

Review of the Competitive Status of the United States Electronics Industry*

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Leadership in the Electronics Industry is Important to the Nation's Economy

Electronics, the largest manufacturing industry in the world, employs 2.6 million Americans and is the technology building block of most manufacturing and service industries.

One out of every eight U.S. manufacturing jobs is in electronics. That is three times the size of the auto industry, and nine times that of the basic steel industry.¹

The worldwide market for electronic goods is over \$800 billion. The U.S. share of this market is approximately \$200 billion. The world market is expected to approach \$2 trillion by the turn of the century. As shown in Figure 1, electronics manufacturing industries have the highest value added of any manufacturing industry. Between 1977 and 1986 value added per production worker hour increased by 150 percent in electronics. Despite our high import of electronics goods, no other U.S. manufacturing industry exports more than does electronics. Twenty-five percent of U.S. electronics industry sales is from exports, and the value of these exports has increased at an average rate of 18 percent a year since 1977.

The U.S. Department of Commerce has identified 12 emerging technologies in four major categories that have a U.S. market potential of \$350 billion and a world

*This work was done at Sandia National Laboratories for the U.S. Department of Energy under Contract DE-AC04-76DP00789.

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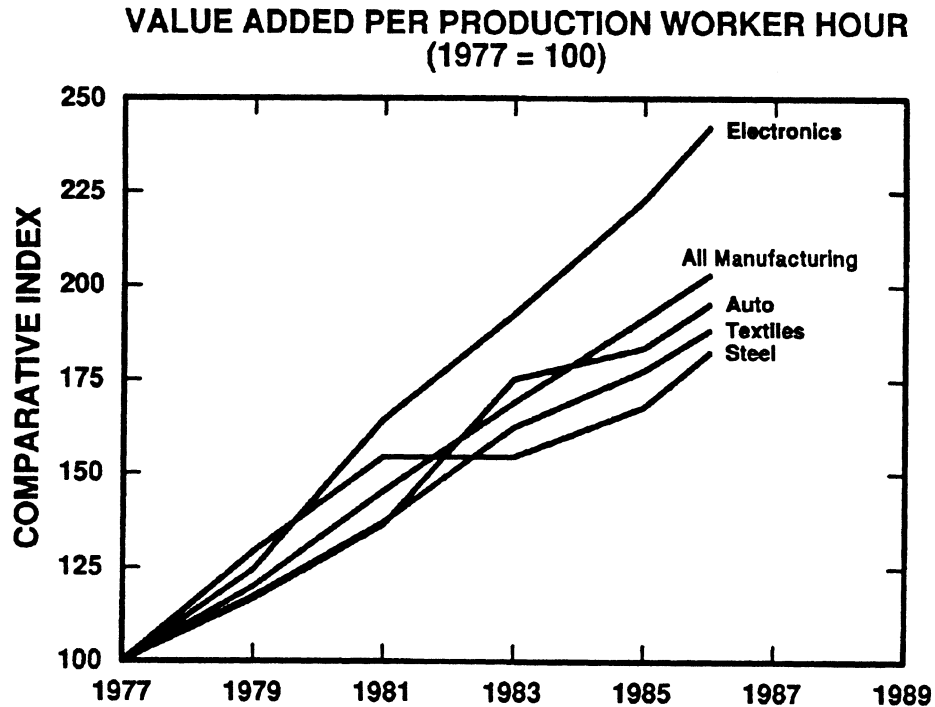


Figure 1. Electronics have the highest value added of the manufacturing industries.

market potential of \$1 trillion by the year 2000. Except for superconductors and biotechnology, ten of these emerging technologies are dominated by electronics.²

The Structure of the Electronics Industry is Complicated

Electronics industries have a complex, multitiered, fragile structure that begins *upstream* with materials and equipment for manufacturing semiconductor integrated circuits and chips. These devices form the basic hardware building blocks for five major *downstream* electronics industrial sectors: communications, data processing, manufacturing, consumer products, and defense electronics. The electronics chain is depicted in Figure 2.

Products of the downstream sectors include telephones, fax machines, satellites, PCs, minicomputers, mainframe computers, workstations, word processors, software, CAD, CAM, robotics, auto electronics, VCRs, radios, television sets, clocks, electronic controls, copying machines, and a wide range of defense products.

Note that packaging has been shown as a separate step in the chain. Up until the early 1990s the packaging function was divided between (1) the manufacturing of semiconductors from which a semiconductor device could leave assembled in a connector with multiple pins and (2) the downstream electronics sector in which these

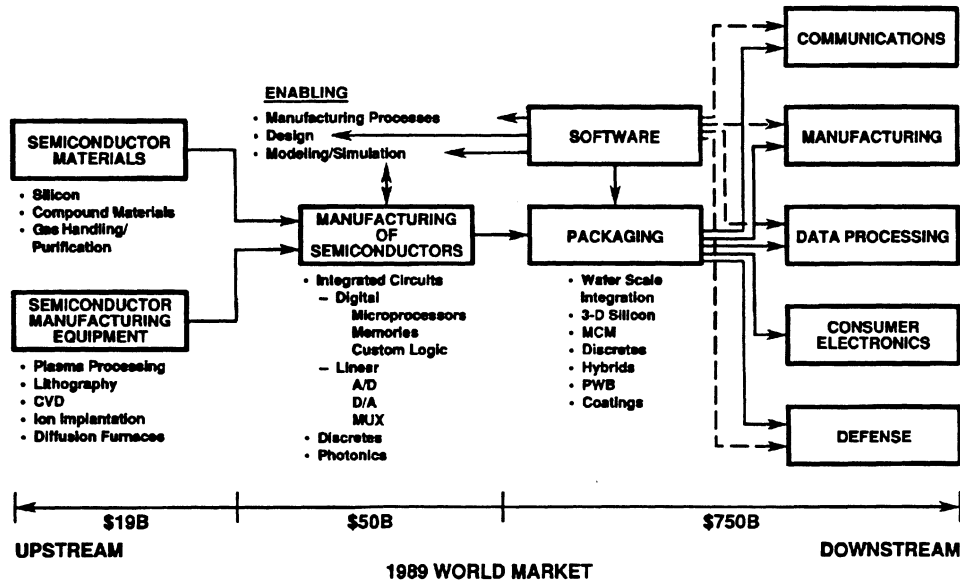


Figure 2. The electronics chain has five major downstream elements, which are fed by upstream sectors comprising packaging, software, semiconductor manufacturing (including enabling capabilities), materials, and manufacturing equipment.

packaged parts could be interconnected on a printed wiring board. As the speed and power density of integrated circuits increases, packaging is developing an identity as a sophisticated discipline for which practices are closely aligned with semiconductor manufacturing. Eventually, for high-performance systems we expect packaging to be absorbed into semiconductor manufacturing and to lose its identity as a separate step in the chain.

Also note that I have shown software as a separate element of the electronics chain located upstream from the downstream electronics sector. Some electronics companies gain competitive advantage by exploiting their excellence in software. However, as competition grows in a downstream sector, core competences in both semiconductor manufacturing technology and software are required as differentiating strengths.

In Japan, most of the companies that are heavily invested in downstream electronics sectors are also vertically integrated and heavily invested in upstream sectors, particularly in semiconductors. Thus these companies may take their profits from sales of upstream manufacturing equipment, midstream semiconductor products, or downstream electronics products. Sony's entry into the entertainment field offers them the option of taking their profits from movies and other entertainment media. If these profits are sufficiently high, they may operate their upstream supporting industries at a loss.

(In Japan) Six firms, all with annual revenues of more than \$10 billion and with close links with other major Japanese industries, produce approximately 85 percent of

Japanese semiconductors, 80 percent of Japanese computers, 80 percent of Japanese telecommunications equipment, and 60 percent of Japanese consumer electronics.³

There are six major firms or bank-centered societies of business, *keiretsu*, in Japan. These include Sumitomo, Mitsubishi, Mitsui, Dai Ichi Kangyo, Fuyo, and Sanwa. In addition to these bank-centered *keiretsu*, Japan has supply-centered *keiretsu* consisting of groups of companies integrated along a supplier chain dominated by a major manufacturer. Bank-centered *keiretsu* include 182 companies, or 10 percent of the companies on the Tokyo Stock Exchange that earn 18 percent of Japan's business profits from 17 percent of total Japanese business sales, employ 5 percent of Japan's labor force, and hold over 14 percent of Japan's total paid-up capital.⁴ Unlike these bank-centered *keiretsu*, in which power is distributed among the various member companies, the supply-centered *keiretsu* are clearly hierarchical with power concentrated in the hands of the major manufacturers.

Charles H. Ferguson, research associate at MIT's Center for Technology, Policy, and Industrial Development, has pointed out that the *keiretsu* structure benefits Japanese business through both vertical and horizontal linkages.⁵

In the United States, only a few companies, notably IBM, AT&T, Motorola, and Hewlett-Packard, are vertically integrated, but those few primarily use their semiconductor products to their strategic advantage in downstream markets. As Japan's semiconductor companies gain control of semiconductor technology, they can and probably will use that asset to control downstream markets, such as computers. Most U.S.-manufactured semiconductors are built by merchant companies whose only business is semiconductors. If these companies collapse, downstream U.S. electronics manufacturers that rely on the purchase of state-of-the-art microelectronics technology will be at the mercy of foreign suppliers who are competing in the same downstream electronics sector.

Control of a large enough segment of the downstream industries creates the cash flow for upstream research and development (R&D) investment. That in turn permits control of upstream industries, and ultimately control of all the downstream markets. For example, Japan's strength in consumer electronics created a market for semiconductors and resulted in their dominance of DRAM memory chips. Their dominance of the DRAM market created a market for DRAM manufacturing equipment built in Japan and led to severe upstream market loss by the U.S. semiconductor manufacturing equipment industry. Because DRAM processing technology is the most demanding of all integrated circuit types, DRAM dominance carries into other areas of microelectronics.

As concurrent engineering practices are developed so that microelectronics manufacturing equipment, manufacturing processes, semiconductor technology, and circuit design are done simultaneously, the necessity for a nation to be prominent in all these elements will be even more important than it is today. For example, as manufacturing equipment is being developed, competitive microelectronics companies will find it necessary to be simultaneously designing the products and processes that use this equipment. To do this will require close cooperation between the equipment manufacturers and the microelectronics product manufacturers. SEMATECH is developing the linkages between these industries in the United States.

If the United States is to be a major player in the world of electronics, we must be strong throughout the upstream building block segments of electronics and at the same time have enough presence in downstream markets to maintain market pull for the upstream technologies.

The United States is Losing Market Share in Electronics to Japan

The best metric for competitiveness assessment is world market share. The United States' share of world electronics markets decreased steadily throughout the 1980s, with entire electronics sectors such as consumer electronics almost vanishing from U.S.-based and -owned manufacturing facilities. "In electronics, . . . the largest U.S. manufacturing industry, the United States exported \$5B to Japan in 1987 but imported \$26B."⁶

The U.S. Commerce Department recently reported that Japan could surpass the United States in production of electronic goods by 1994, and emphasized that since 1984 (except for software and medical equipment) the United States lost market share in 35 of 37 electronics categories.⁷ Even in fields such as personal computers, supercomputers, and microprocessors, long dominated by the United States, the U.S. market share has declined.⁸ Further loss in world market share in most categories continued through 1990. For example, U.S. factories' share of the U.S. market in computers went from 94 percent in 1979 to 66 percent in 1989.⁹

The United States Has Lost Market Share in Semiconductor Manufacturing Equipment

A recent article in the *Far Eastern Economic Review* illustrated the decline in the United States' market share in semiconductor manufacturing equipment with the data shown in Figure 3.¹⁰

Between 1980 and 1990 the top ten manufacturers of semiconductor manufacturing equipment shifted as shown in Table 1.

It is clear that the loss of a \$9 billion industry such as semiconductor manufacturing equipment is not a serious loss to the U.S. economy unless there is a domino or ripple effect into downstream electronics sectors. It is this concern that has prompted so much attention for this relatively small sector of the electronics industry. Even South Korea has expressed concern about their ability to build semiconductors without a competitive presence in semiconductor manufacturing equipment.

Because of the deepening dependence on imported (semiconductor manufacturing) equipment, we are worried that both the balanced growth of the semiconductor equipment industry and the growth of the memory device industry may suffer in the future. This scenario emphasizes the need to develop the semiconductor equipment industry.¹¹

Of most concern is the stepper market, where Japan's firms dominate most of the world market. *Steppers* are a type of lithography equipment that limit the feature

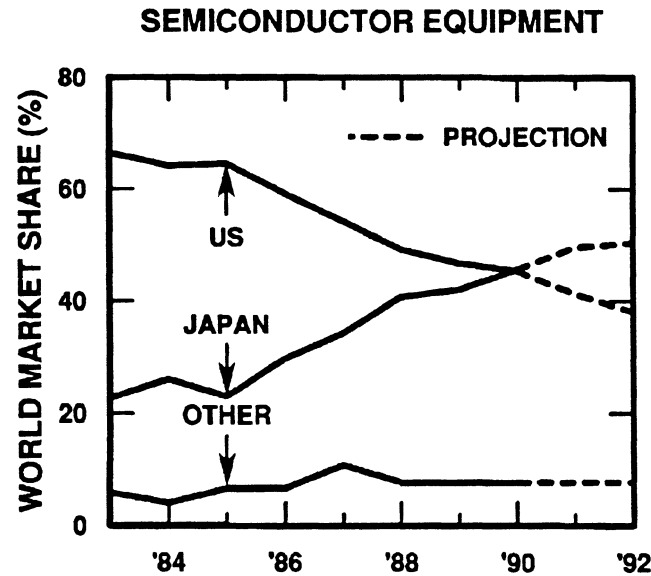


Figure 3. Comparison of the United States' and Japan's world market share in semiconductor manufacturing equipment points up the rapid decline in the United States' market share in this sector.

size and number of transistors that may be made in an integrated circuit. In 1989 Japanese firms held 74 percent of the world market share in optical steppers with U.S. firms holding 15 percent of market share. In diffusion furnaces, Japanese firms held 60 percent of market share and U.S. firms held 35 percent. In deposition technology, ion implanters, and etching equipment U.S. firms held over 50 percent of market share.¹²

TABLE I Comparison of Semiconductor Manufacturing Equipment Sales in 1980 and 1990

1980 Sales (\$million)		1990 Sales (\$million)	
Perkin-Elmer	151	Tokyo Electron	706
GCA	116	Nikon	692
Applied Materials	115	Applied Materials	572
Fairchild	105	Advantest	423
Varian	90	Canon	421
Teradyne	83	Hitachi	304
Eaton	79	General Signal (GCA)	286
General Signal	57	Varian	285
Kulicke & Soff	47	Teradyne	215
Advantest	46	Silicon Valley Group	204
		(Perkin-Elmer)	
Top 10 Total	889	Top 10 Total	4,108
		Total 1989 World Sales	9,078

The United States Has Also Lost Market Share in Semiconductors

Between 1979 and 1989 the top ten manufacturers of integrated circuits built with this equipment shifted as shown in Table 2. Note that as we move down the electronics chain the economic stakes dramatically increase with the market share in downstream sectors depending on market share in upstream sectors and vice versa.

In semiconductors a trend similar to manufacturing equipment has been observed in the United States' and Japan's world market shares. This trend is illustrated in Figure 4.

To many, a 1 percent or 2 percent loss in a world market may seem inconsequential. In a recent presentation to the United States's Industrial Competitiveness Committee of the IEEE, Turner Hasty, former Chief Operating Officer of SEMATECH, shed considerable light on this topic with some very conservative estimates of the economic impact of market share in semiconductors.

The size of the world semiconductor market is about \$49.5B so 1 percent of market share equates to \$495M. The average U.S. (semiconductor) industry sales per employee is \$85K which would give you a total of 5,824 American jobs per each point of market share. . . . You have to take into account that 48.8 percent of the U.S. industry employment is outside this country so we deducted that and came up with the 2,982 jobs you see here (in the U.S.). The corresponding loss in wages to U.S. workers (\$130M) and R&D funds (\$59M) and tax revenues (\$40M) begins to give you a picture of the staggering losses in an industry that is the foundation of America's largest employer, electronics.¹³

Should the United States lose the domestic semiconductor industry, at risk would be the U.S. share of the worldwide electronics industry. Because semiconductors offer the technology leverage for the \$800 billion worldwide electronics industry, using the same scaling factors as Turner Hasty used for semiconductors, I conservatively estimate a 1 percent loss in total electronics sales to result in a loss of

TABLE II Comparison of Semiconductor Sales in 1979 and 1989 Illustrates Japan's Gains

1979 Sales (\$million)		1989 Sales (\$million)	
TI	1,282	NEC	5,015
Motorola	919	Toshiba	4,930
Philips	761	Hitachi	3,974
NEC	595	Motorola	3,319
National	532	Fujitsu	2,963
Fairchild	469	TI	2,787
Hitachi	453	Mitsubishi	2,579
Toshiba	442	Intel	2,430
Intel	440	Matsushita	1,882
Siemens	368	Philips	1,716
Top 10 Total	6,261	Top 10 Total	31,595
		Total 1989 World Sales	55,000

Source: Dataquest.

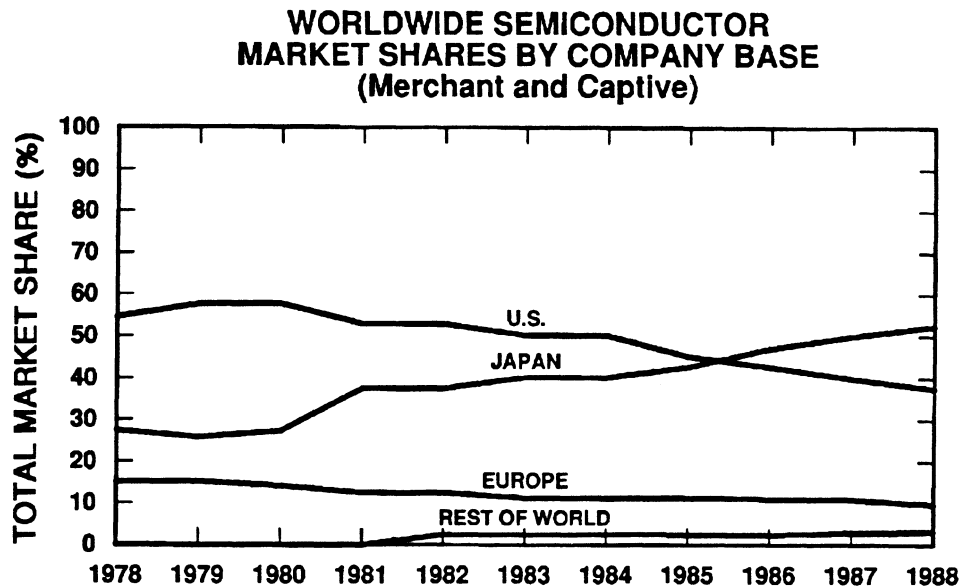


Figure 4. In the world semiconductor market, Japan overtook the United States near the end of 1985, and then rapidly surpassed the United States. (Source: *Dataquest*, January 1989)

over 50,000 jobs for Americans, over \$2 billion loss in wages to American workers, over \$1 billion reduction in R&D funds, and over \$640 million loss in tax revenue.

Furthermore, sustaining market share is more than the financial impact of a 1 or 2 percent loss in market. At stake may be the ability to maintain *any* share of the market. To be competitive, firms must be able to market internationally. United States semiconductor manufacturers have not been very successful in marketing semiconductor products in Japan. In fact, concern for this led to the U.S.-Japan Semiconductor Trade Agreement that was signed in 1986. At that time foreign firms' share of Japan's semiconductor market was only 8.6 percent. By 1990, the share of foreign firms had grown to 13.2 percent of Japan's market, but still fell well short of the 20 percent share that U.S. authorities interpreted the trade agreement to guarantee. Japan's officials have interpreted 20 percent to only be a target. As negotiations for a new trade agreement have progressed to replace the 1986 agreement, which expired in July 1991, Japan's officials have expressed opposition to managed trade and have proposed that the problem would be solved if U.S. manufacturers would improve their competitiveness.¹⁴

The progress of foreign semiconductor market share in Japan is shown in Figure 5.

The U.S. Market Share in Computers Is Also at Risk

Much has been written about the U.S. loss of market share in consumer electronics. Less known, however, is the loss of market share to Japan in computer sales. The data are shown in Figure 6.

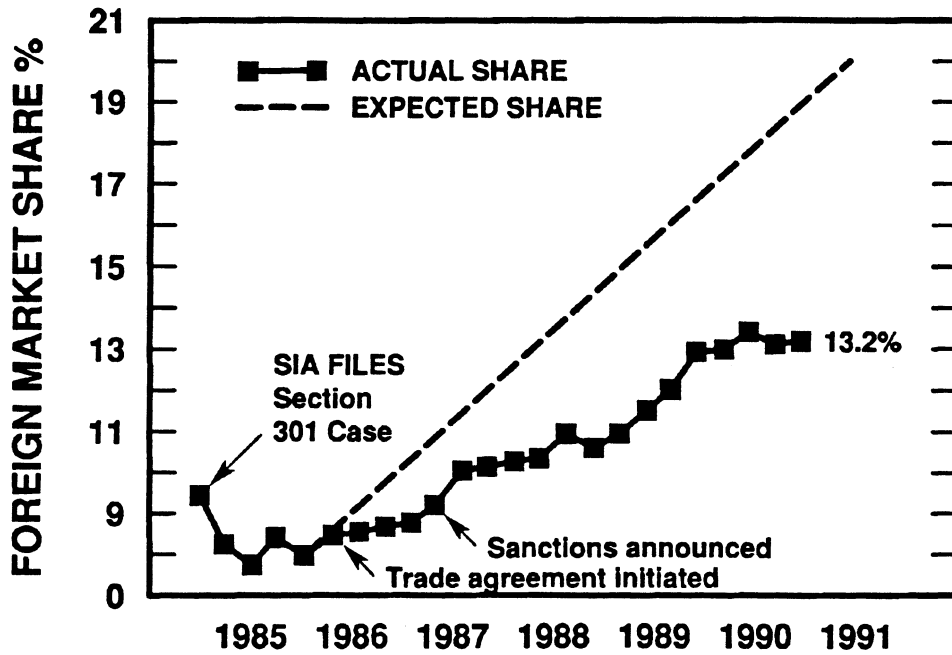


Figure 5. Foreign semiconductor market share in Japan has not met U.S. expectations. (Source: Semiconductor Industry Association)

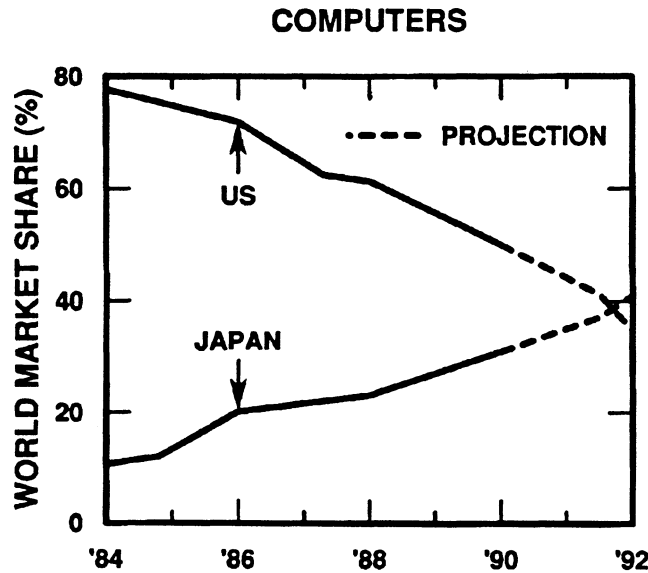


Figure 6. Comparison of U.S. and Japanese world market shares in computers shows the United States is on a rapid downward trend.

Many analysts are predicting that the market for personal computers will rapidly shift to notebook and laptop models, a field in which Japanese-based and -owned companies are expected to dominate sales. To counter this trend, U.S. companies have formed partnerships with Japanese companies. In many, if not most, of these partnerships Japanese firms will provide most of the value-added manufacturing; U.S. firms will market these products with the labels of U.S.-based companies. IBM has teamed with Toshiba in the manufacture of color LCD screens; Apple is negotiating with Sony to manufacture a laptop computer; AT&T has teamed with Matsushita to build a notebook computer; TI is selling laptops designed with a Japanese partner; and Compaq has long depended on its partnership with Japan's Citizen to provide hardware and packaging of its laptop and notebook computers.

Citizen subassemblies make up so much of the finished machines (sold by Compaq) that one market researcher counts all LTEs (a Compaq laptop computer) as Japanese imports.¹⁵

The marketing and service excellence of U.S. companies and their well-established relationship with U.S. consumers will assure that products with U.S. corporation titles maintain a strong presence in the laptop and notebook business. Intel's excellence in microprocessors and flash memories and Conner's excellence in hard disk drives suggest that at least some of the components are built in the United States.

A leading executive of the U.S. electronics industry, Dr. Andrew Grove of Intel, recently tabulated the shift in the top ten computer manufacturers between 1984 and 1989. These data are shown in Table 3.¹⁶ Note how well Hitachi is positioned in computers, equipment, and semiconductors.

Nor should we feel too secure about the United States' strength in software. *The Economist* recently reported that Japan is creating a strong software development capability to support their soaring personal computer business. In many instances, software produced in Japan is selling for less than 10 percent of the selling price for American software.¹⁷

TABLE III The Shift in Leading Computer Manufacturers between 1984 and 1989 Reflects Japan's Growth in Market Share

	1984	1989
1	IBM	IBM
2	DEC	DEC
3	Burroughs	Fujitsu
4	Control Data	NEC
5	NCR	Unisys
6	Fujitsu	Hitachi
7	Sperry	Hewlett-Packard
8	Hewlett-Packard	Siemens
9	NEC	Olivetti
10	Siemens	NCR

Fujitsu is planning a 200-person R&D center in the U.S. to develop a next-generation version of Unix software, which could make Japanese hardware more competitive.¹⁸

Already, Japanese software factories churn out programs with half as many defects as comparable American products, according to a study by the Massachusetts Institute of Technology.¹⁹

One should be aware that even though U.S. market share in software grew from 70 to 72 percent between 1984 and 1987, by 1990 U.S. market share had dropped to 57 percent. In Table 4 we compare world market shares of software.¹⁹

As Japan takes over an increasing share of the computer laptop market, we can expect this to further pull up their sales of software.

Supercomputers, workstations, telecommunications, and semiconductor markets are at risk. *If present trends continue, U.S.-owned electronics manufacturers could be out of the domestic electronics business early in the twenty-first century. Our economy will suffer, our standard of living will diminish, and modern defense technology will be imported.*

These Market Share Losses Have Resulted in a High-Tech Trade Deficit with Japan

Although only 17 percent of total U.S. trade is with Japan, nearly 45 percent (about \$50 billion) of the U.S. trade deficit is with Japan. Between 1987 and 1989 the global U.S. trade deficit went down 29 percent, but the U.S. deficit with Japan went down only 13 percent. While Japan purchases 20 percent of the U.S. agricultural exports, they only purchase 10 percent of the U.S. high-tech exports. About 36 percent of the U.S. imports from Japan are high-tech products. Even though the global U.S. trade balance in high-tech products improved to an \$8 billion surplus in 1988, including a surplus with the European Community, the U.S. high-tech trade deficit with Japan remained above \$20 billion.²⁰

U.S. Semiconductor R&D Performance is Lagging behind Japan's

There are many measures of how competitive an industry is based on sales data. An *estimate* of how competitive an industry will be in the future can be made from their

TABLE IV Software Market Shares by Nation in 1990

Country	Market Share (%)	Total Sales (\$Billion)
United States	57	62.7
Japan	13	14.3
France	8	8.8
Germany	7	7.7
Britain	6	6.6
Canada	3	3.3
Others	6	6.6

investment in R&D, the performance of their R&D, and their capital investment. We may think of sales data as a measure of competitiveness and R&D investment and performance as the time derivative of competitiveness. That is, low R&D performance will eventually lead to diminished competitiveness. One way of assessing the R&D performance of an industry is through their presentations at international meetings, particularly those regarded to be highly prestigious and a valuable marketing tool for industry.

In microelectronics the Institute of Electrical and Electronics Engineers (IEEE) sponsors two annual meetings that are highly regarded around the world. These are the International Electron Devices Meeting (IEDM) and the International Solid-State Circuits Conference (ISSCC). Although Japan has domestic electrical engineering societies that are considered by many Japanese to be technically ahead of, or at least equivalent to, the IEEE,²¹ in the United States IEEE conferences and publications are considered to be the most prestigious, and they are technically superior to any other presentation or publication opportunity in microelectronics. In fact, unlike other nations, U.S. researchers in electronics and microelectronics have no domestic electrical engineering societies that promote the exchange of R&D information at the national level. That ended in the early 1960s when the IEEE absorbed the American Institute of Electrical Engineers. Of course, at that time the United States dominated electronics technology and it was U.S. policy to share R&D with the world. It was not even conceivable in the early 1960s that the United States could lose this dominant position. Even though the 1990 IEEE Secretary, Dr. Fumio Harashima, Professor of Robotics, Tokyo University, has recommended that IEEE-USA sponsor conferences of specific interest to U.S. institutions, the IEEE has not seen fit to shift away from the 1960s paradigm.²¹

United States researchers in microelectronics consider a presentation at IEDM or ISSCC as a very high measure of peer recognition of their work, and our microelectronics companies consider presentations at these meetings as public evidence that their company is pushing the frontiers of technology. There are definite marketing advantages to presenting work at these two meetings. Thus, not only do scientists and engineers compete as individuals to present their work, their employers encourage, if not demand, it.

I have reviewed the program of the 1990 IEDM,²² presented December 9 to 12, 1990, in San Francisco and the 1991 ISSCC,²³ held in San Francisco, February 13 to 15, 1991. Between 2000 and 3000 scientists and engineers attended each of these meetings. In Table 5 major categories of the topics are listed along with the affiliations of the authors as U.S. Industry, U.S. Universities and U.S. Government-Owned Laboratories, Japan, Europe, and Other. Even though the European papers are split between university and industry in about the same proportion as U.S. papers, I have not broken down the European papers because there are so few of them. The Japanese papers are written almost exclusively by industry personnel; therefore, I do not separate the few written by nonindustry personnel.

Presentations at these two U.S.-located meetings are critically reviewed, and substantially fewer than 50 percent of those papers submitted for review are accepted for presentation. Reviewers of papers for these meetings take great pride in their objectivity; nevertheless, about 80 percent of the reviewers are from the United States.

TABLE V The List of First-Author Affiliations of Papers Presented at the 1990 IEDM and 1991 ISSCC Shows Japan and the United States to Be in Close Competition

Conference and Topic	Affiliation				
	U.S. Industry	U.S. Universities and Government	Japan	Europe	Other
IEDM					
1. Integrated Circuits	9	0	14	3	0
2. Device Technology	6	5	18	3	0
3. Solid-State Devices	10	8	16	6	0
4. Detectors, Sensors, and Displays	5	7	8	1	1
5. Quantum Electronics and Compound Semiconductors	10	9	5	1	2
6. Modeling and Simulation	10	16	6	8	0
7. Vacuum Electronics	7	11	1	2	1
ISSCC					
8. Low-Temperature Circuits and Special-Purpose Processors	2	3	2	0	0
9. High-Speed RAM	1	0	6	0	0
10. Oversampling Converters	2	1	1	3	0
11. Microprocessors	3	1	2	0	0
12. High-Density DRAM	0	0	6	0	0
13. Communications	2	1	1	2	0
14. Hard Disk and Data Communications ICs	6	0	1	0	0
15. High-Performance Logic	1	1	4	1	0
16. High-Speed Data Acquisition	5	0	2	0	0
17. Emerging Technologies	4	1	1	0	1
18. Image Sensors and Processors	0	1	5	0	0
19. Telecommunications CKTs	1	0	2	3	0
20. Video Signal Processors	0	0	5	0	0
21. Nonvolatile Memory	1	0	4	0	0
22. Analog Techniques	3	0	0	2	0

Therefore, any minor subconscious bias in paper selection would likely favor U.S. authors. Despite this, conference officials at the ISSCC find the acceptance rate of Japanese papers to be twice that of U.S. papers because of the quality of the work.²⁴

At first glance the total U.S. contribution of 153 papers compares favorably to Japan's contribution of 110 papers. If one then deducts from the U.S. total the 65 papers from universities, the comparison favors Japan, but not by a significant margin (about 20 papers). However, closer examination of specific topics from Table 5 presents much cause for U.S. alarm.

- Japanese industrial researchers are starting to pull away from U.S. industrial researchers in most of those areas where there is significant product market:
 1. Integrated Circuits
 2. Device Technology

- 3. Solid-State Devices
 - 4. Detectors, Sensors, and Displays
 - 9. High-Speed RAM
 - 12. High-Density DRAM
 - 15. High-Performance Logic
 - 18. Image Sensors and Processors
 - 20. Video Signal Processors
 - 21. Nonvolatile Memory
- Areas where the market remains strong and the United States will remain competitive, although not dominant, include:
 - 8. Low-Temperature Circuits and Special-Purpose Processors
 - 10. Oversampling Converters
 - 11. Microprocessors
 - 13. Communications
 - 19. Telecommunications Circuits
 - If one could make a case that U.S. universities and government laboratory research provided an exclusive advantage to U.S. industry, then the United States would also appear to remain competitive in the following areas:
 - 3. Solid-State Devices
 - 4. Detectors, Sensors, and Displays
 - Areas where the market is strong and the United States appears to remain dominant include:
 - 14. Hard Disk and Data Communications ICs
 - 16. High-Speed Data Acquisition
 - 22. Analog Techniques
 - United States universities and government laboratories are important contributors to physics-oriented, microelectronics-device R&D (IEDM), but are practically invisible in engineering-design-oriented, microelectronics-circuit R&D (ISSCC). The latter area, not physics, drives products.
 - United States universities, government laboratories, and industry continue to lead in areas where the market future is most uncertain, the area is new (and therefore offers more publishing opportunities), or the area is only supportive to technology; that is, modeling and simulation.
 - 5. Quantum Electronics and Compound Semiconductors
 - 6. Modeling and Simulation
 - 7. Vacuum Electronics
 - 17. Emerging Technologies

Although we recognize that all crystal balls are speculative, in the absence of a paradigm shift we believe that these data suggest the following disturbing scenarios:

- Continued growth in Japan's share of the worldwide microelectronics market.

- Continued decline in the United States's share of the worldwide microelectronics market.
- Continued superiority of U.S. microelectronics R&D only in those areas of speculative or low market potential.
- Europe and the rest of the world outside the United States and Japan will not be major players in state-of-the-art microelectronics.

As Michael Borrus, director of the University of California's Berkeley Roundtable on the International Economy, has so clearly stated,

At the present rate of attrition, the U.S. merchant semiconductor industry will be an insignificant factor on world markets in roughly five years. That is the window of opportunity for the industry and government to act. . . . When historians trace the decline of the U.S. electronics industry, they will finger the decade of the 1980s, wondering why the United States never seems able to treat the ills that it endlessly documented and diagnosed.²⁵

This decline of the U.S. electronics industry is reflected in a decade-spanning comparison of the number and categories of papers presented by various groups at the international IEDM and ISSCC conferences (Table 6). This comparison can be made for IEDM by categories because they have changed categories very little in the last decade. However, only the total number of papers can be compared for ISSCC because of the many changes in session titles that make categorizing difficult. Note the shift from a preponderance of U.S. papers in 1980 and 1981 to a preponderance of papers from Japan in 1990 and 1991.

United States attendees at last year's Semicon Japan, held in Tokyo the week of October 22, 1990, were surprised to hear the conference's keynote speaker, Tadashi Kubota, Matsushita Senior Managing Director, predict that in 10 years the only U.S. semiconductor manufacturing companies that will survive are IBM, Motorola, and Intel; IBM and Motorola because they have downstream products for their microelectronics and Intel because they have microprocessors as their primary product. (In the case of microprocessors, software is a bigger limiter than manufacturing technology.) Tadashi Kubota predicted that Texas Instruments would be out of semiconductor manufacturing in less than five years because of its lack of downstream commercial products.

To determine the direct economic impact of U.S. loss of the merchant semiconductor industry, one only needs to review the recent rapid growth of this industry. In Table 7 are listed the world trends in semiconductor sales and the investment in manufacturing facilities that is required to support this rapidly expanding industry.

To stay in microelectronics, competition requires great capital investment and great investment in R&D.

Last year (1988) alone, the U.S. semiconductor industry spent about \$3.5B in capital investment. Over the next several product generations, state-of-the-art (semiconductor) manufacturing facilities are expected to cost between \$500M and \$750M. Such spending strains the resources of even very large companies.²⁶

TABLE VI Comparison of First-Author Nationalities for Papers Presented at the IEDM^a Conference in 1980 and the ISSCC^b Conference in 1981 to the Same Conferences One Decade Later Shows that Participation of Japanese Authors Has Increased Markedly, Whereas Participation by U.S. Authors Has Declined

Conference and Category	First-Author Affiliation									
	U.S. Industry		U.S. Universities and Government		Japan		Europe		Other	
	1980	1990	1980	1990	1980	1990	1980	1990	1980	1990
IEDM	<u>1980</u>	<u>1990</u>	<u>1980</u>	<u>1990</u>	<u>1980</u>	<u>1990</u>	<u>1980</u>	<u>1990</u>	<u>1980</u>	<u>1990</u>
Integrated Circuits	15	9	2	0	12	14	0	3	1	0
Device Technology	20	6	6	5	11	18	3	3	1	0
Solid-State Devices	16	10	13	8	7	16	10	6	3	0
Detectors, Sensors, and Displays	17	5	4	7	4	8	3	1	1	1
Quantum Electronics	8	10	10	9	0	5	0	1	2	2
Vacuum Electronics and Electron Tubes	17	7	4	11	0	1	1	2	0	1
ISSCC	<u>1981</u>	<u>1991</u>	<u>1981</u>	<u>1991</u>	<u>1981</u>	<u>1991</u>	<u>1981</u>	<u>1991</u>	<u>1981</u>	<u>1991</u>
All Categories	50	31	6	9	23	42	12	11	1	1

^aInternational Electron Devices Meeting, sponsored by the Institute of Electrical and Electronics Engineers.

^bInternational Solid-State Circuits Conference, sponsored by the Institute of Electrical and Electronics Engineers.

TABLE VII World Data Show the Recent Rapid Growth of Semiconductor Sales and Facility Investment in \$Billions

Year	1986	1987	1988	1989	1990	1991	1992
Semiconductor Sales	29.7	36.5	50.5	55.0	55.4	62.0	81.0
Facility Investment	5.0	6.1	9.3	10.5	10.4	13.7	17.6
Ratio: FI/SS	0.17	0.17	0.18	0.19	0.19	0.22	0.22

Source: Dataquest.

Note that if semiconductor sales sustain through the 1990s the 18 percent growth rate they achieved during the latter half of the 1980s, by the year 2000 annual sales will exceed \$250 billion. By that time computers will be built on a single chip and practically all the value added will reside in this chip, the display, and the software.

Failure of the U.S. merchant semiconductor industry will be of higher consequences than just loss of U.S. market share in microelectronics. Downstream electronics markets will be at risk.

How do you make a better computer than Hitachi and market it sooner if you are dependent on Hitachi for computer chips? asks Stephen Cohen of the Berkeley Roundtable on the International Economy. The answer is: No Way.²⁷

In the supercomputer industry Cray Research, a relatively small American company, attempts to compete for market share with Fujitsu, Hitachi, and NEC. Cray purchases many of its integrated circuit chips from Fujitsu.

"We have our own chip divisions," an NEC spokesman told David Sanger, of the New York Times. "(We) can custom-make the high speed chips we need. Cray can't."²⁸

When semiconductor technology progresses to the point where the system logic and memory are all contained on a single chip, semiconductor manufacturers will be positioned to control all of the downstream electronics sectors. Unless there is a dramatic change in the competitiveness of the U.S. semiconductor industry, by the turn of the century these electronics companies will be Japanese firms.

Notes

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