Industry & Trade Summary

Semiconductor Manufacturing Equipment

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PREFACE[1]

In 1991, the United States International Trade Commission initiated its current *Industry and Trade Summary* series of informational reports on the thousands of products imported into and exported from the United States. Each summary addresses a different commodity/industry area and contains information on product uses, U.S. and foreign producers, and customs treatment. Also included is an analysis of the basic factors affecting trends in consumption, production, and trade of the commodity, as well as those bearing on the competitiveness of U.S. industries in domestic and foreign markets. This report on semiconductor manufacturing equipment covers the period 2001 through 2005.

[1] The information and analysis provided in this report are for the purpose of this report only. Nothing in this report should be construed to indicate how the Commission would find in an investigation conducted under statutory authority covering the same or similar subject matter.

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ABSTRACT

This report addresses trade and industry conditions for semiconductor manufacturing equipment (SME) for the period 2001 through 2005.

- The U.S. SME industry is strongly competitive in most equipment and is one of the few industries in which the United States has a substantial trade surplus ($7.1 billion in 2005). U.S. manufacturers share worldwide production and technological leadership with European and Japanese companies.

- The SME industry is dominated by the major top-tier firms. In 2004, the top 10 worldwide SME companies accounted for almost 58 percent of total industry sales. SME firms within the United States are widely dispersed, although the majority are in California. From 2001 through 2005, the industry witnessed concentration, specialization, and a rapid decrease in employment. Research and development and marketing are extremely important to the industry.

- The U.S. trade surplus in SME grew from $4.1 billion in 2001 to $7.1 billion in 2005. The largest gains were made in bilateral trade with Taiwan, Korea, China, and Singapore. Most countries involved in SME trade are signatories to the Information Technology Agreement, which eliminated tariffs for SME.

- Semiconductor producers are the main consumers of SME. They need SME to outfit newly constructed semiconductor fabrication facilities as well as to replace and upgrade existing equipment. Taiwan, Korea, and Japan were the largest markets for U.S. SME in 2005. Asia has grown as the major market for SME due in part to the increase in new fabrication facility construction from 2001 through 2005.

- Three major long-term trends are driving equipment sales: (1) transition to larger silicon wafer sizes (from 200 mm diameter wafers to 300 mm diameter wafers), allowing more surface area on which to build chips, (2) the use of 0.09 and smaller-micron lithography to improve the functionality of chips while reducing their size, and (3) the use of copper for interconnects instead of aluminum because of its higher conductivity. These changes lead to improved chip performance and manufacturing efficiency, spur equipment investment by semiconductor companies, and, in turn, drive the SME industry.

INTRODUCTION

Semiconductor manufacturing equipment (SME) is used in perhaps the most complex and advanced manufacturing process in the world, the production of semiconductor devices.[1] Semiconductors, such as microprocessors and memory devices, are used in a wide variety of manufactured products, including personal computers, telecommunications equipment, and many common consumer electronics goods. Chip-containing products have proliferated in the past decade and have been a major contributor to increased productivity in virtually every sector of the U.S. economy.[2] SME has been a critical contributor to this technological revolution.

SME refers to all equipment used to produce semiconductor devices. The technology used in this equipment is constantly being improved because of consumer demand for higher performing semiconductors. Rapid advances in chip technology can render existing chips and the SME used to make them obsolete in just a few years, and an aggressive research and development (R&D) program is essential to maintaining competitiveness in the SME industry. The U.S. SME industry is one of the few U.S. industries that consistently maintains a substantial trade surplus, because U.S. firms are strongly competitive in R&D and the production of most types of equipment. The majority of all SME is used for manufacturing semiconductor devices; few other end uses exist.[3]

The SME industry is globally oriented, with a high degree of foreign investment and close interrelationship between domestic and foreign SME producers. The health of the SME industry is tied to the semiconductor industry[4] and follows its global fortunes. This summary covers the SME industry for the period 2001–2005. It describes the SME production processes, profiles the U.S. and foreign industries and markets, and provides U.S. trade and tariff information for the industry.

Industry Coverage

The SME industry consists of two broad categories: front-end and back-end equipment (figure 1). Front-end SME is used to make the silicon wafers and create the semiconductor chips on the wafers. This category includes wafer manufacturing equipment and wafer

[1] Semiconductor devices are commonly referred to by many other names including semiconductors, integrated circuits, ICs, microchips, and chips. This report uses these terms interchangeably.

[2] Dale W. Jorgenson, Mun S. Ho, and Kevin J. Stiroh, "Potential Growth of the U.S. Economy: Will the Productivity Resurgence Continue?" *Business Economics*, January 2006, vol. 41 issue 1, 7–16.

[3] In the past few years, some SME companies have diversified into the flat panel display equipment market, as the technology for making flat panel displays is similar for making semiconductors. See Colin McArdle and Nelson Wang, "Semiconductor Equipment," *Standard & Poor's Industry Surveys*, November 17, 2005, 4. Sources of information available to Commission staff on the semiconductor manufacturing equipment industry are limited. Therefore, Commission staff has relied on a limited number of sources, including the Standard & Poor's Industry Survey, for parts of this report.

[4] For more information on the semiconductor industry, please refer to Box 1.

processing equipment.[5] Back-end equipment is used to assemble, package, and test[6] semiconductors. This equipment is used primarily in the latter part of the production process.

Figure 1: Major product segments of the semiconductor manufacturing equipment industry

Front-end equipment
- Silicon wafer manufacturing equipment
  - This equipment is used to produce pure silicon by growing cylindrical silicon crystals and cutting these crystals into wafers. Prior to silicon growing, the silicon is mined, converted into a gas through a chemical reaction, and then reacted with hydrogen to form a semiconductor-grade silicon crystal. This equipment includes lasers, saws, and grinding and polishing equipment that produce the finished silicon wafers.
- Wafer processing equipment
  - This equipment is used to make the electronic circuit pathways by placing conductive and nonconductive materials on the silicon wafer. The placement is achieved by bombarding the wafer with elements or by adding layers of material. This equipment also includes machines that make masks that act as production templates during wafer processing.

Back-end equipment
- Testing equipment (note: also used in the front-end process)
  - Testing equipment is used at many points during the manufacturing of semiconductor devices, although it is concentrated in the back-end process during packaging. Types of equipment include microscopes, machine vision systems, probe machines, and scales.
- Assembly and packaging equipment
  - This equipment is used to place the semiconductor devices into packages for shipping or placement in electronic equipment. The backside of the wafer is prepared, and the individual chips on the wafer are separated before the die is attached to a package. The chips are attached to the package via gold wiring, which is then set up and trimmed using assembly equipment. Finally, the chip is encapsulated in plastic.

Source: U.S. International Trade Commission, *Global Competitiveness of U.S. Advanced-Technology Manufacturing Industries: Semiconductor Manufacturing and Testing Equipment*, USITC publication 2434, September 1991, 1–2; and Peter Van Zant, *Microchip Fabrication: A Practical Guide to Semiconductor Processing*, 4th edition, (New York: McGraw-Hill, 2000).

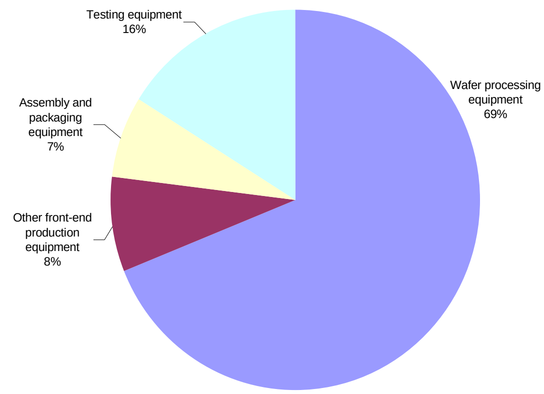
Front-end equipment is much more expensive, because it adds more value to the final semiconductor product than back-end equipment. Similarly, front-end SME is generally more profitable than back-end SME.

Because of higher profitability and rapidly changing customer requirements, most SME producers' sales are concentrated in front-end products (figure 2). This report analyzes global producers, markets and trade trends for both front-end and back-end equipment.

[5] See technical glossary in appendix B for definitions.

[6] Various forms of wafer and chip testing take place throughout the semiconductor manufacturing process, in addition to the final testing at the end of the process.

Figure 2: Worldwide semiconductor manufacturing equipment sales by product type, 2005 *(percentage)*



Source: Semiconductor Equipment and Materials International (SEMI).

Note: Percentages based on 2005 SME total market of $32.9 billion.

Importance of the SME Industry

Demand for SME is directly linked to demand for semiconductors, which, in turn, is linked to the strength of the global economy.[7] The competitiveness of individual SME firms is linked to their ability to design and manufacture products capable of producing the latest generation of semiconductors at the lowest cost. This generally requires a high commitment to R&D expenditures; 20 percent of annual sales is not uncommon. The U.S. SME industry is globally competitive and is considered to be the world leader. SME production for U.S.-headquartered companies is concentrated in the United States, which has consistently run a trade surplus in SME in recent years.

Overview of Industry Trends and Developments

The SME industry has historically been characterized by severe market volatility, and the period 2001 through 2005 was no exception. Following a record-setting year in 2000 with $47.7 billion in global equipment sales, the global SME industry witnessed a 41 percent decrease in sales to $28 billion in 2001, followed by a 30 percent drop to $19.7 billion in 2002. Following the 4–5 year boom-bust cycle that has historically characterized the industry,[8] sales increased by 13 percent to $22.2 billion in 2003 and by 67 percent to $37.1 billion in 2004. Sales leveled off in 2005 with an 11 percent decrease to $32.9 billion.[9]

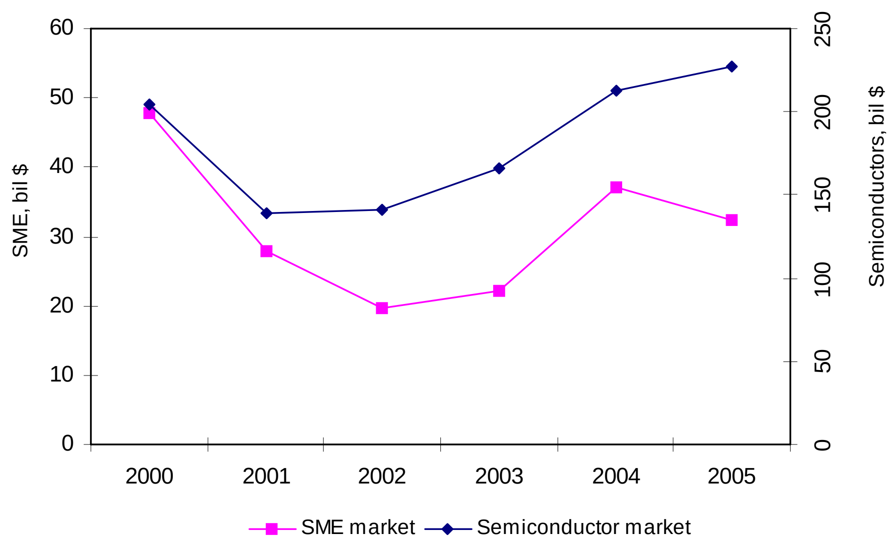
[7] Bill McClean, Brian Matas, and Trevor Yancey, *The McClean Report: A Complete Analysis and Forecast of the Integrated Circuit Industry,* edited by Richard D. Skinner, 2006 (Arizona, IC Insights, Inc., 2006), 2–5.

[8] The SME industry generally follows the fortunes of the semiconductor industry, which has historically followed a 4–5 year boom-bust cycle. For more information, see: McClean, Matas, and Yancey, 2–23 through 2–26.

[9] USITC staff, email communication with Semiconductor Equipment and Materials International (SEMI), February 7, 2006; and McArdle and Wang, 8.

Several key characteristics of the SME industry are responsible for this recurring volatility, the most important being the direct link between demand for SME and demand for semiconductors. An adage notes, "When the economy gets a chill, electronics catches a cold, semiconductors come down with pneumonia, and the equipment industry dies."[10] This relationship underscores specific factors that are responsible for SME industry volatility—rapid growth cycles, sharp price fluctuations, rapid technological innovation, and frequent capacity imbalances. These factors have a strong effect on the ability of companies to compete effectively. It is not surprising that from the last cyclical peak in 2000 to 2005, the SME industry experienced a pattern of cyclical volatility similar to that in the semiconductor industry (figure 3).

Figure 3: Comparison between the global semiconductor manufacturing equipment and semiconductor markets



Source: SEMI, World Semiconductor Trade Statistics (WSTS), and IC Insights.

[10] G. Dan Hutcheson, "Economics of Semiconductor Manufacturing," *Handbook of Semiconductor Manufacturing Technology*, edited by Y. Nishi & R. Doering, (New York: Marcel Dekker, 2000), 1125–1126.

The increase in SME demand that began in 2003 is driven by three major long-term trends in the semiconductor industry: (1) the movement to larger silicon wafer sizes (from 200 mm diameter wafers to 300 mm diameter wafers), allowing more surface area on which to build chips, (2) the use of 0.09 micron and smaller process technology to improve chip performance while reducing chip size, and (3) the use of copper for interconnects instead of aluminum because of its higher conductivity.[11] These changes improve chip performance and manufacturing efficiency. More importantly for the SME industry, these changes have spurred equipment investment by semiconductor companies looking to replace old equipment and equip newly-constructed semiconductor fabrication facilities (fabs). As a result, demand for SME has accelerated and equipment sales increased by 48 percent from 2003 through 2005.

While the United States, Europe,[12] and Japan were the largest producers of SME throughout 2001–2005, the SME market shifted to Asia. During the period, many semiconductor manufacturers either opened or expanded semiconductor manufacturing facilities in Asia or outsourced to Asian facilities in order to be close to their largest customers (electronic equipment manufacturers) and to reduce transportation and production costs.

U.S. INDUSTRY[13] AND MARKET

In the early 1960's, U.S. companies created the SME industry as an outgrowth of domestic demand for tools to build semiconductors and dominated the industry in its early years. In the early 1980s, Japanese and European companies gained market share in several equipment and materials technologies.[14] Over the last decade, however, U.S. companies have regained market share and re-emerged as a global technological leader through R&D investments in cutting-edge SME technology. U.S. producers' SME shipments in 2004 totaled an estimated $13.4 billion (figure 4).[15]

[11] McArdle and Wang, 3–4.

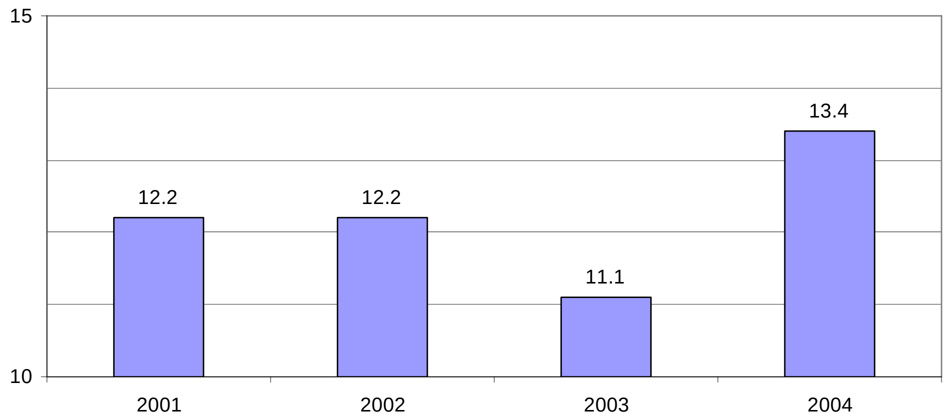
[12] Europe in all cases refers to the EU-15.

[13] The NAICS code for this industry is 333295.

[14] For more information on the history of the semiconductor equipment industry, see VLSI Research's *History of the Equipment Industry*, found at *https://www.chiphistory.org/*.

[15] U.S. Department of Commerce, Bureau of the Census, "Annual Survey of Manufacturers," 2004, 22, found at *http://www.census.gov/prod/2005pubs/am0431gs1.pdf*, retrieved January 23, 2006.

Figure 4: U.S. shipment data for semiconductor manufacturing equipment, 2001–2004 (billion dollars)



Source: Compiled by USITC staff from official statistics of the U.S. Department of Commerce.

U.S. companies share worldwide leadership in the SME industry with Japanese companies. In 2005, North American producers (i.e. predominantly U.S. producers) had an estimated 45 percent share of the world market, while Japan held an estimated 41 percent share.[16] Although recent U.S. SME exports have predominately been to Europe and Japan, exports have increased to Korea, Taiwan, and other parts of Asia in light of increasing production of semiconductors in those countries.

Number of Firms and Industry Structure

The U.S. SME industry is highly competitive. The North American SME industry consists of more than 62 companies, the vast majority headquartered in the United States. Most companies focus on products used in just one or two of the processes involved in making an integrated circuit (IC). U.S. companies are globally oriented and sell in all major SME markets. Photolithography equipment is the only segment of front-end SME equipment in which U.S. manufacturers do not hold a competitive advantage. Firms in Japan, the principal U.S. rival in SME production, and Europe currently dominate world markets for photolithography.[17]

The U.S. SME industry is a major part of the $32.9 billion worldwide SME industry.[18] The number of worldwide SME producers is difficult to ascertain, as many firms are small, niche equipment manufacturers. Semiconductor Equipment and Materials International (SEMI), the industry association for SME, has 161 producers in its Worldwide Semiconductor

[16] USITC staff, email communication with SEMI, February 7, 2006.

[17] Japanese firms Canon Inc. and Nikon Corp. have excelled in the photolithography segment mostly because of their ability to transfer knowledge gained from R&D in their camera operations to their SME operations.

[18] USITC staff, email communication with SEMI, February 7, 2006.

Equipment Market Statistics (WWSEMS) program.[19] Overall, however, the industry is relatively concentrated and dominated by the top-tier firms. For example, the top ten global SME producers accounted for almost 58 percent of worldwide SME sales in 2004.[20] The largest global producer of SME, Applied Materials, Inc., is a U.S.-based company, headquartered in Santa Clara, CA. SME firms exist throughout the United States, although the majority are in California.

Firms Specialize

The SME industry is highly specialized. Today, semiconductor companies rarely make their own tools as was common in the 1950s and 1960s, when the semiconductor industry was in its infancy.[21] The SME industry grew in response to the void left when semiconductor companies began to focus on designing and building chips. In the front-end segment, specialization is so common that, with the notable exception of the top two industry leaders, Applied Materials, Inc. and Tokyo Electron Limited, the majority of SME companies involved in front-end tool manufacturing concentrate on making tools for only one or two of the four basic wafer processing operations: layering, patterning, doping, and heat treatments.

The need for companies to stay competitive in a highly cyclical industry has driven SME segment specialization. The peaks and valleys in equipment demand inherent in the SME industry make survival during downturns challenging, especially for smaller firms that have limited manufacturing capabilities. In order to become more responsive, firms focus their resources and knowhow on a target market segment hoping to concentrate R&D and marketing within that segment to secure greater market share.

Industry Concentration

A parallel trend to segment specialization has been industry concentration, especially around equipment for certain processes. There are high technological and capital barriers to entry in the SME industry. Without a high level of technological sophistication, which often takes years to develop, new entrants find it challenging to establish a foothold in the industry. The result has been that the production of certain tools is dominated by a handful of firms that specialize in only making that one tool. For example, for several years three firms have dominated the wafer patterning process known as photolithography: a Dutch firm, ASML Holding (40 percent market share during the first half of 2004), and two Japanese firms, Canon Inc. and Nikon Corp. (30 percent market share each).[22] Tools for ion implantation, one of two main processes in doping operations,[23] are manufactured principally by three U.S. companies, Varian Semiconductor Equipment Associates Inc., Axcelis Technologies Inc., and Applied Materials, Inc., which maintained a combined 75 percent market share in the first half of 2004.[24]

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[19] Ibid.
[20] McArdle and Wang, 8.
[21] USITC staff, email communication with SEMI, February 7, 2006.
[22] McArdle and Wang, 20.
[23] The process of producing semiconductors using SME is explained in detail in appendix A.
[24] McArdle and Wang, 20.

Employment Decreases

Employment in the U.S. SME industry fell each year during the period 2000-2004,[25] from 50,430 employees in 2000 to 27,212 employees in 2004, a decrease of 46 percent (figure 5).

Figure 5: Semiconductor manufacturing equipment industry employment, 2000–2004[1]

Source: U.S. Department of Commerce,

[1] 2005 employment data is not yet available.

The rapid reduction in employment during the period began as a response to the severe industry downturn in 2001, was exacerbated by several factors (increased productivity, outsourcing of manufacturing and noncore business activity, mergers and acquisitions), and continued as a means to address firms' high cost structures. SME companies' immediate response to the 2001 downturn was to rapidly scale back the number of employees. For example, total employment in the industry decreased by 31 percent in just 1 year, from 50,469 in 2001 to 34,998 in 2002. The decrease was most severe for SME production workers, whose employment rate decreased by 41 percent from 24,709 in 2001 to 14,564 in 2002 (table 1).[26]

[25] U.S. Department of Commerce, Bureau of the Census, "Annual Survey of Manufacturers 2004," 32. Figures for 2000 and 2001 are from "Annual Survey of Manufacturers 2000," 28, found at *http://www.census.gov/prod/2002pubs/m00as-1.pdf*, retrieved January 23, 2006.

[26] Ibid.

Table 1: Payroll and wage rates for production workers in the semiconductor manufacturing equipment industry, 2000-2004[1]

Year	Total Payroll	Total Number of Production Workers	Total Hours Production Workers Worked	Total Wages Paid to Production Workers	Average Hourly Wage of Production Workers
	(*Million dollars*)		(*Million*)	(*Million dollars*)	(*Dollars*)
2000	2,959.86	24,813	49.13	1,102.94	22.45
2001	2,784.33	24,709	49.36	969.88	19.65
2002	2,137.50	14,564	28.76	583.61	20.29
2003	2,025.51	13,344	25.73	556.30	21.62
2004	1,961.81	11,648	23.82	474.76	19.93

Source: Compiled by USITC staff from official U.S. Department of Commerce statistics.

[1] 2005 employment data not yet available.

Recent increases in factory automation have also led to declining employment while also improving SME productivity. The recent move to 300-mm diameter wafer fabrication, in particular, has spurred automation because the larger size and weight of the wafer makes manual handling difficult. For example, 300-mm diameter wafers are transported in a cassette that fits 25 wafers. When fully loaded, the cassette weighs an estimated 90 pounds.[27]

Two segments of the SME labor force for which competition is intense and for which employment levels have remained stable or grown are highly skilled technical workers in R&D and customer support functions.[28] SME companies differentiate themselves by how well and rapidly they create advanced machinery and how well they support and maintain their customers' current tools.

Research and Development Remains Vital

SME companies must be able to continuously develop the equipment needed to meet changing customer needs at competitive prices and in a timely manner. To meet customer needs for chip-making equipment, SME firms devote significant portions of their human and financial resources to R&D. Unlike counterparts abroad, the U.S. government does not provide programs specifically designed to assist the SME industry with R&D. It is not uncommon for SME firms to spend an average of 20 percent of their sales annually on R&D. For example, the world's leading SME company, Applied Materials, Inc., reports that it spent 16 percent of its annual net sales on research, development and engineering from FY2001 to FY2005,[29] or about $1 billion per year.

Even during severe downturns, SME companies will often continue to invest highly in R&D. Many industry leaders reportedly increase R&D investment during downturns as a way to gain market share from financially weaker companies that cannot match such high levels of

[27] McArdle and Wang, 15.

[28] Lam Research Corp., submission to the United States Securities and Exchange Commission, Form 10-K, 2005: Annual Report Pursuant to Section 13 or 15(d) of the Securities and Exchange Act of 1934, Commission file number 0-12933, 5.

[29] Applied Materials, Inc., submission to the United States Securities and Exchange Commission, Form 10-K, 2005: Annual Report Pursuant to Section 13 or 15(d) of the Securities and Exchange Act of 1934, for the fiscal year ended October 30, 2005, Commission file number 0-6920, 15.

R&D spending during downturns.[30] This investment can exacerbate significant financial losses for SME firms during downturns.

High levels of investment in R&D do not ensure company profitability, however. On average, it takes several years for a new machine to become profitable. Typically, a new product will start to generate sales in the third or fourth year after development, and it is only around the sixth year that sales of a new machine may start to turn a profit.[31]

Besides developing their own technology through investment in R&D, SME companies often increase their level of technology through the purchase of other companies that have developed certain technologies. For example, from April 2003 to June 2005, Applied Materials, Inc. spent approximately $146 million to acquire the full or partial assets of five smaller SME firms.[32]

In general, SME firms protect their technology assets through obtaining and enforcing their intellectual property rights. Intellectual property (IP) in the SME industry typically consists of patents but can also include trademarks, trade secrets, and copyrights. As SME are generally large, complicated machines, they are much more difficult to copy than products such as CDs or watches. Most IP infringement in the SME industry is reportedly undertaken by other major industry players. For example, in 2002, Nikon Corp. accused ASML Holding of infringing on its photolithography equipment patents (see page 21 for more information).

Marketing's Valuable Role

Marketing is a major activity for U.S. SME companies. For example, Applied Materials, Inc. reports that it devoted 10 percent of its net sales to marketing, selling, general, and administrative expenses during FY2005.[33] Marketing of SME takes place through several channels of distribution and through both push and pull strategies[34] between SME producers and their customers, semiconductor manufacturers. Larger SME firms tend to market directly to semiconductor manufacturers, while smaller producers often hire representative firms. Also, due to the international nature of the SME business, most firms have sales and support offices in major equipment markets worldwide.[35]

SME companies focus marketing efforts on building long-term, close relationships with their customers. It is common to have SME engineers working directly in semiconductor manufacturing facilities to assist the chip makers with using and maintaining their equipment. Because tools are very sophisticated and often built to customer specifications, repeat business is common in the industry. In addition, because chip makers have to update their equipment with the latest technology, there is a built-in replacement cycle that may provide regular orders once a business relationship has been established. This tendency for chip makers to buy again from an initial SME supplier means that the total amount of

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[30] McArdle and Wang, 25.
[31] Ibid., 22.
[32] Applied Materials, Inc., 22.
[33] Ibid., 21.
[34] A push strategy creates demand for a product through selling, or pushing it, to customers. A pull strategy relies on advertising and promotions to create enough consumer demand for a product that the consumers begin requesting it.
[35] For example, approximately 80 percent of Applied Material's net sales in FY2005 was outside of the United States. Applied Materials, Inc., 8.

software and machinery in service at a customer site—or the so-called "installed base"—is an important gauge of an SME firm's acceptance in the marketplace and measure of its level of industry prestige.[36]

Pricing

SME is very expensive. Construction of a state-of-the-art semiconductor fab costs between $3 and $4 billion, with equipment accounting for the majority of this cost.[37] Equipment prices vary widely, depending on the machine's function. In general, tools used in front-end wafer fabrication and testing are relatively costly, because of the high level of sophistication of the operations they perform. For example, one of the most complicated front-end fabrication processes is photolithography. According to ASML Holding, which is currently the world's leading producer of photolithography equipment, the average selling price of a new lithography system was roughly $15.2 million in the fourth quarter of 2005.[38] At the other end of the pricing spectrum are machines used in back-end assembly and packaging functions. For example, a wire-bonding machine costs around $100,000, and a molder, which works in the packaging process by melting black carbon around the bare semiconductor die, costs about $30,000.[39]

Factors Affecting Production

The SME industry has become increasingly global in recent years. Leading firms in the United States, Japan, and Europe earn less than one-half of their revenues through sales in their home markets. The top global SME companies are shown in table 2.

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[36] McArdle and Wang, 21.
[37] Ibid., 10.
[38] Peter Clarke, "Dropping Prices Signal Spending Restart, Says ASML," *EE Times*, January 18, 2006, found at *http://www.eetimes.com/news/semi/showArticle.jhtml;jsessionid=LWM2GG1GGQ23QQSNDBCCKH0CJUMEKJVN?articleID=177101313&printable=true*, retrieved February 1, 2006.
[39] Industry representative, interview with USITC staff, January 13, 2005.

Table 2: Top 10 semiconductor manufacturing equipment companies, ranked by 2005 revenue

Company	Headquarters	Revenue in $ millions
Applied Materials, Inc.	United States	6,234
Tokyo Electron Limited	Japan	4,455
ASML Holding	Europe	3,160
KLA-Tencor Corp.	United States	2,005
Advantest Corp.	Japan	1,960
Nikon Corp.	Japan	1,566
Lam Research Corp.	United States	1,382
Novellus Systems, Inc.	United States	1,302
Hitachi High-Technologies Corp.	Japan	1,277
Canon Inc.	Japan	1,247

Source: VLSI Research.

Long-term trends, including further industry concentration in a trend toward overall production efficiency, have accelerated since the last downturn. Smaller manufacturers are likely to consolidate during industry downturns in order to survive. Also, it is frequently easier to obtain technology and customers through acquisition than through internal product development. Further, consolidation can offer economies of scale and scope, leading to greater efficiency.

With the move toward consolidation and high startup costs, it is unlikely that new companies will be entering the SME business. Both startup costs and high R&D costs are difficult barriers to overcome. Semiconductor companies, the main customer for SME producers, are loyal and tend to stay with the same company for replacement equipment and parts. Companies must have the ability to send customer service personnel to the client site to assist with installation and upkeep of equipment; a local office near the customer is sometimes preferred.

Suppliers are also important to the SME industry. As SME is built-to-order, suppliers must be able to send equipment subsets and/or equipment parts to the SME company in a timely fashion. This ensures that the necessary SME is shipped to the customer in as timely a manner as possible. Suppliers to the semiconductor equipment industry tend to be smaller manufacturers throughout the world. Most large U.S. SME firms outsource the manufacturing of major parts for the machines that they produce. Such activities consist mainly of assembling and testing components, subassemblies, and modules for finished products. Because the number of subassembly suppliers for certain key parts can be very small, it is not uncommon for a few suppliers to provide the same part to a number of SME firms that make the same end product. Such dependence on a limited number of key suppliers is a major risk that many SME firms try to mitigate by outsourcing to a variety of suppliers, where possible.[40] For example, the photolithography equipment business is dominated by three SME firms—ASML Holding, Canon Inc., and Nikon Corp.—all of whom are dependent on two companies that manufacture laser light sources for DUV

[40] Applied Materials, Inc., Lam Research Corp., Novellus Systems, Inc., and KLA-Tencor Corp., submissions to the United States Securities and Exchange Commission, Form 10-K, 2005: Annual Report Pursuant to Section 13 or 15(d) of the Securities and Exchange Act of 1934, Commission files 0-6920, 0-12933, 000-17157, and 0-9992.

photolithography applications - the U.S. firm Cymer, Inc. and the Japanese firm Gigaphoton.[41]

Outsourcing of major subassemblies to smaller more specialized firms is economically beneficial to both groups. For the SME firm, outsourcing parts manufacturing reduces costs for research, development, and manufacturing, while for the subassembly manufacturer, specialization increases product efficiency and allows its engineers to increase product functionality.[42]

Consumer Characteristics and Factors Affecting Demand

Semiconductor producers are the main consumers of SME (Box 1). They need SME to outfit newly constructed semiconductor fabs as well as to replace and upgrade existing equipment in their current fabs. The top 25 semiconductor companies in terms of capital spending in 2005 (top 10 of these are shown in table 3), accounted for 86 percent of total semiconductor capital spending in that year, up from 75 percent in 2002.[43] By location of headquarters, North American companies[44] are the largest spenders ($13.7 billion in 2005), followed by companies from Japan, Korea, and Taiwan.

Table 3: Top 10 semiconductor companies, ranked by capital spending, 2005

Company	Headquarters	Spending in $ millions
Samsung Electronics Co., Ltd.	South Korea	6,160
Intel Corp.	United States	5,900
TSMC, Ltd.	Taiwan	2,600
Hynix Semiconductor Inc.	South Korea	2,000
Toshiba Semiconductor Co.	Japan	1,950
Sony	Japan	1,525
Advanced Micro Devices, Inc.	United States	1,500
Micron Technology, Inc.	United States	1,500
Infineon Technologies AG	Europe	1,500
STMicroelectronics N.V.	Europe	1,500

Source: The McClean Report 2006 Edition, 4–6.

Note: Spending on semiconductor manufacturing equipment is a major element of capital spending for semiconductor manufacturers.

[41] Cymer, Inc., submission to the United States Securities and Exchange Commission, Form 10-Q: Quarterly Report Pursuant to Section 13 or 15(d) of the Securities and Exchange Act of 1934, for the quarterly period ended September 30, 2005, Commission file number 0-21321, 37.
[42] McArdle and Wang, 10.
[43] McClean, Matas, and Yancey, 4-5 through 4-11.
[44] Company headquarters does not necessarily indicate country of production.

Box 1: Consumer of semiconductor manufacturing equipment: the semiconductor industry

The semiconductor industry was a $227 billion industry in 2005. The most common type of semiconductor device produced is the integrated circuit (IC), which accounts for roughly 85 percent of semiconductor production today. Another type of semiconductor known as discrete devices accounts for the rest. North American sales (for which the United States is the major market) accounted for about 18 percent ($40 billion) of the global market in 2005. U.S.-based semiconductor manufacturers are largely global companies with fabrication facilities located both domestically and abroad. Seventy-seven percent of manufacturing capacity of the U.S. industry is located in the United States with a domestic workforce of over 225,000. Because of the constant pressure to innovate and stay on the cutting edge of technology, semiconductor companies reinvest a high percentage of revenue in research and development. It is not uncommon for a semiconductor firm to reinvest half of its gross profit in the form of research and development. Also, because the industry is highly capital intensive, companies spend significant sums on capital equipment from the SME industry. Currently, a state-of-the-art semiconductor fabrication facility costs approximately $3–4 billion to build, the vast majority of the cost going to the machinery inside the facility to fabricate the semiconductors. Major players in the semiconductor industry include Intel Corp., Samsung Electronics Co., Ltd., Texas Instruments Inc., Renesas Technology Corp., Toshiba Semiconductor Co., STMicroelectronics N.V., TSMC, Ltd., NEC Electronics Corp., and Freescale Semiconductor, Inc.

Sources: Semiconductor Industry Association, SIA Issue Backgrounders, "State and Local Government Policies to Keep Manufacturing in U.S.," found at *http://www.sia-online.org/backgrounders_government.cfm*, retrieved January 20, 2006; Semiconductor Industry Association, SIA Issue Backgrounders: "Free and Fair Trade," found at *http://www.sia-online.org/backgrounders_trade.cfm*, retrieved January 20, 2006; Bill McClean, Brian Matas, and Trevor Yancey, *The McClean Report: A Complete Analysis and Forecast of the Integrated Circuit Industry*, Richard D. Skinner, 2006 Edition (Arizona, IC Insights, Inc., 2006); Amrit Tewary and Elayne Sheridan, "Semiconductors," Standard & Poor's Industry Surveys, September 1, 2005; and USITC staff telephone interview with Doug Andrey of the Semiconductor Industry Association, June 26, 2002.

As noted, semiconductor manufacturing facilities exist throughout the world. As the growth of semiconductor wafer processing by foreign chip manufacturers has significantly outpaced that of U.S. semiconductor production, much of the U.S. SME industry's customer base is overseas, concentrated in Asia. The SME industry's customers look for quality of technology and product, timeliness of product introductions, customer support, breadth of product line, and price in making purchasing decisions.[45] Established customer relationships are also significant considerations. SME companies must try to differentiate themselves in most, if not all, of these areas in order to survive.

As previously mentioned, the SME industry is cyclical. SME demand is driven by demand for semiconductors, which in turn tends to rise and fall together with the economy as a whole. Consumer products are responsible for much of the current growth in semiconductor sales. One-half of all semiconductors sold in 2004 were used in consumer products, and this share is expected to grow to two-thirds by 2010.[46] Specific products contributing to this rise in demand include consumer electronics, mobile phones, and automobiles.

[45] Applied Materials, Inc., Lam Research Corp., and Novellus Systems, Inc.
[46] McArdle and Wang, 12.

Shipments, Consumption, and Trade

Apparent U.S. consumption of SME decreased by 45 percent from 2001 through 2005 (table 4), as offshore production of semiconductors increased. The ratio of imports to consumption rose sharply at the end of the period, reflecting, in part, increased U.S. demand for expensive photolithography equipment that is not produced in the United States. The large increase in the ratio of exports to shipments reflects the shift of semiconductor production to foreign (mostly Asian) countries.

Table 4: Semiconductor manufacturing equipment: U.S. shipments, U.S. exports of domestic merchandise, U.S. imports for consumption, apparent U.S. consumption, the ratio of imports to consumption, and the ratio of exports to shipments, 2001–2005

Year	U.S. shipments	U.S. exports	U.S. imports	Apparent U.S. consumption	Ratio of imports to consumption	Ratio of exports to shipments
	Million Dollars				*Percent*	
2001	12,200	8,044	3,947	8,103	49	66
2002	12,200	6,972	3,304	8,532	39	57
2003	11,100	7,242	2,750	6,608	42	65
2004	13,400	12,790	3,586	4,196	85	95
2005	11,580	10,971	3,857	4,466	86	95

Source: Compiled from official statistics of the U.S. Department of Commerce. Shipment data for 2005 are estimated by Commission staff, using industry input.

Most SME is produced to order and shipped when ready. Because SME is sophisticated and often made to customer specifications, production time is lengthy; the typical time to fill an order is 5 to 6 months. Even during industry downturns, the turnaround may be still be up to 3 months.[47] Because this machinery is very expensive to produce and tends to be custom-made for a certain semiconductor production facility, inventories are low.

U.S. TRADE

Overview

The United States maintained a positive trade balance in SME throughout the period 2001–2005 (table 5). The trade surplus has grown from $4.1 billion in 2001 to $7.1 billion in 2005, a 73 percent increase. The trade surplus fluctuated throughout the 5-year period, from a low of $3.7 billion in 2002 to a high of $9.2 billion in 2004. The largest gains were with Korea, Taiwan, China, and Singapore, and the combined 2005 U.S. surplus with the four countries was $5.4 billion.

[47] Ibid., 21.

Table 5: Semiconductor manufacturing equipment: U.S. exports of domestic merchandise, imports for consumption, and merchandise trade balance, by selected countries, 2001–2005 *(Million dollars)*

Item	2001	2002	2003	2004	2005
U.S. exports of domestic merchandise:					
Taiwan	1,359	1,660	1,177	2,979	2,206
Korea	807	602	928	1,618	1,999
Japan	1,440	1,166	1,293	2,020	1,922
Singapore	527	583	560	1,476	764
China	338	551	529	1,261	662
Germany	823	440	420	544	658
Canada	373	354	350	325	338
Malaysia	328	252	228	362	298
United Kingdom	316	129	141	208	174
Netherlands	95	64	77	185	154
All Other	1,639	1,173	1,538	1,809	1,794
Total	8,044	6,972	7,242	12,790	10,971
U.S. imports for consumption:					
Japan	2,406	1,750	1,292	1,811	1,972
Netherlands	472	665	665	636	761
Germany	348	258	193	284	291
United Kingdom	226	170	133	147	165
Singapore	29	16	28	84	85
Korea	12	20	38	48	61
Malaysia	7	15	34	77	49
Canada	41	32	32	50	46
Taiwan	25	23	17	37	39
China	4	8	25	31	34
All Other	378	347	291	382	354
Total	3,947	3,304	2,750	3,586	3,857
U.S. merchandise trade balance:					
Taiwan	1,335	1,636	1,159	2,943	2,167
Korea	795	581	890	1,571	1,938
Singapore	497	567	531	1,392	679
China	334	543	504	1,231	628
Germany	475	182	227	260	367
Canada	332	322	318	276	292
Malaysia	321	236	194	286	249
United Kingdom	90	-41	8	61	([2])
Japan	-966	-584	([2])	209	-50
Netherlands	-376	-601	-587	-451	-607
All Other	1,261	826	1,247	1,427	1,440
Total	4,096	3,668	4,492	9,204	7,113

Source: Compiled from official statistics of the U.S. Department of Commerce.

Note: Because of rounding, figures may not add to totals shown.

[1] Import values are based on customs value; export values are based on f.a.s. value, U.S. port of export.
[2] Less than $500,000.

The Netherlands is the only country with which the United States maintains a sizeable trade deficit ($607 million in 2005). This deficit is reportedly due to U.S. imports of expensive photolithography equipment from Dutch producer, ASML Holding, as well as the fact that the Netherlands is not a leading market for U.S. SME exports.

U.S. Exports

U.S. exports of SME rose irregularly during the period 2001–2005 (table 6). The United States exported close to $11.0 billion of SME in 2005, 36 percent more than in 2001 but less than the 2004 level. Exports of wafer production machinery accounted for about 67 percent of SME exports, with test machinery and assembly and packaging equipment exports making up an estimated 29 percent and 4 percent, respectively.

Table 6: Semiconductor manufacturing equipment: U.S. exports of domestic merchandise, by principal product groups, 2001–2005[1]

Product group	2001	2002	2003	2004	2005	Percent change, 2005 from 2001
Assembly and packaging machinery	322,372	271,710	284,772	327,210	388,139	20
Test machinery	2,303,959	2,033,093	2,229,338	3,859,576	3,203,333	39
Wafer production and fabrication machinery	5,417,340	4,667,678	4,727,616	8,602,799	7,379,044	36
Total	8,043,672	6,972,481	7,241,726	12,789,584	10,970,516	36

Source: Compiled from official statistics of the U.S. Department of Commerce.

Note: Because of rounding, figures may not add to totals shown.

[1] Export values are based on f.a.s. value, U.S. port of export.

The leading markets for U.S. exports of SME in 2001 were Taiwan and Japan, which together accounted for 35 percent of total U.S. SME exports. These markets increased their share of U.S. exports throughout the 5-year period. The Korean market surpassed that of Japan in 2005; together, these three Asian markets received 56 percent of U.S. exports in 2005. Much of the increase in exports to Taiwan was due to the expansion of the foundry industry.[48]

U.S. Imports

From 2001 through 2005, U.S. imports of SME fluctuated largely in response to an economic downturn and subsequent decreased U.S. demand following the September 11, 2001 terrorist attacks (table 7). By 2005, however, demand had rebounded and import levels approximated those of 2001. U.S. imports largely consist of photolithography equipment of which there is no U.S. production.

Imports of front-end wafer production and fabrication machinery accounted for 74 percent of all U.S. imports of SME in 2005; this percentage remained unchanged from 2001. Wafer production and fabrication machinery and test machinery imports fluctuated during the period; these groups were 3 percent and 2 percent lower in 2005 than in 2001, respectively.

[48] Semiconductor foundries are semiconductor companies that specialize in only the fabrication of chips, as opposed to semiconductor design. Foundries provide services to “fabless” semiconductor companies that only design chips, and to integrated device manufacturers (IDMs) that outsource some chip production to foundries, especially during business upturns when IDMs may not have sufficient capacity to meet demand. The foundry model was pioneered in Taiwan in the late 1980s and has since become very popular in the global semiconductor industry.

Table 7: Semiconductor manufacturing equipment: U.S. imports for consumption, by principal product groups, 2001–2005[1]

Product group	2001	2002	2003	2004	2005	Percent change, 2005 from 2001
Assembly and packaging machinery	78,680	55,438	56,746	62,404	78,782	([2])
Test machinery	961,438	750,836	685,474	1,119,264	943,395	-2
Wafer production and fabrication machinery	2,907,329	2,498,029	2,007,372	2,404,299	2,835,213	-3
Total	3,947,446	3,304,303	2,749,593	3,585,967	3,857,390	-2

Source: Compiled from official statistics of the U.S. Department of Commerce.

Note: Because of rounding, figures may not add to totals shown.

[1] Import values are based on customs value.
[2] Less than 0.5 percent.

Japan was the largest supplier of SME to the U.S. market throughout the period 2001–2005. Although U.S. imports from Japan fluctuated, the country accounted for 51 percent of total U.S. imports of such machinery in 2005, a decrease from a 61 percent share of imports in 2001. Other principal suppliers of SME to the U.S. market were the Netherlands, Germany, the United Kingdom, and Israel. The Netherlands' share of U.S. SME imports increased during this period, while the German, British, and Israeli market shares decreased.

U.S. and Foreign Trade Measures

Tariff Measures

All SME imports enter the United States free of duty. Duties on SME were eliminated by the Information Technology Agreement (ITA), which entered into force in July 1997. All developed country signatories were obligated to reduce their tariffs to zero by January 2000. There are currently 63 signatories to the ITA, including all major SME-producing and -importing countries.

SME imports enter under various tariff subheadings in chapters 84, 85 and 90 of the Harmonized Schedule (HS) (appendix C). There has been an international initiative to classify some of this equipment under one HS heading (Box 2); this is expected to take effect in January 2007.

Nontariff Measures

The Commission is unaware of any nontariff barriers (NTBs) affecting the SME industry. No NTBs were reported by the Office of the United States Trade Representative in its 2006 National Trade Estimate Report on Foreign Trade Barriers.[49] However, government-funded R&D programs have been set up in many countries for SME manufacturers (see Foreign Industry Profiles section).

[49] Office of the United States Trade Representative, *2006 National Trade Estimate Report on Foreign Trade Barriers.*

Box 2: A new Harmonized Schedule (HS) heading for semiconductor manufacturing equipment in 2007

Since the advent of the HS in 1989, semiconductor manufacturing equipment has been classified under many different categories in three separate chapters: 84, 85, and 90. However, beginning in January 2007, all front-end SME will be classified under one HS heading: 8486. Back-end equipment will remain scattered throughout chapter 90.

This reorganization of the HS was originally proposed to the World Customs Organization in the second HS review cycle by the government of Japan, with limited success. It was reintroduced in the third HS review cycle.

The new heading and subheadings will appear as listed below:

8486	Machines and apparatus of a kind used solely or principally for the manufacture of semiconductor boules or wafers, semiconductor devices, electronic integrated circuits or flat panel displays; machines and apparatus specified in Note 9(C)[1] of this chapter; parts and accessories
8486.10	Machines and apparatus for the manufacture of boules or wafers
8486.20	Machines and apparatus for the manufacture of semiconductor devices or of electronic integrated circuits
8486.30	Machines and apparatus for the manufacture of flat panel displays
8486.40	Machines and apparatus specified in Note 9 (C)[1] to this chapter
8486.90	Parts and accessories

[1] Note 9 (C) states that heading 8486 also includes machines and apparatus solely or principally of a kind used for (i) the manufacture or repair of masks and reticles; (ii) assembling semiconductor devices or electronic integrated circuits; and (iii) lifting, handling, loading or unloading of boules, wafers, semiconductor devices, electronic integrated circuits and flat panel displays.

Other Trade Issues Affecting the Industry

The Commission identified only one trade-related investigation conducted with respect to SME imports during the period 2001–2005, an investigation conducted by the Commission under section 337 of the Tariff Act of 1930.[50] This investigation was instituted by the Commission in January 2002 on the basis of a complaint filed by Nikon Corp. of Japan, et al. Nikon Corp. alleged that ASML Holding of the Netherlands, et al. had violated section 337 in the importation and sale in the United States of certain microlithographic machines and components thereof by reason of infringement of certain claims of seven U.S. patents.[51] In March 2003, the Commission found no violation of section 337 and terminated the investigation.[52] Nikon Corp. appealed the Commission's determination to the U.S. Court of Appeals for the Federal Circuit. The parties subsequently settled, and the appeal has been dismissed. There were no orders in place under the U.S. countervailing duty and antidumping laws with respect to imports of SME at the time this summary was written.[53]

[50] 19 U.S.C. 1337.

[51] USITC, *Microlithographic Machines and Components Thereof*, investigation No. 337-TA-468.

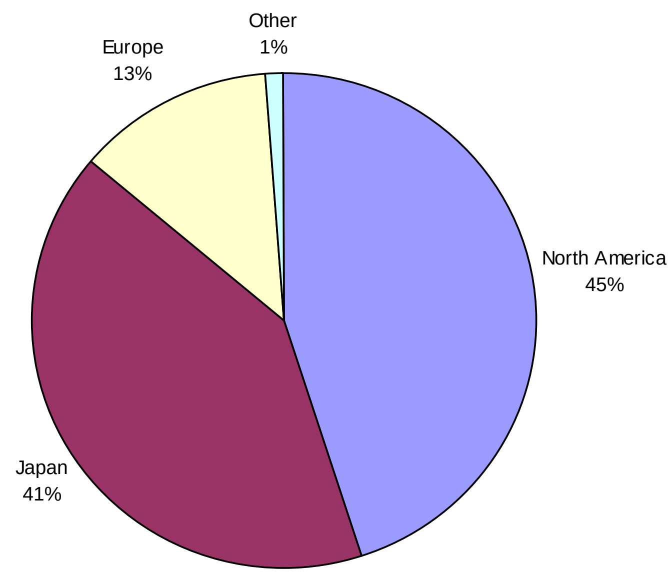
[52] Commission notice issued on March 18, 2003.

[53] Such orders are issued by the U.S. Department of Commerce. Commerce will issue such an order if it finds that imported merchandise is subsidized and/or sold in the United States at less than fair value (dumped), and the U.S. International Trade Commission determines that an industry in the United States is materially injured or threaten with material injury by reason of such imports of such merchandise. The U.S. countervailing duty and antidumping duty laws are found at 19 U.S.C. 1671, et seq.

FOREIGN INDUSTRY PROFILES

U.S. SME producers share global leadership with Japanese and European producers. In 2005, North American SME manufacturers (predominantly U.S. producers) had an estimated 45 percent share of global production, while Japan held an estimated 41 percent share.[54] European manufacturers accounted for an estimated 13 percent of production (figure 6).

Figure 6: Total semiconductor manufacturing equipment production by country/region, 2005, percentage



Source: SEMI.

Note: Percentages based on 2005 semiconductor manufacturing equipment total market of $32.9 billion.

Japan

The Japanese SME industry shares global leadership with the United States. Japan accounted for 41 percent of world SME production in 2005, shared among 71 producers.[55] In the early 1980s, Japanese SME manufacturers seized manufacturing technology leadership with major capital commitments, increasing manufacturing yield and factory efficiency. Japanese producers of SME remain competitive in SME production.

Although the United States appeared to be turning around its long-term SME trade deficit with Japan during 2001–2004, the U.S. SME trade balance with Japan registered a deficit of $50 million in 2005. Overall, from 2001 through 2005, imports from Japan decreased by 18 percent, to about $2.0 billion. On the other hand, U.S. exports to Japan increased by

[54] USITC staff, email communication with SEMI, February 7, 2006.
[55] Ibid.

33 percent due, in part, to increased demand for semiconductors in Japan resulting from strong consumer electronics sales.[56]

SME production was originally developed in Japan to support that country's semiconductor production facilities. Approximately 21 percent of global semiconductor manufacturing is in Japan,[57] and semiconductor producers in Japan are generally much larger than their counterparts in the United States. Japanese SME companies are leading global producers of steppers, a type of photolithography equipment. Japan exports this expensive photolithography equipment while importing many other types of equipment for the country's large semiconductor industry**.**

According to SEMI, the Japanese government is supporting its industry through programs ranging from direct subsidies for specific 300-mm diameter equipment development activities to new tax benefits for high-technology sectors. All of these programs are part of a national effort to promote Japanese semiconductor manufacturing, which the Semiconductor Industry Research Institute of Japan (SIRIJ) coordinates. SIRIJ's members include the country's top 10 manufacturers of electronics. SIRIJ manages four main research projects, including research for the development and promotion of semiconductor technology (ATLAS), research on the social contribution of the semiconductor industry (BASIS), research on international cooperation within the semiconductor industry (C-Project), and research for the revitalization of the semiconductor industry (D-Project).[58]

Europe

Specializing in front-end equipment, the European SME industry is a mature industry. As previously noted, Europe accounts for more than 10 percent of global SME production, shared among 18 EU producers.[59] The largest EU producer countries are the Netherlands, Germany, France, and the United Kingdom. The largest EU producer, ASML Holding, is the global leader in the production of photolithography equipment.

In 2005, the United States had a $335 million trade surplus in SME with Europe, as $1.7 billion worth of SME was exported to Europe in exchange for $1.3 billion worth of imported equipment. Exports of SME to Europe fell about 15 percent during 2001-2005, while imports from Europe increased 12 percent.

Several European research initiatives exist that seek to assist the European SME industry. MEDEA+ (EUREKA 2365) is the latest European program for advanced cooperative R&D in microelectronics. Launched in January 2001, MEDEA+ aims to ensure Europe's global technological and industrial competitiveness in this sector.[60] The 8-year MEDEA+ program, which will be completed in 2008, channels both private and public funding into R&D projects. Other European government programs include the Semiconductor Equipment Assessment (SEA), a program based in the United Kingdom and funded by the European Union that enables equipment manufacturers to develop state-of-the-art applications together

[56] Industry representatives, interview with USITC staff, October 14, 2004.

[57] McClean, Matas, and Yancey, 2-53.

[58] Semiconductor Industry Research Institute of Japan (SIRIJ), found at *http://www.sirij.jp/index.html*, retrieved April 3, 2006.

[59] Figures are from SEMI. USITC staff, email communication with SEMI, February 7, 2006.

[60] Medea+, found at *http://www.medea.org/*, retrieved April 3, 2006.

with semiconductor companies.[61] NanoCMOS is a third government program developed to help the semiconductor and semiconductor manufacturing equipment producers of Europe. Beginning in March 2004, NanoCMOS focused on developing 45-nm, 32-nm, and other advanced CMOS manufacturing processes.[62]

FOREIGN MARKET PROFILES

Although the traditional SME-producing regions (the United States, Japan, and Europe) also are the traditional markets for SME, consumption of SME has been shifting to other Asian countries in recent years (figure 7). In 2004, semiconductor demand in the Asia-Pacific region, including Japan, was 63 percent of the global total.[63] Four of the world's five largest foundries are in Asia, primarily in Taiwan.[64] Many new chip fabrication plants are being built in Asia, particularly in Singapore, Korea, and China. There are a number of reasons for increasing chip production in Asia, including the growth of semiconductor foundries, foreign government incentives such as tax breaks and guaranteed constant access to water and electricity, and access to low-cost engineers and other skilled labor.[65] The primary reason, however, is proximity to market as many semiconductor consumers and electronic equipment manufacturers are in this region of the world. This discussion will focus on these emerging Asian markets.

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[61] Semiconductor Equipment Assessment, found at *http://www.sea.rl.ac.uk/*, retrieved April 3, 2006.

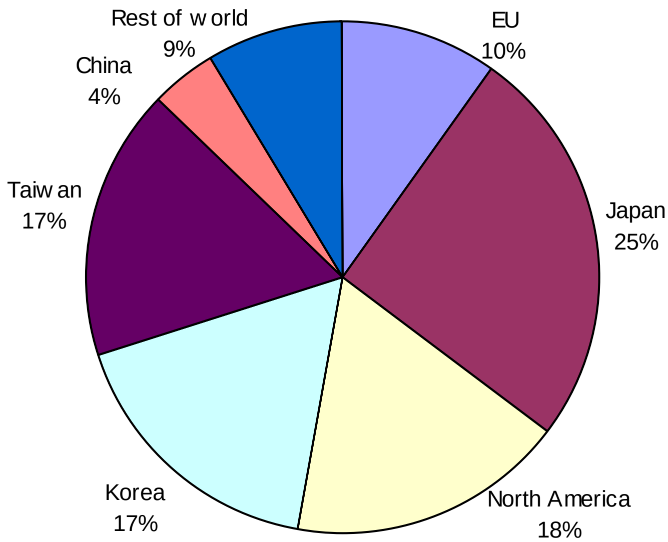
[62] Kelly Smith, "Semiconductor Production Equipment," STAT-USA Market Research Report, May 7, 2004.

[63] McArdle and Wang, 10–12.

[64] Ibid., 9–10.

[65] Testimony of Thomas R. Howell, Partner, Dewey Ballantine, LLP, before the Committee on Commerce, Subcommittee on Technology, Innovation and Competitiveness, United States Senate, Washington, DC, Hearing on Manufacturing Competitiveness, June 8, 2005, found at *http://commerce.senate.gov/hearings/testimony.cfm?id=1526&wit_id=4322*, retrieved March 31, 2006; and Dennis Normile, "The Strategic Art of International Site Selection, *Electronic Business*, November 1, 2005, found at *http://www.reed-electronics.com/eb-mag/article/CA6261844.html?industryid=43311*, retrieved April 6, 2006.

Figure 7: Total spending on semiconductor manufacturing equipment by country/region, 2005, percentage



Source: SEMI.

Note: Percentages based on 2005 semiconductor manufacturing equipment total market of $32.9 billion.

Korea

Korea's large semiconductor industry accounted for 12 percent of global SME sales in 2004 and 18 percent of global SME sales in the first 9 months of 2005.[66] As such, Korea is a large net importer and consumer of SME. Korea consumed $5.8 billion of SME in 2005.[67]

The United States maintained a trade surplus in SME with Korea from 2001 through 2005, amounting to $1.9 billion in 2005. Korea exported about $61 million of SME to the United States and received about $2.0 billion of U.S. SME exports in 2005.

Although Korea is the world's leading maker and exporter of dynamic random access memory (DRAM) chips and one of the world's leading manufacturers of mobile handsets, Korean chip makers are still working toward making state-of-the-art nonmemory semiconductors. Dongbu Electronics, a foundry that produces nonmemory chips, was established in 2001. This new company is helping Korea diversify away from DRAM production.

The Korean government has been known to provide support to its DRAM memory chip industry, stimulating the semiconductor industry and, thus, increasing the size of the SME market in that country. In August 2003, the Commission determined that the U.S. DRAM

[66] SEMI Capital Equipment Consensus Forecast And Nanoelectronics Markets and Opportunities Report, SEMI Member Webcast, December 14, 2005.
[67] USITC staff, email communication with SEMI, February 7, 2006.

industry was materially injured by imports of DRAMs and DRAM modules subsized by the Government of Korea.[68] Korea subsequently initiated a dispute settlement proceeding at the WTO against the U.S. countervailing duty measure. The WTO Dispute Settlement Body concluded that the Commission's determination was not WTO-inconsistent in almost all respects in July 2005.

Taiwan

Taiwan is one of the world's leading and fastest-growing semiconductor producers. In particular, Taiwan is currently the world's largest provider of chip foundry services with 70 percent of the market.[69] Taiwan accounted for 21 percent of global SME sales in 2004 and 17 percent of global SME sales in the first 9 months of 2005.[70] Taiwan consumed $5.7 billion of semiconductor manufacturing equipment in 2005.[71]

The United States maintains a large trade surplus in SME with Taiwan, which amounted to $2.2 billion in 2005, a 62 percent increase from the 2001 surplus. U.S. imports from Taiwan were only $39 million in 2005, rising from $25 million in 2001. U.S. exports to Taiwan have increased 62 percent from 2001 through 2005.

Taiwan rapidly rose from the periphery of electronics manufacturing to become a major computer and semiconductor manufacturer in the mid-1990s. Taiwan has been the center of foundry activity since 1987, when Taiwan Semiconductor Manufacturing Co., Limited (TSMC) was founded by a U.S.-based executive (Box 3). Taiwan is also the global leader in semiconductor packaging, accounting for 36 percent of the market.[72]

Taiwan government policies to encourage growth in the chip industry include R&D cost sharing, tax incentives, and the provision of land in the main Taiwan industrial parks for investors. Shared R&D with industry is carried out by research institutes. The largest of these is the Industrial Technology Research Institute (ITRI), which receives 55 percent of its funding from the Taiwan Ministry of Economic Affairs (MOEA). Taiwan research initiatives under ITRI take place in such industries as precision machinery and microelectrical technology to promote the integration and upgrade of precision machinery, Micro Electro-Mechanical System (MEMS), and microelectronics.[73]

[68] U.S. International Trade Commission, inv. No. 701-TA-431: DRAMs and DRAM Modules from Korea, USITC publication 3839, February 2006.
[69] Bruce Einhorn, et al. "Why Taiwan Matters," *Business Week*, May 16, 2005, Issue 3933, 76–81.
[70] SEMI Capital Equipment Consensus Forecast And Nanoelectronics Markets and Opportunities Report, SEMI Member Webcast, December 14, 2005.
[71] USITC staff, email communication with SEMI, February 7, 2006.
[72] Einhorn, 76–81.
[73] Industrial Technology Research Institute, found at *http://www.itri.com/*, retrieved April 3, 2006.

Box 3: The growth of the semiconductor foundry industry in Taiwan

The first semiconductor foundry in the world was United Microelectronics Corp. (UMC), established in Taiwan in 1980. UMC produced both its own semiconductors, as well as those under contract for other companies. The first foundry to produce chips only for contract manufacturing was Taiwan Semiconductor Manufacturing Co., Ltd. (TSMC), established in 1987. Other foundries have since been built in Singapore, Korea, Malaysia, Israel, and China, but Taiwan has remained at the center of the global foundry business. TSMC is the world's largest foundry, with 46 percent market share in 2004. Its share has declined in recent years with more foundries entering the market.

Foundry revenues grew 44 percent in 2004, compared with 28 percent for all semiconductor producers. Many foundries have state-of-the-art technology and are taking orders from both fabless companies (companies that design, but do not produce, chips) and integrated device manufacturers.

Source: Colin McArdle and Nelson Wang, "Semiconductor Equipment," *Standard & Poor's Industry Surveys*, November 17, 2005.

China

China has rapidly become a semiconductor manufacturer, accounting for 7 percent of global SME sales of semiconductors in 2004 and 4 percent of global SME sales in the first 9 months of 2005.[74] One study predicts that the Chinese semiconductor industry will account for 15 percent of wafer fab expenditures in 2010, up from about 7 percent in 2004.[75] China is home to more than 35 manufacturers with wafer fabrication facilities,[76] and 20 new fabs are expected to open in China by 2008.[77] There are about 200 semiconductor assembly and test companies in China; most of these are foreign-invested joint ventures and other operations with foreign involvement.[78] China consumed $1.3 billion of SME in 2005.[79]

The United States has a growing trade surplus in SME with China, expanding from $334 million in 2001 to $628 million in 2005. U.S. SME imports from China have expanded rapidly, but remain minimal compared with imports from some other countries. U.S. exports of SME to China have almost doubled from 2001 through 2005. U.S. exports of SME to China peaked in 2004, reaching $1.3 billion.

China's growth lifted the semiconductor industry, and therefore the SME industry, out of the latest downturn. The rapid growth of the semiconductor industry in China is driven by demand for electronics to serve China's large population and rapidly expanding economy.[80] Chinese demand accounted for 17 percent of global semiconductor demand in 2004 and is expected to reach 30 percent by 2009.[81]

[74] SEMI Capital Equipment Consensus Forecast And Nanoelectronics Markets and Opportunities Report, SEMI Member Webcast, December 14, 2005.

[75] McArdle and Wang, 9–10.

[76] SEMI, China Capital Equipment and Electronic Materials Outlook, 2005.

[77] McArdle and Wang, 11–12.

[78] SEMI, China Capital Equipment and Electronic Materials Outlook, 2005.

[79] Ibid.

[80] "Chip Equipment Awaits a Recovery," *Standard & Poor's,* February 13, 2002, found at *http://www.netadvantage.standardandpoors.com*, retrieved April 3, 2006.

[81] McClean, Matas, and Yancey, 2–57.

However, recent reports indicate that Chinese demand for SME is slowing. For example, U.S. exports to China decreased from 2004 to 2005. One source attributed this slowdown to possible concerns about the potential for intellectual property rights infringement in China,[82] while SEMI has noted that chip inventories have accumulated.[83]

U.S. producers have indicated that the Chinese government is planning to spend $100 million per year for semiconductor R&D.[84] Many regional governments within China are also offering semiconductor producers location incentives and R&D assistance.[85]

In December 2003, Chinese foundry Semicondutor Manufacturing International Corporation (SMIC) applied for a $1.2 billion loan guarantee to finance equipment purchases from U.S. SME companies.[86] This equipment would be used to expand SMIC's operations, increasing the size of the Chinese market for SME.

[82] "Semiconductor Quarterly Report," U.S. Taiwan Business Council. Third Quarter, 2005.
[83] McArdle and Wang, 11–12.
[84] USITC staff, email communication with SEMI, February 7, 2006.
[85] Ibid.
[86] Export-Import Bank of the United States, "Semiconductors/China," December 23, 2003, found at *http://www.exim.gov/products/policies/23dec04.html*, retrieved April 3, 2006.

APPENDIX A
Detailed Description of the Semiconductor Manufacturing Process

The first step in the creation of a chip is the formation of a wafer. The stages involved in this formation process are indicated in figure A-1.

Figure A-1: Formation of a silicon wafer

Silicon Made from Sand
↓
Silicon Cut into Ingots
↓
Ingot Ground and Polished
↓
Ingot Sliced into Wafers
↓
Edges of Wafers Rounded
↓
One Side of Wafer Polished
↓
Wafer Cleaned

Source: Compiled by USITC staff.

Next, a mask or reticle is formed,[1] and put aside to be used further along in the manufacturing process. Mask fabrication equipment is usually in the form of an E-Beam mask-making machine, which uses an electron beam light on the photoresist. A photoresist is a chemical that is sensitive to light.

Figure A-2: Front-end wafer fabrication process

1. Place a layer of silicon glass (referred to as a dielectric since it will not conduct electricity) on the wafer.
2. Photolithography, whereby a light is projected onto a wafer to create multiple layers of circuit patterns on a chip.
3. Etching, whereby materials not hardened during photolithography are removed in a series of steps using various manufacturing tools.
4. Photolithography and etching are repeated to achieve the multiple layers of circuitry that appear on a chip.
5. Doping, in which some areas of a wafer are exposed to chemicals that make the wafer more conductive in terms of electricity.
6. A conducting metal, such as aluminum, is deposited on the entire surface of a wafer. Certain areas of this metal are removed through photolithography and etching. This step connects the individual horizontal and vertical conductive pathways on the chip, allowing it to function properly.

[1] A mask is a glass plate covered with an array of patterns consisting of opaque and clear areas that prevent or allow light to go through. Masks are aligned with existing patterns on silicon wafers and used to expose photoresist. The terms reticle and mask are sometimes used interchangeably, but a reticle usually refers to a mask that is smaller than the wafer for use in repeated exposures.

Photolithography equipment is probably the most important type of machinery in the semiconductor manufacturing process. The degree of accuracy required in the correct exposure of patterns and alignment of the masks have led to a high degree of automation in this process. Oxidation is the first process step involving photolithography equipment. In oxidation, the silicon wafer is exposed to pure oxygen in order to grow a thin layer of silicon dioxide. This is done in an oxidation furnace, which can be horizontal or vertical. The color that the films turn is an indicator of the thickness of the film, with green signifying the thickest layer. The wafer is then coated with a photoresist using a spinner. Microlithographic equipment is also known as spinners, coaters, wafer tracks, photoresist processing, photo clusters, and photoresist clusters.

In the mask exposure and development or masking step, a pattern is written onto the photoresist with light, electrons, x-rays, or ions. The photoresist either hardens where the light hits it and remains soft in unexposed areas, or vice versa, depending on whether a positive or a negative photoresist is used. For multiple copies on a wafer, a stepper is used.[2] In the alignment and exposure step, a solvent, such as hydroxide, dissolves away the unexposed photoresist, revealing the silicon dioxide underneath. This part of the silicon dioxide is chemically etched to reduce its thickness. The hardened photoresist is then also dissolved, leaving an area of silicon dioxide. In the second masking, layers of polysilicon and photoresist are applied to the wafer and, again, a pattern is exposed onto the photoresist.

The unexposed, soft photoresist is then dissolved, and then the polysilicon and silicon dioxide are etched away, revealing the silicon base in the areas where the unexposed photoresist was. The hardened photoresist is removed, revealing an area of polysilicon. The critical dimension is measured, as well as the alignment. Adjustments are made, as necessary.

The oxide is etched using fluorine ions contained in Zyron gas. The wafer is etched in this process, too, but very slowly. This is known as a dry etch. Plasma etching using fluorescent light bulbs are also an option. The photoresist is stripped using pure oxygen plasma in the same machine used for etching.

During doping, the layers are treated with dopants, which are chemical elements such as arsenic and boron that change the conductivity of the wafer. Ion implantation is the technique used to treat the layers. This allows for cleaner, more controlled doping. In this method, the dopant atoms are applied through a blocking mask, given a charge and accelerated to a high speed. The ions bombard the wafer surface where it is exposed. The temperature of the wafer is then increased in order to diffuse the impurities deep into the silicon. Positive ions are more common than negative ones in this process. Implant annealing is performed with rapid thermal processing, as the surface of the wafer is heated to about 1200º C in 10 seconds.

In the contact mask process, all of the above steps are repeated. An additional layer of photoresist is applied, and the masking, developing, etching, and stripping processes are repeated. Alignment is necessary in this stage so that the contact made with the wafer is next to the already formed diode. Next, a thin aluminum film is deposited onto the wafer. This aluminum is sputtered using an argon plasma.
This process is then repeated a third time using a metal mask in the metallization step: apply photoresist, align, expose, develop, etch, strip. A sample probe, or fab area test, is completed at this stage using probe wires attached to contact pads. Chemical vapors are then used to

[2] A stepper is a photolithography machine used to expose a pattern on a wafer by shining light through a mask.

form a film on the wafer. This film is usually patterned using photolithography and the wafer is heated. All modern fabs use chemical vapor deposition for several thin films.

The diode is covered using silicon nitride at low temperature so as not to melt the aluminum. Plasma enhanced chemical vapor deposition is used in this step known as passivization.

Once the diode is safely covered, the pads must be uncovered for contact. A fourth mask is used, photoresist is applied, and the wafer is etched and stripped as before. Most integrated circuit devices use 10 to 20 masks, but up to 100 can be used. This concludes wafer fabrications or front-end processing.

Back-end processing begins with backlap, in which wafers are ground, or lapped, in order to thin them. The machine for backlap is the same one used when wafers were ground after being cut from the ingot.

Gold is sputtered on the back of the wafer, known as backside gold. The machinery used for applying backside gold is the same as for aluminum sputter.

The die sort tests each chip on the wafer (similar to the way the sample probe tested the chips) and puts ink spots on the bad ones. The die sort requires automatic probe stations and a high speed computer tester. Test and measuring equipment is used throughout the semiconductor manufacturing cycle. Metrology equipment ensures that design dimensions of the semiconductor devices are achieved and maintained during the various manufacturing steps. Test equipment includes a variety of testers with various capabilities, sophistication, and price ranges. These machines are identified by the type of semiconductor devices they are designed to test or perform, such as memory testers, microprocessor testers, and digital integrated circuit testers (logic testers). Sample probe equipment involves a probe station, computer, wires, and a PC board fixture.

In the cutting and assembly stages, the wafer is sawed up into die, or chips, with a diamond-coated blade, and each die is attached and bonded to a lead frame[3] through the use of a die bonder. A copper tape must be cut or stamped into a series of frames for packaging the chip. This copper should be coated with solder. The die is glued to the frame using epoxy containing silver powder. Gold wire is melted and pressed against the aluminum pad. This is repeated for the copper frame. The wire is cut and the frames are cut apart and mounted in a die. Hot plastic is injected and allowed to cool. Once cool, the edges are trimmed. The lead frame is cut off and the lead bent.

After the package is sealed, the chip should be tested one final time before being pronounced complete. Labeling, packaging, and shipping take place to complete the cycle.

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[3] A lead frame is a spider-like mass of wires to which the chip will be connected. The lead frame is then bent to form the metal pins that run out of the semiconductor package, allowing connection between the chip and the electrical socket.

Figure A-3: The stages of integrated circuit fabrication

Formation of Silicon Wafer
⇓
Formation of Mask
⇓
Oxidation
⇓
Photoresist
⇓
Mask Exposure and Developing
⇓
Etching
⇓
Doping (Ion Implementation)
⇓
Implant Annealing
⇓
Contact Mask
⇓
Metal Mask (Including Sample Probe)
⇓
Passivization
⇓
Sputtering
⇓
Die Sort
⇓
Wafer Cut into Die
⇓
Assembly: Die Attach and Bond
⇓
Package Sealing
⇓
Electrical and Mechanical Testing
⇓
Labeling, Packaging, and Shipping

Source: Compiled by USITC staff using U.S. International Trade Commission, *Global Competitiveness of U.S. Advanced-Technology Manufacturing Industries: Semiconductor Manufacturing and Testing Equipment*, USITC publication 2434, September 1991, E-2; and other publications.

APPENDIX B
TECHNICAL GLOSSARY

Anneal - Fix

Back-end manufacturing - Portion of semiconductor manufacturing that happens after the wafer has left the clean room; test, assembly, packaging.

Capacitance - Ratio of charge to potential on an electrically charged, isolated conductor.

Capacitor - Two connecting plates with an insulator between them.

Chemical Vapor Deposition (CVD) - A method for depositing some of the layers which function as dielectrics, conductors, or semiconductors, whereby a chemical containing atoms of the material to be deposited reacts with another chemical.

Chip - one of the individual integrated circuits or discrete devices cut from a silicon wafer.

Clean room - Ultraclean place where wafer processing is done so that dust and particles do not contaminate the wafer.

Cluster tool - Machine that contains more than one process module.

Critical dimension - Minimum width that is allowed as part of the circuit design on any given patterning layer.

Deposition - Process in which layers are formed as the result of a chemical reaction in which the desired layer material is formed and coats the wafer surface.

Dicing - Cutting up the wafer into individual chips, usually done with a circular dicing saw.

Die - Single semiconductor chip.

Dielectric - Insulator.

Diode - Device that allows a current to go only one way.

Dopant - Tiny amount of impurities added to change the electronic properties of silicon and affect how it conducts electricity.

Epitaxy - Deposition of a thin film of silicon on a wafer so that the deposited layer forms a single continuous crystal with the underlying wafer.

Etch - To apply a strong acid to spur a chemical reaction.

Fab- Wafer fabrication facility or a clean room; location in which semiconductors are made.

Front-end manufacturing - Wafer processing that takes place in the clean room; stage of manufacturing in which the semiconductor device is formed.

Furnace - Long glass tube that can be heated to high temperatures; may be horizontal or vertical.

Ingot - Metal cast into a bar or block.

Integrated circuit (IC) - Complete electronic circuit with transistors and wires connecting these transistors on a semiconductor chip.

Interconnect - Wires patterned in integrated circuits to connect different devices together.

Ion implantation - Process by which dopants are introduced into silicon in exact quantities by being directed at a silicon wafer at a controlled velocity.

Lead - Metal prongs that stick out of a chip package.

Lead frame - Spider-like wire frame that the chip is connected to; allows electrical connection from the chip package to an electrical socket.

Mask - A print; a dark image on a clear background through which light is shown to create patterns on a wafer.

Negative photoresist - Process that hardens an organic material when exposed to light.

Oxidation - Adding oxygen to a substance by adding high temperatures to an oxygen environment.

PC boards - Printed circuit boards; part of an electronic system.

Photolithography - Photographic processes used to transfer circuit patterns onto a semiconductor wafer by projecting light through a mask or reticle onto a photoresist-coated wafer.

Photoresist - Any organic (photosensitive) material; liquid that can be applied to a wafer as a thin film to be developed into an image.

Plasma - Highly excited gas that is exposed at low pressure to an electric or electromagnetic field.

Plasma enhanced chemical vapor deposition (PECVD) - A process by which plasma, created from reactant gases, is used to allow films to grow on a wafer at a lower temperature.

Plasma etching - Dry etching; using plasma to etch a semiconductor layer.

Positive photoresist - Process that dissolves organic material when exposed to light.

Reticle - A mask that is smaller than the wafer for use in repeated exposures; glass plate with chrome on one side in which a pattern is etched.

Spin coater - Spinner; machine for applying photoresist uniformly to a wafer by spinning the wafer during or after pouring on the photoresist; also used for developing and drying photoresist.

Sputtering - Involves knocking metal atoms off a disc of pure metal using ions so that metal atoms will redeposit onto the wafer to build up the desired metal film.

Stepper - Photolithography machine that works like a backwards microscope, exposing a pattern on a wafer by shining mercury light through a reticle or mask.

Wafer - Round disc of silicon upon which semiconductors are developed.

Wet etching - Etching away of layers on a wafer by chemical immersion.

APPENDIX C
Semiconductor Manufacturing Equipment: Harmonized Tariff Schedule Subheading, Description, U.S. Col. 1 Rate of Duty as of Jan. 1, 2006, U.S. Imports, 2005, and U.S. Exports, 2005

Semiconductor manufacturing equipment: Harmonized Tariff Schedule subheading, description, U.S. col. 1 rate of duty as of Jan. 1, 2006, U.S. imports, 2005, and U.S. exports, 2005

2006 HTS subheading	Description	Col. 1 rate of duty as of Jan. 1, 2006 General	U.S. imports, 2005	U.S. exports, 2005
		Percent	*– Thousand dollars —*	
8421.19.30	Spin dryers for semiconductor wafer processing	Free	2,754	108,169
8424.89.30	Spraying appliances for etching, stripping or cleaning semiconductor wafers	Free	18,181	102,582
8424.89.50	Spray appliance to develop semiconductor wafers; spray appliance to etch, develop, strip or clean flat panel screen; certain deflash machine	Free	5,104	92,836
8456.10.60	Machine tool operate laser/other light/ photon beam process in semicond wafer production; lasercutter to cut contacting track in semiconductor	Free	11,941	113,026
8456.91.00	Machine tools for dry etching patterns on semiconductor materials by electro-chemical, electron-beam, ionic-beam or plasma arc processes	Free	260,829	1,683,359
8456.99.10	Focused ion beam milling machines to produce or repair masks and reticles for patterns on semiconductor devices	Free	1,103	13,385
8456.99.70	Machine tool for stripping and cleaning semiconductor wafers,operated by electro-chemical/electron-beam/ ionic-beam/plasma arc process, n.e.s.o.i.	Free	15,380	38,595
8462.21.40	Bending, folding or straightening machines, numerically controlled, for semiconductor leads	Free	10,026	41,671
8462.29.40	Bending, folding or straightening machines, not numerically controlled, for semiconductor leads	Free	8,025	10,799
8464.20.10	Grinding or polishing machines for processing of semiconductor wafers	Free	71,914	192,977
8464.90.10	Machine tools for scribing or scoring semiconductor wafers; machine tools for wet-chemical etching semiconductor wafers	Free	122,120	8,919
8464.90.60	Machine tool for wet-etching or -stripping semiconductor wafers; machine tool for wet-etching, -developing or -stripping flat panel screens	Free	78,548	22,421
8465.99.40	Deflash machines (by chemical bath) for cleaning and removing contanimants from metal leads of semiconductor packages	Free	280	9,573
8466.10.40	Tool holders for use solely or principally with machines of headings 8456 to 8465 described in add. US note 3 to chapter 84	Free	7,688	18,741

Semiconductor manufacturing equipment: Harmonized Tariff Schedule subheading, description, U.S. col. 1 rate of duty as of Jan. 1, 2006, U.S. imports, 2005, and U.S. exports, 2005—*Continued*

2006 HTS subheading	Description	Col. 1 rate of duty as of Jan. 1, 2006 General	U.S. imports, 2005	U.S. exports, 2005
		Percent	*Thousand dollars*	
8466.20.40	Work holders for the machine tools described in additional U.S. note 3 to chapter 84	Free	30,358	4,490
8466.30.45	Special attachments mach, us note 3 ch 84, n.e.s.o.i.	Free	7,009	20,141
8466.93.47	Certain specified parts and accessories for machines of subheading 8456.10.60, 8456.91, 8456.99.10 or 8456.99.70, n.e.s.o.i.	Free	9,195	6,516
8466.93.85	Other parts and accessories for machines of subheading 8456.10.60, 8456.91, 8456.99.10 or 8456.99.70, n.e.s.o.i.	Free	108,918	32,580
8466.94.55	Other specified parts and accessories for machines of subheading 8462.21.40 or 8462.29.40, n.e.s.o.i.	Free	1,645	19,629
8466.94.75	Other parts and accessories for machines of subheading 8462.21.40 or 8462.29.40, n.e.s.o.i.	Free	4,964	19,629
8477.10.70	Injection-molding machines for encapsulation in the assembly of semiconductors	Free	3,964	12,213
8477.40.40	Transfer molding and compression molding machines for encapsulation in the assembly of semiconductors	Free	7,784	13,576
8477.59.40	Liquid encapsulate molding machines for encapsulation in the assembly of semiconductors	Free	238	69,218
8477.90.15	Base, bed, platen, clamp cylinder and other specified parts of machines of subheading 8477.10.70, 8477.40.40 or 8477.59.40	Free	7,015	0
8477.90.35	Barrel screws of machines of subheading 8477.10.70, 8477.40.40 or 8477.59.40	Free	356	21,250
8477.90.55	Hydraulic assemblies of machines of subheading 8477.10.70, 8477.40.40 or 8477.59.40	Free	409	10,625
8477.90.75	Parts of machines of subheading 8477.10.70, 8477.40.40 or 8477.59.40, n.e.s.o.i.	Free	5,650	10,625
8479.89.84	Machines for production & assembly of diodes, transistors and similar semiconductor devices & circuits; machines for mfg video laser discs	Free	624,340	2,706,296
8479.89.87	Machines for wet-cleaning flat panel displays, n.e.s.o.i.	Free	227	609,728

Semiconductor manufacturing equipment: Harmonized Tariff Schedule subheading, description, U.S. col. 1 rate of duty as of Jan. 1, 2006, U.S. imports, 2005, and U.S. exports, 2005—*Continued*

2006 HTS subheading	Description	Col. 1 rate of duty as of Jan. 1, 2006 General	U.S. imports, 2005	U.S. exports, 2005
		Percent	*Thousand dollars*	
8480.71.40	Injection or compression type molds for rubber or plastics for the manufacture of semiconductor devices	Free	6,136	10,095
8514.30.20	Electric furnaces and ovens for diffusion, oxidation or annealing of semiconductor wafers	Free	77,753	31,770
8514.30.60	Industrial or laboratory electric furnaces and ovens, n.e.s.o.i., for the rapid heating of semiconductor wafers	Free	32,861	78,521
8515.90.10	Parts of electric welding die attach apparatus, tape automated bonders and wire bonders of subheading 8515.80 for assembly of semiconductors	Free	15,281	119,096
8543.11.00	Ion implanters (particle accelerators) designed for doping semiconductor materials	Free	85,927	439,216
8543.89.10	Physical vapor deposition apparatus to process semiconductor material or produce diodes, transistors & similar semiconductor device & circuits	Free	27,909	734,016
8543.90.10	Parts of physical vapor deposition apparatus	Free	134,540	261,926
9010.41.00	Direct write-on-wafer apparatus for projection or drawing of circuit patterns on sensitized semiconductor materials	Free	16,321	964
9010.42.00	Step and repeat aligner apparatus for projection or drawing of circuit patterns on sensitized semiconductor materials	Free	943,552	29,311
9010.49.00	Apparatus for the projection or drawing of circuit patterns on sensitized semiconductor materials, n.e.s.o.i.	Free	28,587	16,494
9010.90.70	Part/accessory of apparatus: of subheading 9010.41-9010.49 or of subheading 9010.50.60 projection/drawing circuit patterns on flat panel display	Free	119,163	32,207
9030.82.00	Instruments and apparatus for measuring or checking electrical quantities, n.e.s.o.i.: for measuring or checking semiconductor wafers or devices	Free	393,865	1,452,452
9030.90.64	Printed circuit assemblies for instruments and apparatus for measuring or checking semiconductor wafers or devices	Free	94,233	54,919
9030.90.84	Parts and accessories for instruments and apparatus for measuring or checking semiconductor wafers or devices, n.e.s.o.i.	Free	123,660	73,301

Semiconductor manufacturing equipment: Harmonized Tariff Schedule subheading, description, U.S. col. 1 rate of duty as of Jan. 1, 2006, U.S. imports, 2005, and U.S. exports, 2005—*Continued*

2006 HTS subheading	Description	Col. 1 rate of duty as of Jan. 1, 2006 General	U.S. imports, 2005	U.S. exports, 2005
		Percent	*Thousand dollars*	
9031.41.00	Optical measuring/checking instruments/ appliances for inspecting semiconductor wafers/devices or photomasks/reticle used to mfg such devices	Free	143,009	1,225,911
9031.49.70	Optical instrument & appliance: to inspect masks (not photomask) used to mfg semiconductor devices; to measure contamination on such devices	Free	4,353	184,304
9031.80.40	Electron beam microscopes fitted with equipment specifically designed for the handling and transport of semiconductor devices or reticles	Free	95,243	93,862
9031.90.54	Parts & accessories of measuring & checking optical instruments & appliances of subheading 9031.41 or 9031.49.70	Free	55,790	44,469
9031.90.70	Parts and accessories of articles of subheading 9031.80.40	Free	33,241	74,115

Source: U.S. exports and imports compiled from official statistics of the U.S. Department of Commerce.

Note: The abbreviation “n.e.s.o.i.” stands for “not elsewhere specified or otherwise included.”