticated manufacturing equipment and materials required to build the chips. Currently worth approximately $9 billion in annual sales, this equipment industry market could reach $100 billion by the year 2000.[2] Not only would the demise of these two industries mean loss of sales to the United States, but the concomitant decrease in skilled jobs would be tremendous.

While this would represent a significant loss to the economy, more important is the effect on "downstream" industries, i.e., those industries, such as computers and telecommunications, for which semiconductors are at the heart. The Chief Executive Officer (CEO) of Advanced Micro Devices has stated, "We have entered the information age, based on the development and widespread use of semiconductors as the building blocks for automation and data processing. Dominance in semiconductors will provide the same economic impetus in the new era that steel production gave the United States in the early part of this century".[3] The nature of the competition in this new information age, however, is vastly different from that of the previous industrial revolution. A look at the structure of the Japanese market shows that the same six companies that dominate Japanese "downstream" markets (NEC, Hitachi, Toshiba, Fujitsu, Matsushita, and Mitsubishi) also dominate semiconductor production. In fact, each one of the three leaders in 1986 semiconductor sales (NEC, Hitachi, and Toshiba) is also a leader in the computers, telecommunications, or consumer electronics markets.[4] The implications are clear for the U.S. manufacturers of these "downstream" systems who have turned to Japanese chip suppliers. As U.S. companies become more dependent upon the Japanese semiconductor firms, which are also the same companies that sell end products in competition with U.S. companies, there will be a real incentive for the Japanese to withhold chips from the American market. This, in fact, is already happening. All of the memory chips, as well as ten percent of the logic components for the CRAY-2 Supercomputer are provided by Japanese sources.[5] Cray has reported difficulty in obtaining a particular chip from Hitachi, its only supplier. Hitachi is also one of its principle competitors in the supercomputer market.[6]

Even if Japan continues to supply chips, if we lose our domestic semiconductor industry, there is no reason to believe that the Japanese firms would provide their most advanced chips to the U.S. firms. Thus, the U.S. electronics industries could be at the mercy of Japanese rivals using state-of-the-art chips first and selling the "leftovers" in this country.

In addition to the impact on existing industries, there is also a potential impact on developing industries which rely on semiconductors. Computer Integrated Manufacturing (CIM) which has been portrayed as a hope for improving efficiency in virtually all areas of U.S. manufacturing is highly dependent upon the use of semiconductors. Japan is probably the world's leader in CIM and is using it to improve quality and reduce labor costs. If Japan continues to dominate the semiconductor industry and gets to be in a position to impede access by U.S. companies to semiconductors, the hope for any improvement in manufacturing capability through CIM would be totally lost.

Losing the U.S. semiconductor industry would also mean losing access to the best technology. Much of the decreasing costs and increasing capabilities of electronic products have been a direct result of innovations in semiconductors. The country that produces the best chips will ultimately produce the most capable and competitive systems for the information age.

The decline of the U.S. semiconductor industry also has strong defense implications. The Defense Science Board, a scientific advisor to the Pentagon, has recently completed a report expressing deep concern that deterioration of the semiconductor industry would leave the U.S. dependent upon foreign companies for chips that are vital to national defense. Continued availability to the Department of Defense of the most technologically advanced products will be dependent on a domestic technology infrastructure capable of rapidly supplying defense needs.[7] U.S. defense strategy, which rests on the premise that numerical superiority of potential adversaries can be offset by technologically superior weapons, depends upon high technology as a "force multiplier." Electronics is the key to high technology, and semiconductors are at the heart of electronics. Volume production, which provides the impetus for improving process technology, manufacturing techniques, and sophisticated equipment, is vital to leadership in semiconductors. Volume production, in turn, is supported by a strong commercial market. In line with this reasoning, the Defense Science Board has recommended that actions be taken to retain a strong domestic production base for semiconductors.

Therefore, the answer to whether we need a U.S. semiconductor industry is clearly yes; however, the path to helping the industry isn't as clear. Before exploring an approach, the history will be reviewed to get an insight into how the industry got into these straits.

HISTORY

After almost two and a half years of fundamental research in semiconductor behavior, the birth of the industry occurred during the so-called "magic month" from November 17 to December 17, 1947, when two scientists at Bell Telephone Laboratories, John Bardeen and Walter Brattain, invented the transistor, which provided the basis for all future semiconductor developments and innovations. Their research was encouraged by the forward looking corporate strategy of American Telephone and Telegraph Company (ATT) which recognized the potential applications of semiconductors to telephone networks and computers being built at the time with vacuum tubes.

Although there were some technically important milestones in semiconductor research achieved during the early 50's, progress was slow, and it appeared at the time that most of the future applications would be for the military.

Perhaps the most important development for U.S. semiconductor research during the 50's came as a result of the anti-trust legal battles between ATT and the Federal Government, culminating in the ATT Consent Decree of 1956, which required Bell Labs to license on demand all semiconductor patents it then controlled. Thus, for the price of a license agreement, other companies had access to the semiconductor research of one of the most important research laboratories in the world. This ushered in a period of technical innovations lasting from 1956 to 1962, which were to lay the foundations of the modern semiconductor industry. These innovations allowed extensive digital capabilities to be put on miniaturized chips. Unimagined markets opened for the chips, and vacuum tube producers saw their business overtaken by the new semiconductor industry.

The structure of the new industry changed dramatically during the 60's. While ATT dominated the industry in the 50's, start-up firms were rampant in the 60's, with executives and engineers of companies one day becoming founders of their own firms the next. Venture capital was readily available during this period, and Silicon Valley was fertile ground for engineers and entrepreneurs. As a result, starting a company was relatively easy. A pattern developed in which new firms would dominate their segment of the market for a few years, only to be replaced by newer firms. No particular semiconductor product dominated the market during the 60's, and different firms took the production lead at different times. New advanced chips were incorporated into ever changing, advanced applications in larger systems.

By the late 60's and early 70's technology advanced to the point where thousands of transistors could be put on a single chip -- a level known as Large Scale Integration. This innovation opened the market for semiconductor memories and microprocessors, which are at the heart of virtually all advanced electronic products. In 1971, Intel introduced its one thousand bit random access memory on the market, and started the United States on the road to dominance in the early and mid 70's. As Table 2 illustrates, U.S. firms were the leaders of the industry in 1974, capturing the top seven, as well as ninth spots in world market share.

TABLE 2

Worldwide Semiconductor Producers Ranked by World Market Share in 1974

Firm	Rank in 1974
Texas Instruments	1
Fairchild	2
National Semiconductor	3
Motorola	4
Signetics[a]	5
Intel	6
RCA	7
NEC	8
American Micro Systems, Inc.	9
Hitachi	10

[a] Signetics is no longer a U.S. company

Source: Dataquest

Competition in the industry was intense as each company optimized its particular process and technology to get more circuits and more functional power on a chip. Advances in designs and technologies occurred rapidly, and semiconductor lifetimes rarely lasted more than a few years. For each new product generation, firms had to decide whether to make major new capital investments or employ a "mix and match" philosophy, using new equipment only when absolutely necessary and using older technology for everything else. Most U.S. firms chose the "mix and match" philosophy.

Throughout this time, the military market was decreasing as the number of users in the computer and industrial market increased. Table 3, which illustrates the shifts in the U.S. semiconductor market, shows the complete dominance of the market by the military in 1962 decreasing to a minor portion by 1978.

TABLE 3

U.S. Semiconductor Markets as Percentage of U.S. Sales, 1962 - 1978

Markets	1962	1965	1969	1972	1974	1978
Military	100%	55%	36%	25%	20%	10%
Computer	0	35%	44%	40%	35%	37.5%
Industrial	0	9%	16%	25%	30%	37.5%
Consumer	0	1%	4%	10%	15%	15%

Source: Finan, W. F., and La Mond, A.M. U.S. Competitiveness in the World Economy (edited by Scott, B.R. and Lodge, G.C.), p.159. Boston: Harvard Business School Press.

While this shift had ramifications for the military, there were also ramifications for the industry which were not fully realized at the time. In the early 60's when the military was the major customer for semiconductors, it was also a financier of improvements. Cost-plus contracts provided industry with a secure means of obtaining experience in new technologies, which they could translate to the commercial market. Thus, military purchases were an important contributor to the early domination of the industry by the United States. With the dwindling proportion of military support, more of the cost of learning had to be passed on to the commercial customers.

In addition to the decline of the military market, other forces were also at work during the 60's and early 70's which helped to weaken the competitive position of the industry. The pattern of fragmentation was a weakening influence since innovations in design and manufacturing techniques were spread out among many relatively small companies and were not shared.

High employee turnover was the rule of the day. Wages and incentives were high, and their costs were passed on to the customer. Technology transfer, both between companies and countries, was extensive. Much of this was due to the high turnover rate of critical people who had much of the information in their heads; much was due to the relatively easy art of reverse engineering a product from a competitor. However, most technology transfer was more open. As the industry continued to be populated with relatively small companies, large "downstream" customers who relied on chips as the basis of their large systems often required that semiconductor companies provide second sources for the chips to help assure availability. This reinforced the general pattern of fragmentation, since the primary source semiconductor firm would often choose a new start-up firm as the second source, thereby minimizing competitive pressures on themselves. The major influence, however, on the diffusion of semiconductor technology was the liberal licensing policies by the industry. Japan was able to take advantage of this to gain valuable insights into the knowledge of U.S. industry during this time. By licensing their processes, U.S. firms gained immediate cash flow, but sacrificed market share to foreign companies.

Automation in the U.S. industry also lagged and production methods became more labor intensive. Price competition and short-term business strategies were paramount. Improved manufacturing technology, which would have had a high capital investment cost, was often neglected. The "upstream" industry, which provided semiconductor manufacturing equipment, began to feel these effects and became fragmented. Since this industry is vital to making cost competitive chips, any weakening helps deteriorate the overall U.S. position in semiconductors.

Another phenomenon that occurred during this time was the formation of captive semiconductor producers formed by the larger electronic systems firms. Large scale consumers, such as IBM and ATT, found it more advantageous to make the necessary investment to produce semiconductors for their own internal use rather than depend upon the merchant semiconductor industry. Thus, the captive producers began gaining market share at the expense of the merchant firms.

While the competitive position of the U.S. industry was being weakened by the above factors, two challenges occurred beginning in the late 70's and lasting through the present, which had the most profound effect. One was a technological innovation -- Very Large Scale Integration (VLSI) which allowed hundreds of thousands of transistors to be put on a single chip. The other was the emergence of the Japanese competition.

With the advent of VLSI technology major subsystems or even complete systems could be put on a single chip. This, in turn, required closer interactions between chip suppliers and system companies who were critically dependent upon their semiconductor vendors for deliveries. Delays or inappropriate design by the semiconductor firm in a microprocessor or memory chip could take a system company completely out of a business opportunity. The fragmented U.S. industry was often not up to the task. Large system firms were increasingly turning to their own captive production facilities. Other system firms found Japanese vendors who not only had competitive prices, but also dependable schedules and a willingness to work closely with the customer. By contrast, U.S. semiconductor companies were getting a reputation for not really listening to what the buyer wanted and presenting the customer with "take it or leave it" choices.

The manufacture of VLSI chips also presented new challenges. The fabrication process is one of the most expensive, complex, and capital-intensive businesses in the world. Sophisticated semiconductor manufacturing equipment, as well as wide use of automated techniques for controlling the manufacturing process and for testing, is required. Again, a fragmented semiconductor industry, focusing on short term business interests, was not in a good position for the VLSI age requiring high levels of capital investment.

Meanwhile, the Japanese competition was coming on strong. In the early 70's the Japanese Ministry of International Trade and Industry (MITI) began to be concerned about Japan's dependence upon the United States for semiconductor devices. MITI pressured their largest electronics firms to begin cooperation in order to minimize duplication, share information, allocate specialties among themselves, and reduce R&D costs. In July 1975, the VLSI Development Association was formed in Japan to develop very large scale integrated circuits. Their target product was a one million bit dynamic random access memory (D-RAM), far and away the most advanced design in the world. The members were Fujitsu, Hitachi, Mitsubishi, NEC, and Toshiba; the funding was provided jointly by the government and the corporations. A major aim was to improve manufacturing technology, as well as improve design and test techniques.[8] The VLSI Development Association disbanded in four years after achieving spectacular success. While they never produced a one million bit D-RAM, by 1978 Japanese firms had captured 40 percent of the world semiconductor market for 16 thousand bit D-RAMs and had proved out a 256 thousand bit D-RAM. Equally important, they had established a semiconductor manufacturing equipment industry that was world class.

From the late 70's to the early 80's even though the signs of declining U.S. competitiveness were there, the semiconductor industry prospered. In fact, starting in 1983 and continuing through mid-1984, the industry experienced its biggest growth period in history, when sales of computer products ranging from personal computers to video games created intense demand for the semiconductor chips integral to their operation. When the computer industry's expansion halted in late 1984, the bottom dropped out of the semiconductor market, with overall demand for chips in the United States falling by 30 percent in 1985 and flattening out in 1986.[9]

The competition was ready and took full advantage of the weak U.S. competitive posture to gain dominant market share. Table 1 reaffirms this; the top three companies in 1986 sales, (as well as 7, 8, and 9) are all Japanese.

NATURE OF THE PROBLEM

In macrocosm, the semiconductor industry can be analyzed in three main areas -- research and development (R&D), including design technology; manufacturing; and product distribution. The United States retains superiority in research and development, although the gap with Japan is closing as our traditional strengths in computer aided design and software are increasingly being matched. Japanese R&D expenditures as a percentage of U.S. R&D expenditures have steadily increased from approximately 50 percent in 1976 to over 90 percent currently.[10] More importantly, their investments are efficient. Instead of competing against each other, Japanese companies have amalgamated their efforts and focused their research and development. Until recently, this type of cooperation in research and development in the United States had been deterred by anti-trust laws often resulting in firms duplicating the same research and development when they might have been working collectively. To attempt to alleviate this situation, Congress passed the National Cooperative Research Act in October 1984, which revised the existing anti-trust laws to encourage joint R&D ventures. By 1986, approximately 40 research consortia had been registered, and beneficial results are being obtained.[11] Another legislative initiative in the R&D area which has helped is the Semiconductor Chip Protection Act of 1984. This legislation, which prohibits the unauthorized copying of semiconductor chip designs, has resulted in a reduction in the number of chips that have been pirated.[12]

Product distribution has been a major weakness for American firms, particularly within the last two years. With the precipitous drop in demand for chips in the United States, the Japanese market, which is comparable in size to that of the United States, became extremely important. Foreign access to the Japanese market, however, has been very restricted. In the mid 70's, as Japan was developing its fledgling semiconductor industry, barriers were erected to foreign-based semiconductor manufacturers, and their market became essentially closed. At that time, the U.S. share of the Japanese market was limited to about 10 percent. Following objections by the United States, MITI removed most of the formal barriers by the end of the 70's; by that time, however, the Japanese market had been restructured so that semiconductor suppliers were also the semiconductor purchasers. The Japanese semiconductor producer-consumers were thus procuring semiconductors primarily from each other. Even though barriers were officially down by the late 70's, the U.S. share of the Japanese market never rose above 10 percent.

In addition, particularly within the last two years, a practice called "dumping" became prevalent. In an effort to find buyers for excess product, Japanese firms dropped their prices below the cost of manufacture. This strategy provided the opportunity to gain market share in the U.S. and other world markets, drive competition out of the business, and then recoup profits from a sole source position. The practice of selling products below fair market value, defined as the cost of production plus a profit margin of 8 percent, is illegal under U.S. law. On June 14, 1985, the Semiconductor Industry Association (SIA), which represents U.S. based semiconductor manufacturers, filed a petition with the office of the U.S. Trade Representative under Section 301 of the Trade Act of 1974. In the complaint, SIA maintained that Japan's closed market condition inevitably leads to dumping.[13]

After intense negotiations, the United States and Japan reached an agreement on July 30, 1986. This Semiconductor Trade Agreement had the potential for achieving the two objectives raised by SIA -- increasing the access that U.S. based semiconductor manufacturers have to the Japanese market, and preventing Japanese firms from dumping semiconductors in the U.S. and other world markets. In return, SIA's 301 petition was suspended.

The results of the agreement to date, however, have not been encouraging. The government's first fair market value, set by the U.S. Department of Commerce, pushed prices for Japanese semiconductors exceedingly high. In one case, prices almost tripled from $3 to $8.75 although the subsequent quarterly adjustment lowered the price to around $4.[14] Users of semiconductors complained about the higher prices, but, by and large, they continued to buy Japanese chips.

Increased access to Japanese markets has also been disappointing. Although no specific market share was mentioned in the agreement, a goal of 20 percent was considered realistic. No appreciable penetration has occurred, and the share remains, as it always has, at approximately 10 percent. Anti-dumping provisions haven't worked either. Though the agreement forbids dumping in third world countries, there have been reports of Japanese chip producers dumping chips in those countries at prices below those set by the Semiconductor Agreement.[15] The chips sold to third countries often end up in the United States.

These types of problems prompted SIA in November 1986 to call for sanctions against Japanese firms that have violated the Semiconductor Trade Agreement through continued dumping.[16] The rhetoric is heating up; the SIA Board Chairman recently stated, "The U.S. Government and semiconductor industry demonstrated good faith in July when they immediately suspended the 301 petition pending against the Japanese. By contrast, Japanese firms have virtually ignored the anti-dumping elements of this Agreement since it was signed. It is time for Japan to deliver on its commitments."[17]

All of this illustrates the difficulty in legislating competitiveness. Increasingly, experts agree that the key element in saving the U.S. semiconductor industry ultimately lies in improving manufacturing rather than trying to insist that other countries play by U.S. rules. One indicator of the manufacturing weakness is an estimate that the United States trails its Japanese competitors by at least two years in the ability to make high quality, cost competitive products.[18]

The semiconductor manufacturing process is a complicated one which starts with a thin wafer of material (usually silicon), four to six inches in diameter. Through a series of photolithographic and chemical processing steps, hundreds of chips are built on a single wafer. The chips are tested throughout the process, and the good ones that make it through to the end are assembled into individual packages. The success of the semiconductor manufacturing process is measured by yield, the percentage of good chips at any one particular step. In general, as yield increases, price decreases. Table 4, which gives typical yields of good chips per wafer for U.S. and Japanese production of 256 thousand bit memory chips, clearly shows why Japanese chips are more cost competitive.

TABLE 4

U.S. VS JAPANESE PRODUCTION OF 256K D-RAMs

Process Step	Typical Yields of Good Chips per Wafer	
	U.S.	Japan
Start of wafer fabrication	100%	100%
After first quality check	66%	88%
After final wafer test	20%	57%
Salable chips after assembly	17%	54%

Source: Business Week from Robert F. Graham, and Hambrecht and Quist, Inc.

State-of-the-art capital equipment, extensive automation, and rigorous manufacturing discipline have allowed typical final yields in Japan to be triple those in the United States.

As chip densities increase and more circuits are put on a single chip, yield tends to decrease until more capital intensive production techniques are brought on line. This translates into large capital investment in the semiconductor manufacturing equipment used to build the chips.

One method of comparing an industry's dedication to new technology is to measure the "ability to pay" for capital equipment by looking at the plant and equipment expenditures as a percentage of sales (PE/net sales ratio).

Unfortunately, U.S. semiconductor firms have not kept pace with their Japanese counterparts. Table 5 illustrates a comparison of PE/net sales ratio between U.S. and Japanese firms from 1979 through 1985.

TABLE 5

CAPITAL INVESTMENT - U.S. VS. JAPAN
(Plant and Equipment as Percent of Sales)

YEAR	U.S.	JAPAN
1979	15.8%	14.5%
1980	17.0%	16.6%
1981	17.7%	16.2%
1982	15.5%	17.2%
1983	15.1%	22.3%
1984	21.6%	31.0%
1985	19.6%	34.2%

Source: Dataquest

As shown by the data, investment in capital equipment for U.S. firms closely follows the market for semiconductors. It was only during the growth period of 1983-84 that U.S. investments increased appreciably; when the demand for chips dropped in 1985, capital investment also began to taper. By contrast, since 1982 Japanese firms have had a steadily rising PE/net sales ratio, to the point in 1985 where their investment effort was almost twice that of the United States.

There has also been the tendency in the United States to adapt older manufacturing equipment first and buy state-of-the-art equipment only when absolutely necessary. Meanwhile, Japan has been forging ahead on manufacturing research and is currently at the forefront in highly automated process and assembly equipment. An assessment of the status of semiconductor manufacturing equipment in the Defense Science Board report indicates that overall, the United States and Japan are now at par, with the Japanese gaining. Of the twelve types of manufacturing equipment evaluated, Japan leads in three, while the United States leads in two, with parity in the other seven. Furthermore, the U.S. position relative to Japan is declining in eight of the twelve types of manufacturing equipment, while maintaining its position in the other four. In no case is the U.S. gaining.[19] The trend of the Japanese semiconductor equipment manufacturers becoming dominant in this industry worries not only the merchant producers, but also the captives such as IBM and ATT. Although they make chips for their own internal use, the captive producers do not make most of the equipment used to process the chips. The loss of this "upstream" industry would almost certainly result in a dominant Japanese equipment manufacturing industry withholding the latest equipment from all U.S. chipmakers.

There is no clearer indicator of the decline of the U.S. semiconductor industry than the loss of the dynamic random access memory (D-RAM) market to Japan. This type of chip, which serves as the main means of storing information in computers, is the industry's highest volume product. More than profits are at stake, however. D-RAMs serve as a "technology driver" that companies use to get their overall producton costs down and to hone manufacturing technology that can be used later on other chips. They are at the cutting edge of semiconductor technology and thus lead the way to greater chip densities and capabilities.

Japan recognized the importance of a technology driver in the mid 70's when the target product for their VLSI Development Association was a one million bit D-RAM. Although the chip wasn't produced in the 70's, it provided the impetus for the first large scale entry of the Japanese into the semiconductor market in 1978. Japan now dominates the D-RAM business. Without a high volume product as a technology driver, U.S. semiconductor companies are continuing to fall behind not only in D-RAMs but also in other products, such as microprocessors. Table 6 illustrates the rise in the Japanese share of the D-RAM market with each successively more complex chip being more completely dominated by Japan.

TABLE 6

JAPANESE D-RAM WORLD MARKET SHARE

PRODUCT	YEAR ENTERED PRODUCTION	JAPANESE MARKET SHARE
1 K D-RAM	1970	0
4 K	1974	5%
16 K	1978	40%
64 K	1982	70%
256 K	1985	85%
1 M	1986	90+% (Estimated)

Sources: Dataquest,; Hambrecht and Quist, Inc; Semiconductor Industry Association

The one million bit D-RAM is fast replacing the 256 thousand bit D-RAM with demand expected to reach 50 million units in 1987, a tenfold increase from 1986. While ATT makes the one million bit D-RAM, Japanese companies, Hitachi and Toshiba, dominate the market.[20]

One U.S. firm, Texas Instruments, has steadfastly remained in the D-RAM business and has recently produced the world's first experimental four million bit D-RAM. For most U.S. companies, however, the D-RAM business and its technology driver benefits are gone.

AN APPROACH TO HELPING THE INDUSTRY

As previously concluded, the most prominent weakness of the U.S. semiconductor industry lies in manufacturing. With the primary competition coming from abroad and with capital investment demands not being met in the face of declining sales, U.S. industry needs a new approach to attack the manufacturing problem. There is little doubt that the spectacular success of the Japanese VLSI Development Association from 1975 to 1979 formed the basis for the current Japanese domination of the industry. The cornerstone of that success was cooperation and collaboration among Japanese companies so that resources were shared, duplication was minimized, and costs were reduced. While that type of cooperation in a manufacturing effort has been non-existant in the U.S. semiconductor industry, there has been an increasing awareness of the advantages of U.S. cooperative ventures in R&D.

A feasible approach to the manufacturing problem should capture the emerging cooperative attitude among U.S. firms and build from the Japanese experience of their VLSI project. The concept would be for U.S. chipmakers to combine their manufacturing know-how, work closely with the "upstream" industry to develop next generation semiconductor manufacturing equipment, integrate it all into a manufacturing environment, and then transfer the knowledge back to the U.S. semiconductor industry. In fact, such a cooperative manufacturing venture is being advanced at this very time. In early March 1987, the Board of Directors of the Semiconductor Industry Association, composed of 12 top executives of the leading U.S. semiconductor companies, will receive a task force report addressing the technical and funding issues for a cooperative venture.

The Defense Science Board, in its own report, recommended that "DoD should stimulate the industry to help itself by facilitating the formation of an industry consortium."[21] The name given to the venture is the Semiconductor Manufacturing Technology Institute or Sematech. The purpose, as stated in the Defense Science Board report, would be to "develop, demonstrate, and maintain the technology base for efficient, high-yield manufacture of advanced semiconductor devices."[22]

There are many issues, however, before Sematech becomes a reality. The first is whether the semiconductor industry could really work together in a cooperative atmosphere. Some industry watchers say that, unlike the Japanese firms which thrive on cooperative efforts, U.S. firms don't work well in groups.[23] Previous industry efforts at cooperation have been slow. After two attempts in the early 80's had failed, a third attempt, Project Leapfrog, was initiated in 1984.[24] Ten companies originally participated and had agreed to fund the project among themselves. However, there was disagreement on the choice of a suitable technology driver as well as how concerned they should mutually be about volume production. In addition concerns about the survivability of the industry were less than today. Companies dropped out of the project, and by the end of 1984, the companies that remained felt that they could better use their funds internally. Although Project Leapfrog died, there was the recognition that manufacturing deficiencies throughout the industry were becoming an increasing problem. In addition, survival of a viable U.S. equipment manufacturing industry was recognized as vital to the survival of the U.S. semiconductor industry. As an outgrowth of Project Leapfrog, a Manufacturing Competitiveness Panel was formed within the industry in 1985, which for the first time encouraged semiconductor manufacturers and equipment vendors to share information and begin to work together.

While cooperation has been slow in the semiconductor manufacturing area, it has been more encouraging in the R&D area. In 1982, 11 firms pooled $4 million to form a nonprofit research consortium, the Semiconductor Research Corporation (SRC). Currently, numbering 34 members, SRC supports a large part of the semiconductor research being done at U.S. universities. Another research consortium that is working well is the Microelectronic and Computer Technology Corporation, or MCC, formed by 12 companies in early 1983. Much of MCC's impetus was derived from Japan's announcement of a nationwide, government-funded, crash research program to develop fifth generation computers before the United States. Unlike SRC, which does its research through universities, MCC does its own research at its headquarters in Texas. MCC is basically a commercial research venture, focusing on those projects which can potentially derive the biggest revenue opportunities and profit for the member companies. Thus, the goals of Sematech would be similar to those of MCC with the primary difference being MCC is research oriented while Sematech would be manufacturing oriented.

That difference, however, will probably open up anti-trust concerns that must be resolved. While the National Cooperative Research Act of 1984 allowed cooperative ventures focusing on research and development, anti-trust laws still prohibit competitors from cooperating in the manufacture of products. Another problem faced by MCC which inevitably would be faced by Sematech is the assembling of staff. Member companies, who would provide the critical core personnel will, most likely, be reluctant to let their top talent leave. A strong CEO at Sematech, similar to the CEO at MCC during its formative years, is absolutely essential to getting the venture started.

Perhaps the most critical question at this time is how Sematech would be financed. The consensus of industry experts is that $200 million per year for approximately five years is needed.[25] While it would be most preferable to have industry assume the financial burden, that appears to be impossible as

U.S. semiconductor sales continue to plummet. Government funding is an alternative; however, with federal budgetary constraints, the probability of a five-year, billion-dollar program seems small. Nonetheless, the Defense Science Board in its report, recognizing the criticalness of the semiconductor industry to the U.S. defense posture, recommended that the Department of Defense (DoD) provide the financial support of $200 million per year for five years to Sematech[26]

There is precedence for DoD providing substantial support to the semiconductor industry. In 1980, the Very High Speed Integrated Circuit Program (VHSIC) was initiated, which was intended to respond to the concern that the U.S. technology lead over the Soviets, once estimated at ten to fifteen years, had slipped to only three to five years. An additional concern was that the military, which had formerly gotten the latest semiconductors, were getting them two or three years after they were commercially available.[27] The goal of the VHSIC Program was to correct that deficiency by giving system developers a military-qualified semiconductor technology that was on a par with technology available commercially. DoD encouraged the computer, defense, and semiconductor industries to team up and actively pursue the small and specialized military market. The program was not aimed at volume production and was not focused on the Japanese threat to the U.S. semiconductor industry. While the original goal is being met, the VHSIC Program has not helped much in rectifying the current manufacturing weakness of the U.S. semiconductor industry.

There are those in DoD who favor more limited support for Sematech than that recommended by the Defense Science Board. They argue that with the defense budget under close scrutiny, $200 million per year for five years is questionable; something closer to a quarter of that amount would be more realistic. The intent would be to provide "seed" money from DoD under Title III of the Defense Production Act. Such support, intended to strengthen the defense industrial base and promote long-term survival of needed technologies, was recently provided to the machine tool industry.[28] While industry can't finance the entire $200 million per year for Sematech, there is a feeling that $100 million per year from industry should be possible. A funding problem, however, still exists, and a resolution has not yet been found. Both DoD and the Semiconductor Industry Association are continuing to address the issue.

Another important issue for Sematech is a choice of a technology driver which would leapfrog the industry into the future. While there is agreement that a memory chip, manufactured in a high volume environment, should be the driver, there is a question as to how far the technology should leapfrog. Some suggest that the four million bit D-RAM, being built today in a laboratory environment, should be the choice, and Sematech should be oriented towards achieving high volume production of it before

Japan. This could, however, have problems since one of the possible consortium members, Texas Instruments, has built the experimental chip and hopes to produce it, thus potentially placing Sematech in competition with Texas Instruments. Others feel this problem could be avoided by jumping further in technology to a 16 million bit D-RAM, a product that has yet to be designed. This, however, could be an invitation to delay since there would still be R&D problems in its implementation.

Other issues remain such as the challenge of transferring the manufacturing technology from Sematech back to the U.S. industry. Companies that by nature have been extremely competitive must openly share manufacturing process technology in the Sematech environment, and then bring that knowledge back to the competitive environment of the marketplace. In order for Sematech to be effective, however, successful technology transfer must occur.

While none of these issues are easy, they all must be resolved. In the face of the Japanese challenge, the future of the U.S. semiconductor industry depends upon a new approach to manufacturing, one that is based more on cooperation and collaboration among firms rather than competition. Sematech provides such an approach.

CONCLUSIONS

The U.S. semiconductor industry is in trouble and is rapidly losing to the Japanese competition. While the problem has been exacerbated since the halt of the computer market expansion in 1984, it is more than a cyclical problem. With industry losing money, capital investments are being neglected, resulting in quality and cost competitiveness falling further behind Japan. Much of the problem was caused by the industry itself when its past market lead resulted in complacency. The competition was viewed as internal between U.S. companies rather than international. U.S. industry was ill prepared to face a strong, determined Japanese challenger, who had a strategic view of the importance of the semiconductor market, and effectively banded government and industry together to achieve phenomenal results.

The United States needs a viable domestic semiconductor industry. More important than the direct loss of semiconductor sales is the effect on "downstream" industries. Without a domestic semiconductor industry, computer and telecommunications firms would be totally at the mercy of foreign sources who would control availability and performance of chips used in their systems. This is particularly significant since the same Japanese companies that sell semiconductors to the U.S. also compete with U.S. computer and telecommunications firms. In addition, leaving the military dependent upon foreign sources for their semiconductor needs would be totally unacceptable.

The primary weakness in the U.S. semiconductor industry lies in manufacturing. A new approach, based more on cooperation and collaboration than on competition, must be tried in the industry. The Japanese collaborative effort in semiconductors, as well as U.S. R&D cooperative ventures should be used as models.

The loss of the U.S. semiconductor industry is a national problem and one that must be addressed with Government resources. The Defense Science Board recognized this and recommended that the Department of Defense financially support an industry consortium called the Semiconductor Manufacturing Technology Institute. This approach holds out the most prominent hope of revitalizing the manufacturing capability of the U.S. semiconductor industry.

NOTES

1. The 1986 sales figures for the world's top 50 semiconductor companies were provided by Dataquest. The projection to the year 2000 was obtained from Business Week, "Is It Too Late to Save the U.S. Semiconductor Industry?", August 18, 1986, p. 63.

2. "Effects of a Substantial Reduction in U.S. Production of Dynamic Random Access Memory Circuits on 'Upstream' and 'Downstream' Industries", Draft Report prepared by the National Science Foundation, Division of Electrical, Communications, and Systems Engineering, p. 26.

3. 1985-86 Yearbook and Directory, Semiconductor Industry Association, P. 1.

4. "Japanese Market Barriers in Microelectronics", Semiconductor Industry Association, Summary Report, June 1985, Figure 4.

5. Information was provided by the Semiconductor Research Corporation. Source for the data was Cray Research, Inc.

6. "Effects of a Substantial Reduction", p. 4.

7. Defense Science Board, Executive Summary, Report of the Task Force on Defense Semiconductor Dependency, p. 3.

8. Alan Wm. Wolf, "The Effect of Government Targeting on World Semiconductor Competition", Proceedings of the Semiconductor Industry Association Long Range Planning Conference, November, 1982.

9. "Is It Too Late to Save the U.S. Semiconductor Industry?", Business Week, August 18, 1986, p. 63.

10. Information was provided by the Semiconductor Research Corporation.

11. "America Can Beat Anyone in High Tech. Just ask Bruce Merrifield", Business Week, April 7, 1986, p. 96.

12. 1985-86 Yearbook and Directory, Semiconductor Industry Association, p. 18.

13. "The U.S.-Japan Semiconductor Trade Agreement", Semiconductor Industry Association, September 23, 1986.

14. "Feeling the Crunch from Foreign Chips", Time, October 27, 1986, p. 73.

15. Joan Tyner, "U.S. Appraised as Losing Ability to Compete in Global Technology Markets", The Baltimore Sun, January 18, 1987, p. 8D.

16. "SIA Calls for Sanctions Against Japanese Trade Violators", Semiconductor Industry Association, November 18, 1986.

17. Ibid.

18. Information was provided by the Semiconductor Research Corporation.

19. Defense Science Board, Executive Summary, p. 7.

20. "Demand Turned On For 1-Million Bit Chip", USA Today, February 1987.

21. Defense Science Board, Executive Summary, p. 9.

22. Ibid.

23. John Hillkirk, "Made-In-USA Computer Chips Wanted", USA Today, January 13, 1987.

24. Information was obtained by discussions with industry representatives.

25. Ibid.

26. Defense Science Board, Executive Summary, p. 9.

27. William G. Ouchi, How American Teamwork Can Recapture the Competitive Edge, p. 132. Addison-Wesley Publishing Company.

28. Information was obtained by discussion with DoD personnel.

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