TAIWAN AND THE GLOBAL SEMICONDUCTOR SUPPLY CHAIN

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1. Executive Summary

The semiconductor is the backbone of today's technology-driven world. It is the brain of modern electronics, enabling technologies that make modern life more convenient, efficient, and connected. With exciting developments in artificial intelligence (AI), internet of things (IoT), 5G communications, cloud computing, electric vehicles (EV) and autonomous driving, the global semiconductor industry is expected to continue to grow and is on track to cross the trillion-dollar sales mark by the end of this decade.

The global semiconductor supply chain consists of seven sectors: 1) research and development; 2) design; 3) frontend manufacturing (wafer fabrication); and 4) backend manufacturing (assembly, packaging, and testing); 5) electronic design automation (EDA) and core intellectual property (IP); 6) equipment and tools; and 7) materials. The latter three sectors comprising materials, equipment and software design tools and core IP suppliers are considered a specialized support ecosystem of chip manufacturing.

Owing to the need for deep technical know-how and scale, the global supply chain of a semiconductor chip is complex and spans the globe. The USA leads in the most R&D-intensive activities for front-end chip design and semiconductor equipment; Taiwan hosts the world's most advanced process production foundries and is a leader in assembly, packaging and testing; while Advanced Semiconductor Materials Lithography (ASML), a Dutch-based company, is the only company that manufactures high-tech extreme ultraviolet (EUV) lithography machines.

Taiwan, home to world-leading firms such as Taiwan Semiconductor Manufacturing Company (TSMC), United Microelectronics Corporation (UMC), MediaTek Incorporated and Silicon Motion Technology Corporation, has become synonymous with advanced technology and semiconductor manufacturing capacity. With a complete semiconductor ecosystem, Taiwan is home to the world's largest foundry (63.8% of global market) and packaging and testing sectors (58.6% of global market), and second largest IC design sector (20.1% of global market). When it comes to making the most advanced chips, Taiwan leads the way. Taiwan manufactures approximately 70% of chips under seven nanometers and is at the cutting edge of two nanometer process R&D.

The Taiwan government continues to encourage and facilitate investment in the domestic semiconductor industry to sustain its remarkable progress. Cooperation among the academia, research and technology organizations, and industrial partners in the semiconductor value chain is strong and Taiwan is also fully committed to semiconductor talent development.

Semiconductors produced in Taiwan are essential components of the world economy. As semiconductor technologies expand into every aspect of industry and daily life, or as enablers for new services, the semiconductor industry is the foundation for not just Taiwan's but the world's future. A semiconductor supply chain disruption involving Taiwan will be devasting to not only Taiwan but the rest of the world as well. As a result, countries committed to economic growth and technological innovation have an enormous stake in the resilience of the global semiconductor supply chain as well as in the stability and peace across the Taiwan Strait.

The semiconductor industry is a cornerstone of global industrial development in the digital age. Taiwan's Ministry of Economic Affairs has outlined three areas of partnership in the semiconductor industry, namely, 1) joining Taiwan's core cluster, 2) exploring the growing market for semiconductor equipment and materials, and 3) establishing operations and research centers to tap into the fast-growing Asia market.

2. Background: Global Semiconductor Industry

A. Introduction

Chips, or semiconductors, are the cornerstone of today's digital and globalized world. As a complete circuit system used to process information, they are the brains of modern electronic devices—everything from smartphones to electric vehicles, satellites and national defense systems. It should therefore come as no surprise that the global semiconductor industry which totaled US$ 574.1 billion in sales in 2022,[1] has been projected to become a trillion-dollar industry by 2030.[2]

The making of a chip involves niche expertise of different production stages, multi-billion-dollar wafer foundries and multi-million-dollar equipment that is supplied across an interdependent network of companies around the world. The market for highly specialized equipment for chip production exceeded US$ 60 billion in sales for the first time in 2020, with Intel (USA), TSMC (Taiwan) and Samsung (South Korea) accounting for most of this spending.[3]

Besides being a complex and expensive undertaking, semiconductor foundries are also described as a winner-take-all industry. This is because a semiconductor foundry company can lose its edge if its manufacturing prowess is just a fraction behind that of its competitors. In the semiconductor value chain, the top one or two players routinely earn all the economic profits in that niche due to scale, learning efficiencies, and high switching costs for customers. For instance, TSMC, the first dedicated competitor in the foundry segment, has not relinquished its lead in its history of over 30 years.[4]

There are three broad categories of chips, namely, Logic, Memory, and Discrete, Analog and Other (DAO), which respectively contribute 42%, 26% and 32% to the industry revenue of US$ 412 billion in 2019 (see Figure 1). The arrangement of integrated circuits, or ICs, give chips their specific purpose. To stay ahead, chip makers are constantly striving to enhance semiconductor performance, by packing more transistors into chip bodies. This in turn makes end-devices more energy efficient.

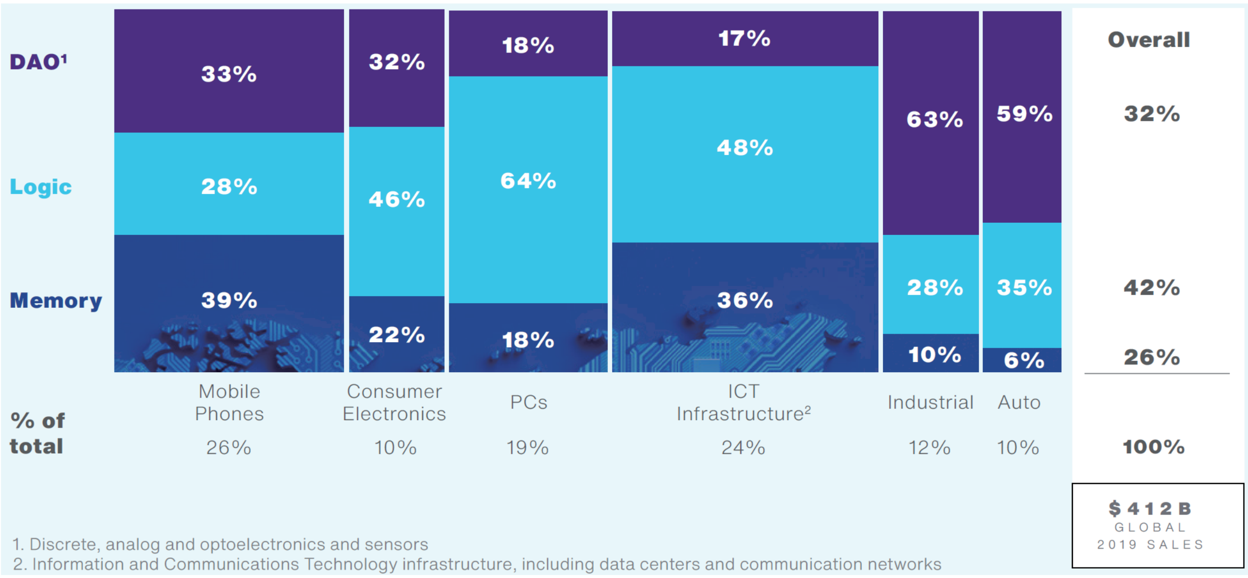
1 Semiconductor Industry Association, "Global Semiconductor Sales Increase 3.3% in 2022 Despite Second-Half Slowdown", February 3, 2023

2 McKinsey & Company, "The semiconductor decade: A trillion-dollar industry", April 1, 2022

3 Bloomberg, "The chip shortage keeps getting worse, why can't we make more", May 5, 2021.

4 Brookings, "Lagging but motivated: The state of China's semiconductor industry", January 7, 2021.

Figure 1: Global Semiconductor Sales by Application Market, 2019



Source: BCG, April 2021

There are also different nodes of chips. The most advanced ones—with transistor line widths (or "nodes") below 7 nanometers (nm)— are the most sought after and most difficult to produce. Global manufacturing capacity of these chips is dominated by Taiwan and South Korea.[5] As of 2023, the smallest node in mass production is 3 nm, which is offered by both TSMC and Samsung.

The widespread shortage of semiconductors in late 2020 highlighted how indispensable all types of chips are in today's economy. With nearly US$ 1.5 trillion in annual trade flows, semiconductors are the world's 4th most traded product, after only crude oil, refined oil, and cars.[6] In fact, Taiwan's export of integrated circuits was a record high of US$ 184.1 billion in 2022, accounting for 38.4% of the total export value.[7] Similarly, the electronics sector, of which the semiconductor sector forms a major component, contributes 8% to Singapore's GDP, and has consistently been the largest contributor to growth for Singapore's manufacturing sector.[8]

5 Boston Consulting Group, "Strengthening the Global Semiconductor Supply Chain in an Uncertain Era", April 1, 2021.

6 Semiconductor Industry Association, "Meeting of Semiconductor Associations from Around the World Underscores Importance of Global Chip Sector Collaboration", March 2, 2023.

7 Ministry of Finance, R.O.C (Taiwan), "2022 trade statistics on export of ICs".

8 Ministry of Education, Singapore, "Singapore-Industry Scholarship (SgIS) Sponsoring Organisations-

The semiconductor industry is expected to continue to grow given the megatrends of automation, internet of things, 5G, artificial intelligence and electric vehicles. Looking ahead, about 70% of the semiconductor industry growth is predicted to be driven by just three industries: automotive, computation and data storage, and wireless.[9]

As the world continues to digitalize and technology evolves, semiconductors play a critical role. This is why, aside from public and private companies, governments around the globe are also involved in the global supply chain of chips by way of subsidies, regulations, investment incentives, friend-shoring, and supporting research, development and innovation infrastructures.

B. Global Interest and Policies

The semiconductor supply chain is dominated by a handful of countries. Given the high specialization of companies, however, no country is independent or autonomous over the entire chain, and different countries retain a leading position in specific segments of the chain.

With the COVID-19 crisis disrupting global supply chains and indispensable components to various important industries, many governments around the globe have become increasingly interested in achieving end-to-end design and manufacturing capabilities for leading-edge technology and are attempting to support their local semiconductor production.

Taiwan

Overview

In 2022, Taiwan's wafer fabrication output value was US$ 90.7 billion—63.8% of the global output value (US$ 142.1 bn). Furthermore, Taiwan's IC design output value was US$ 41.4 billion (20.1% global market share) and Taiwan's output value of packaging and testing was US$ 23.0 billion (58.6% global market share). TSMC is both the biggest chip maker in Taiwan and the world. Taiwanese companies exist across almost all key aspects of the semiconductor design, fabrication, and assembly, testing, and packaging (ATP) processes.

Electronics Industry", April 14, 2023.

9 McKinsey, "The semiconductor decade: A trillion-dollar industry", April 2022.

Between 2011-2022, Taiwan consistently ranked number one globally in both foundry, and packaging and testing, and number two in IC design (behind the USA) (see Table 1). In 2022, for example, the global wafer foundry output value stood at US$ 162.4 billion, and Taiwan's IC manufacturing output value was US$ 98.1 billion (including foundry, memory and IDM chip production).

Table 1: Global Ranking of Taiwan's Semiconductor Industry

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
IC Design	2	2	2	2	2	2	2	2	2	2	2	2
Wafer foundry	1	1	1	1	1	1	1	1	1	1	1	1
IC Packaging and Testing	1	1	1	1	1	1	1	1	1	1	1	1

Source: IDB, MoEA, July 2023

Strengths

Advanced Chips (< 7 nm)

Taiwan holds a significant lead in producing advanced chips below 7 nm. In 2022, Taiwan accounted for approximately 70% of global production capacity of such chips. In terms of its generated revenue, Taiwan contributed US$ 40.2 billion out of the global total of US$ 57.4 billion. This is because TSMC leads in its global capacity to mass-produce such chips.

Policies

For over 40 years, Taiwan has been providing Taiwan-based semiconductor manufacturers with a high-quality investment environment, including the provision of water, electricity and land, and generous tax incentives. Government policies not only helped to reform the capital markets in the direction of equities but also contributed substantial R&D support through the Industrial Technology Research Institute (ITRI). The government also helped to set up industrial parks in an effort to build sound infrastructure and industrial clusters where they did not previously exist.

Faced now with the challenge of various nations vying to develop semiconductor industries of their own, the Taiwan government is taking steps to strengthen the resilience of the nation's industrial supply chains and capitalize on Taiwan's existing competitive advantages, so as to consolidate and elevate the status of Taiwan's key national industries within the global supply chain.[10] It has been supporting semiconductor firms' continued development within the country and providing policy incentives to attract major international firms in semiconductor fabrication, equipment and materials to invest in the nation. In January 2023, tax breaks for local companies' R&D investment were raised from 15% to 25%, and an additional 5% tax credit was offered for NT$ 10 billion (US$ 0.3 billion) spent on new equipment for advanced process technology.[11] The minimum corporate income tax rate would remain at 12% this year for qualified businesses and rise to 15% in 2025.

Taiwan's role in the manufacturing side of the international semiconductor market has made it an important node along the global semiconductor supply chain. In an increasingly uncertain international environment, Taiwan is working closely with like-minded partners on issues of strategic resiliency in the global supply chain.

USA

Overview

In 2022, the USA's wafer fabrication output value was US$ 8.3 billion—6% of the global market share. The USA contributes US$ 5.7 billion in revenue of advanced chips below 7 nm—10% of the global market share. The country's largest chip maker, Intel Corporation, began mass-producing 7 nm chips in 2022 and is expected to launch 4 nm chips in the second half of 2023.[12]

Strengths

Research and Development

The USA leads in the most R&D-intensive components of the value chain: electronic design automation (EDA), core intellectual property (IP), chip design and advanced manufacturing equipment.

[10] Department of Information Services, Executive Yuan, R.O.C. (Taiwan), October 27, 2022.

[11] Taipei Times, "Taiwan 'Chips act' sets R&D spending at NT$6 billion", May 2, 2023.

[12] Industrial Development Bureau, Ministry of Economic Affairs, R.O.C. (Taiwan), March 2023.

Policies

The Creating Helpful Incentives to Produce Semiconductors (CHIPS) and Science Act

The CHIPS and Science Act of 2022 provides US$ 52.7 billion for American semiconductor research, development, manufacturing, and workforce development. This includes US$ 39 billion in manufacturing incentives, including US$ 2 billion for the legacy chips used in automobiles and defense systems, US$ 13.2 billion in R&D and workforce development, and US$ 500 million to provide for international information communications technology security and semiconductor supply chain activities. It also provides a 25% investment tax credit for capital expenses for manufacturing of semiconductors and related equipment.[13]

Companies that receive subsidies under the Chips Act must abide by a caveat: not to increase production of chips more advanced than 28 nm in "countries of concern," which includes China and Russia, for the next 10 years.[14] Companies affected the most by this rule include Intel and TSMC.

Chip 4 Alliance

The Chip 4 alliance of the United States, Taiwan, Japan and South Korea, also known as the Fab 4, was first proposed by US President Joe Biden in March 2022. With the USA as a chip design powerhouse and the other three countries having top capabilities in manufacturing and production of critical equipment and materials, the envisioned alliance would cover all major areas of the chips value chain. The alliance is part of the USA's friend-shoring strategy of moving supply chains away from perceived rivals and towards trusted partners, and is aimed at enhancing the security and resilience of semiconductor supply chains, including by reducing the world's reliance on chips made in China.[15]

The first meeting of the group was held in September 2022 after a two-year global chip crunch which had prompted car manufacturers to halt production and exposed the larger supply chain issues. A second meeting conducted via videoconference on February 16, 2023, discussed

[13] The White House, FACT SHEET: "CHIPS and Science Act Will Lower Costs, Create Jobs, Strengthen Supply Chains, and Counter China", September 9, 2022

[14] Bloomberg, "US to Stop TSMC, Intel From Adding Advanced Chip Fabs in China", August 1, 2022.

[15] Economist Intelligence, "The Chip 4 alliance will struggle to find cohesion in 2023", December 8, 2022.

the creation of an "early warning and mutual reminder" system to ensure a stable supply chain for chip manufacturers.[16]

South Korea

Overview

South Korea contributes US$ 11.5 billion in revenue of advanced chips below 7 nm — 20% of the global market share. In 2022, South Korea's wafer fabrication output value was US$ 24.7 billion — 17% of the global market share.[17] In addition, South Korea dominates the memory chip market, with domestic firms Samsung Electronics Co. and SK Hynix Incorporated holding close to 70% of the global market share.[18]

Strengths

Advanced Chips (< 7 nm)

Samsung Electronics Co. was the first to start mass producing 3 nm chips in June 2022. This reduced device power consumption by 45% and boosted performance by 23% compared to its previous generation of 5 nm chips.[19] The company is working to start producing 2 nm chips by 2025.

Policies

South Korea's "K-Chips Act", passed on March 30, 2023, would increase the tax credit to 15% from the current 8% for major companies investing in manufacturing facilities, while smaller and medium size firms would see the tax break go to 25%, up from the 16% now. The

[16] Central News Agency, "US-led 'Fab 4' chip alliance meets to coordinate supply chain resilience", February 27, 2023.

[17] Industrial Development Bureau, Ministry of Economic Affairs, R.O.C. (Taiwan), March 2023.

[18] CNBC, "South Korea wants to be a top A.I hub- its memory chip dominance could be an advantage", July 5, 2023

[19] Bloomberg, "Samsung Is First to Start Mass Production of 3-Nanometer Chips", June 29, 2022.

measure is expected to boost domestic investment for the local chip industry, especially for Samsung and SK Hynix Inc, which are dominant producers of memory chips globally.[20]

Japan

Overview

Japan designated semiconductors as a product critical to daily lives and economic activities under an economic security law enacted in 2022. It will dedicate 368.6 billion yen (US$ 2.8 billion) from a 1.3 trillion yen (US$ 9 billion) supplementary fiscal 2022 budget to fund the new subsidies designed by the Ministry of Economy, Trade and Industry.[21]

Strengths

Japan's share of the global electronic device market has fallen but it has niches in optical sensors and the materials for the formation of integrated circuits and high-density packaging of semiconductors.[22] JSR Corporation is one of the world's top producers of photoresists, which are used in the process of making circuits on silicon wafers. JSR and four other Japanese manufacturers account for roughly 90% of the global market for photoresists.[23]

Policies

Japan's new strategy for semiconductor and digital industries announced in June 2021 comprises three steps: the establishment of manufacturing bases, the forming of alliances between Japan and the United States on next-generation technology, and the development of game-changing future technologies.

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[20] Troy Stangarone, "The Role of South Korea in the U.S. Semiconductor Supply Chain Strategy", part of the roundtable "The Role of Allies in the U.S. Strategy for Semiconductor Supply Chains," National Bureau of Asian Research (USA), April 13, 2023.

[21] Nikkei Asia, "Japan to subsidize domestic chipmaking beyond the cutting edge", February 7, 2023.

[22] JSR Corporation, Corporate Brochure 2023.

[23] NHK World-Japan, "Japanese state-backed fund to buy chip materials maker JSR", June 27, 2023.

Japan has encouraged TSMC to set up a presence in Kumamoto, and TSMC has established a joint venture with Sony-Denso in the form of Japan Advanced Semiconductor Manufacturing, with a new factory operating in 2024. Additionally, to make the mass production of next-generation semiconductors a reality, Japan is taking a two-pronged approach comprising the establishment of the Leading-Edge Semiconductor Technology Center (LSTC), an open platform research and development facility, and Rapidus, a new chip maker.[24] IBM will serve as the technology provider for Rapidus, enabling the production of 2 nm chips within Japan by 2027.[25]

These policies are significantly different from those adopted by previous government-led projects, in that rather than directly supporting industry, the government is both getting some of Japan's biggest tech names, including Sony, Toyota, and SoftBank, to work together, and also partnering with overseas manufacturers.[26]

Mirroring recent restrictions imposed by the United States and the Netherlands, two other major producers of cutting-edge semiconductors, Japan listed 23 types of semiconductor technology that are now subject to export restrictions, beginning July 23, 2023. They include advanced microchip manufacturing equipment, such as machines that deposit films on silicon wafers, to devices that etch out the microscopic circuits of chips. For China, it would be a de facto ban, similar to US export curbs announced in October 2022, dealing a heavy blow to Beijing's push for greater self-sufficiency in chips.[27]

China

Overview

As of 2023, China's biggest chip maker Semiconductor Manufacturing International Corporation (SMIC) offers 0.35 um – 14 nm chips.[28] In contrast, Hua Hong Semiconductor, China's second-largest chip foundry, specializes in mature technology, and generates most of its revenue making chips using 65/55 nm to 40 nm process technology.[29] China also has

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24 Nippon.com, "Last Chance to Make Japan a Semiconductor Superpower Again?", December 28, 2022.

25 AsiaTimes, "Japan's Rapidus positioning to win 2nm chip race", December 16, 2022

26 Foreign Policy, "Japan Bets Big on Bringing Semiconductor Manufacturing Home", January 2023.

27 VOA News, "Japan Imposes Microchip Export Ban, Angering China", July 27, 2023

28 Industrial Development Bureau, Ministry of Economic Affairs, R.O.C. (Taiwan), March 2023.

29 Yicai Global, "Chinese Chipmaker Hua Hong to Set Up USD6.7 Billion Wafer JV", January 19, 2023

an increasing number of indigenous IC design houses and equipment companies due to the increasingly restrictive import policy of American chips and the Made-in-China movement.[30]

Strengths

China is currently one of the leaders in assembly, packaging and testing, which compared to wafer fabrication, is relatively less skill- and capital-intensive back-end manufacturing activities.[31]

Policies

Chinese President Xi Jinping announced in 2015 a "Made in China 2025" plan, the aim of which is Chinese global dominance in 20 key sectors including information technology, green energy technology, and semiconductors.[32] In November 2020, China released its 14th five-year plan, advocating the autonomy in semiconductor production as a way to achieve technological self-reliance. To grow its chip industry, China has already committed to investing around US$ 150 billion between 2014 and 2030.[33]

According to the South China Morning Post, the Chinese government distributed more than 12.1 billion yuan (US$ 1.75 billion) in subsidies to 190 domestically listed semiconductor companies in 2022.[34] China's largest chip maker, SMIC, was its biggest subsidy recipient at US$ 274 million, illustrating national priorities amid a protracted tech war. Other top recipients include Apple supplier Wingtech Technology (US$ 54 million) and equipment maker Naura Technology (US$ 45 million), although some companies received as little as US$ 30,000 (see Table 2). However, despite the Chinese government's push to expand the local semiconductor

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30 Center for Strategic and International Studies, "Choking off China's Access to the Future of AI", October 11, 2022

31 Boston Consulting Group, "Strengthening the Global Semiconductor Supply Chain in an Uncertain Era", April 1, 2021.

32 German Marshall Fund, "China's Industrial Policy and Semiconductors", April 25, 2023.

33 Jan-Peter Kleinhans, Reva Goujon, Julia Hess, and Lauren Dudley, Rhodium Group, "Running on Ice: China's Chipmakers in a Post-October 7 World", April 4, 2023.

34 South China Morning Post, "China gave 190 chip firms US$1.75 billion in subsidies in 2022 as it seeks semiconductor self-sufficiency", May 7, 2023.

sector, about 10,000 Chinese chip companies went out of business during 2021-2022 due to intense competition between each other and global players.[35]

Table 2: China's Top 10 Chip Subsidy Recipients in 2022

Company	2022 subsidies (US$, million) *	2021 subsidies (US$, million) *
Semiconductor Manufacturing International Corp (SMIC)	274	341
Sanan Optoelectronics	144	129
Tianshui Huatian Technology	65	71
Wingtech Technology	54	49
HC SemiTek	46	59
Naura Technology	45	43
Anhui Truchum	42	31
Cambrian Technologies	38	31
Chaozhou Three-circle	30	19
Loongson Technology	27	11
TOTAL	**766 (5.458 billion yuan)**	**787 (5.606 billion yuan)**

Source: South China Morning Post, "China gave 190 chip firms US$ 1.75 billion in subsidies in 2022 as it seeks semiconductor self-sufficiency", May 7, 2023.

Note: * Numbers may not add up due to rounding.

The European Union (EU)

Overview

Europe is strong in some specific areas, including semiconductor research, chip manufacturing equipment, silicon wafers, and chips for automotive and for industrial equipment. Upstream in

[35] Digitimes Asia, "Natural selection in chip industry: 10,000 chip companies closed in China in the past two years", May 9, 2023

the production chain, the EU is a net exporter of machines for the production of semiconductors. However, the EU has only roughly 10% of global semiconductor market share and is heavily dependent on third-country suppliers. The EU aims to play a leading role in the design and manufacturing of the next generation of microchips, down to 2 nm nodes and below.[36]

Policies

European Chips Act

The EU is investing US$ 47 billion to boost its semiconductor industry, cut reliance on US and Asian semiconductors and start a green industrial revolution. It aims to double the bloc's share of global chip output to 20% by 2030. The plan was first announced in 2022 and has reportedly also attracted over US$ 110 billion in public and private investments.[37] The act is seen as a response to similar plans to encourage semiconductor manufacturing in the USA, Taiwan, South Korea, Japan, and China.[38]

Germany

Strengths

Germany's Merck Group and BASF SE provide firms around the world with critical chemicals required to make semiconductors. Merck's products and services are found in almost every chip worldwide, while BASF is a market leader in Europe and Asia, with customers including TSMC.[39] Germany is also expanding its deep know-how in automotive technologies into semiconductors via recently announced partnerships such as Bosch Group's acquisition of US-based TSI semiconductor foundry for US$ 1.5 billion.[40]

36 European Commission, European Chips Act Factsheet, February 8, 2022.

37 Reuters, "EU takes on United States, Asia with chip subsidy plan" , April 19, 2023.

38 European Commission, European Chips Act.

39 Bloomberg, "Germany in Talks to Limit Export of Chip Chemicals to China", April 27, 2023.

40 Reuters, "Bosch buys US semiconductor foundry to expand EV chip output", April 26, 2023.

Policies

Germany announced in September 2021 that it would be investing roughly EUR€ 3 billion (US$ 3.2 billion) to encourage domestic production. In May 2022, it also announced EUR€ 14 billion (US$ 14.9 billion) in financial support to entice foreign chipmakers to invest in Germany.[41]

The Netherlands

Strengths

Advanced Semiconductor Materials Lithography (ASML) is the only company making extreme ultraviolet lithography (also known as EUV) machines needed to print every advanced microchip. ASML is Europe's most valuable tech company, with a market capitalization of over US$ 247 billion—more than twice that of USA's Intel.[42] The company also beat its 2023 Q1 forecast earnings; it posted a threefold jump in net profit to US$ 2.15 billion on revenue up 91% at US$ 7.5 billion.[43] This also makes it a key choke point in the global supply chain. ASML is expecting to launch a new machine capable of etching even smaller wafer patterns by 2025.[44]

Policies

The Netherlands has joined the USA and Japan, the only two other countries that are home to manufacturers of advanced machines to print microchips, in restricting supplies of chipmaking equipment to China.[45] In March 2023, the Dutch government outlined three goals which include preventing Dutch goods from contributing to undesired military applications by foreign powers; preventing unwanted strategic dependencies; and maintaining Dutch technological leadership. Sales of ASML's EUV tools to China have already been restricted since 2019, and in March 2023, the Dutch government further tightened the restrictions on the sale of deep ultraviolet lithography machines.

[41] Reuters, "Germany wants to attract chip makers with 14 bln euros state aid", May 6, 2022.

[42] Bloomberg, "ASML, Europe's Most Valuable Tech Firm, Is at the Heart of the US-China Chip War", April 26, 2023.

[43] Reuters, "ASML beats estimates but sees some chipmaker caution", April 19, 2023.

[44] ASML Press Release: "Intel and ASML strengthen their collaboration to drive High-NA into manufacturing in 2025", January 19, 2022.

[45] Politico Europe, "The Netherlands to block export of advanced chips printers to China", March 8, 2023.

Singapore

Overview

Singapore's semiconductor sector is dominated by brand name foreign companies, including Applied Materials, Advanced Micro Devices, Infineon Technologies, MediaTek, United Microelectronics Corporation, Soitec and STMicroelectronics Pte Ltd. The semiconductor sector is currently Singapore's largest manufacturing segment, contributing 7% of its GDP in 2021. Singapore accounts for about 5% of the global wafer fabs output and 11% of the global semiconductor market. According to Alvin Tan, Singapore's Minister of State at the Ministry of Trade and Industry, 20% of global semiconductor equipment were manufactured in Singapore in 2021.[46] As part of its ambitions to expand the manufacturing sector by 50% by 2030, Singapore aims to further grow its electronics sector, with the semiconductor industry as its backbone.

Strengths

Singapore's stability, robust intellectual property protection regime, and skilled workforce, have allowed it to develop and grow the semiconductor sector over the decades.[47]

Policies

Singapore's favorable tax and regulatory environment, coupled with its investment incentives and competitive logistics costs, have made it an appealing destination for high-value-added manufacturing investments. Amid US-China tension, Singapore's Economic Development Board (EDB) is looking at attracting its "fair share" of investments in semiconductor assembly and integrated circuit design. EDB sees Singapore continuing to attract mature nodes, wafer fabs and those in semiconductor design.[48]

[46] Singapore's Ministry of Trade and Industry, Speech by MOS Alvin Tan at the SSIA Semiconductor Business Connect 2022, May 19, 2022.

[47] Singapore's Ministry of Trade and Industry, September 2022.

[48] Bloomberg, "Singapore Eyes Chips Investments Amid US-China Tension", February 12, 2023.

C. Global Supply Chain of Semiconductor Industry

According to an April 2021 report by the Boston Consulting Group (BCG) and the Semiconductor Industry Association (SIA), “the need for deep technical know-how and scale has resulted in a highly specialized global supply chain, in which regions perform different roles according to their comparative advantages.”

At a high level, the supply chain includes seven sectors:

1. Research and Development
2. Design
3. Front-end manufacturing: Wafer Fabrication
4. Back-end manufacturing: Assembly, Testing and Packaging (ATP)
5. * Electronic Design Automation (EDA) and Core Intellectual Property (IP)
6. * Equipment and Tools
7. * Materials

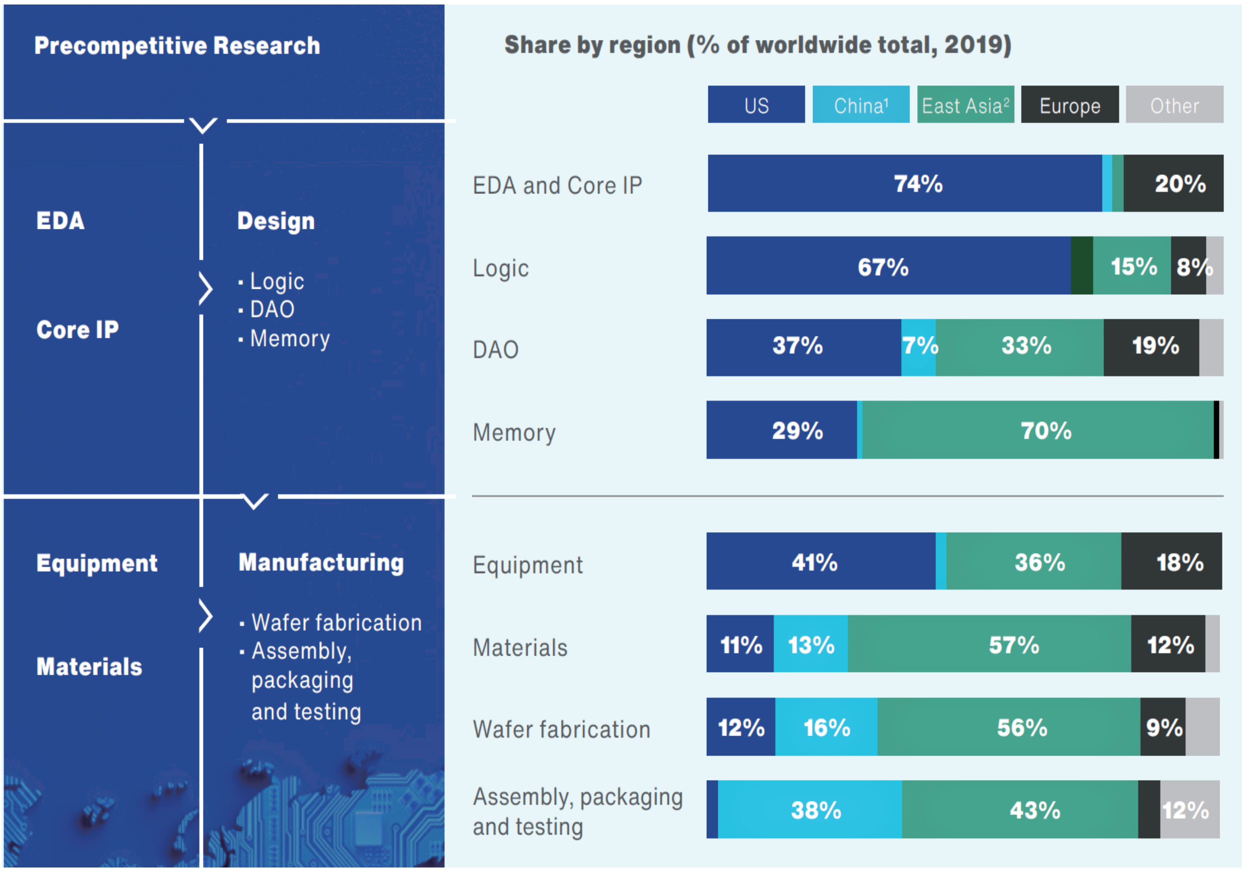
* These components are considered a specialized support ecosystem of chip manufacturing.

In 2019, the USA dominated electronic design automation and core IP (74%) as well as logic (67%), according to the report. In the category of “discrete, analog, and other (including sensors and optoelectronics),” the USA maintained a small edge at 37%, followed by East Asia (Taiwan, South Korea and Japan, excluding China)* at 33%. In terms of memory, East Asia* dominated at 70%, followed by the USA at 29%. On the manufacturing side, the USA led in equipment at 41%, followed by East Asia* at 36%. East Asia* led in the remaining three categories – materials (57%), wafer fabrication (56%), and assembly, packing and testing (43%), though in the latter category China held a 38% share (see Figure 2).

The hypercompetitive and increasingly complex nature of the semiconductor industry means that firms must invest in making continual innovations and improvements to eke out more growth than competitors. Government funding and resources also play a very significant role in advancing research and innovation. Research and development includes pre-competitive, exploratory research on foundational technologies and competitive research directly advancing the leading edge of semiconductor technology.

Besides being highly specialized, the semiconductor industrial supply chain is also extremely complex, involving the coordination of a number of different stages and sectors. Sectors in integrated circuit (IC) industry can be categorized according to position in production process, including IC design at the upstream, IC manufacturing at the mid-stream, and IC packaging and testing and applications for industries at the downstream (see Figure 3).

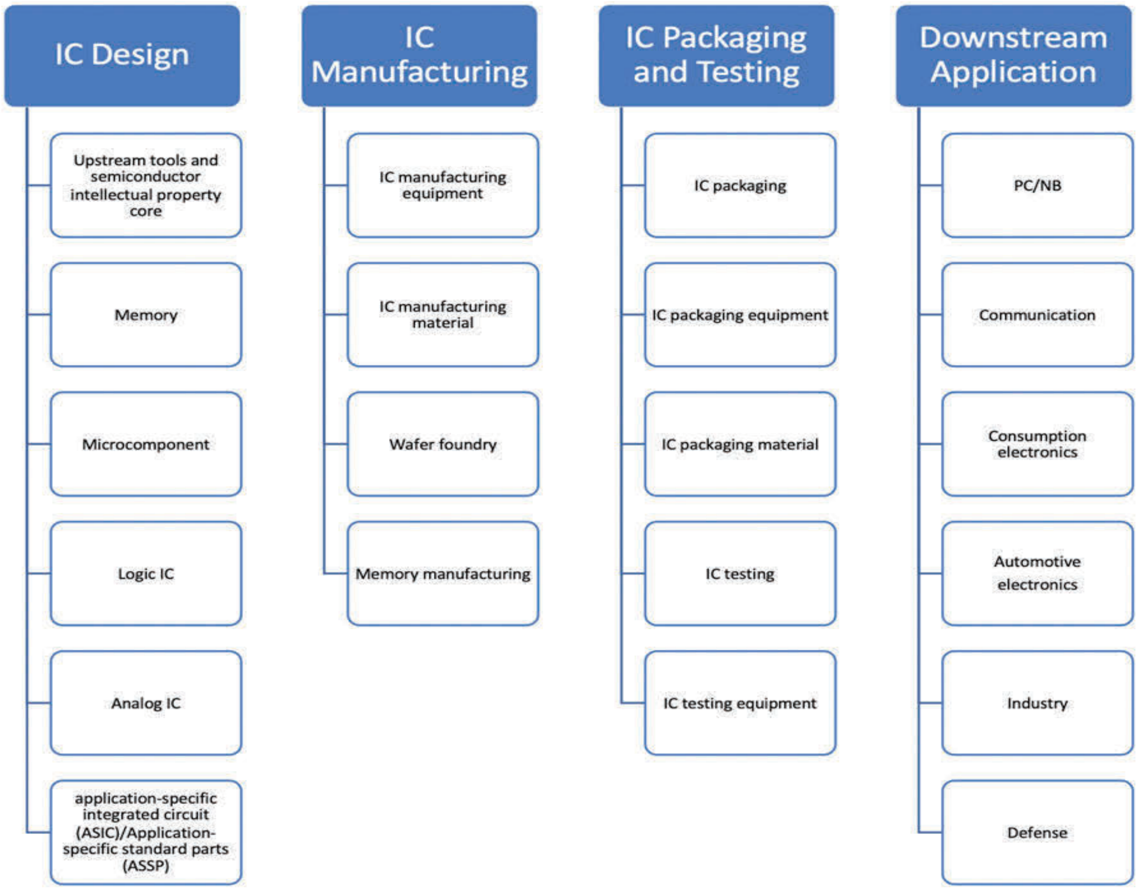
Figure 2: Semiconductor Supply Chain



Source: BCG, April 2021

*East Asia refers to Taiwan, South. Korea and Japan, but excludes China

Figure 3: Semiconductor Industrial Map



Source: IEK Consulting, ITRI

Upstream of the Semiconductor Industry: IC Design Process

IC design is the entire process from logic design to wafer design of chip functions while intellectual property (IP) refers to the intellectual property rights aim to protect the original layout designs for integrated circuits and computer chips. The IC design process is knowledge-intensive with high entrance barrier and return on investment.

Before manufacturing a chip, engineers must first plan the functions that the chip needs to have according to requirements, and which areas on the chip to distribute these functions. They use Hardware Description Language (HDL), which describes the chip's functions and puts it into program code. IC design tools such as the Electronic Design Automation (EDA) tool allows the computer to convert the program code into a circuit diagram.

An IP core is a reusable unit of logic or integrated circuit layout design, while integrated circuits, like microchips, are composed of semiconductor materials. Chips can be divided into three categories according to their functions:

- Memory IC: An IC used to store data. Divided into ICs that will either continue or not continue to hold stored data after the power supply is stopped.
- Logic IC: An IC that performs logic operations.
- Analog IC: An IC that processes analog signals, mainly used in power management, amplifier, and converter.

IC standard products may be mass-produced and sold to different customers or in the case of an application specific integrated circuit (ASIC), be tailored for special purposes or a single customer, with the characteristics of customization, differentiation, and small quantity, and is used in markets with fast industrial changes and high integration requirements. Those companies that only design integrated circuits are known as fabless semiconductor companies.

The United States, Taiwan, South Korea, Europe, Japan and China perform almost all of the world's semiconductor design.[49]

Midstream of the Semiconductor Industry: IC Manufacturing Process

The process of IC manufacturing is the meticulous undertaking of turning silicon into a semiconductor chip. A semiconductor foundry, commonly called a fab, refers to a factory where devices like integrated circuits are manufactured.

Semiconductor production takes three major steps: design, fabrication, and assembly, testing, and packaging (ATP). These steps either occur in a single firm—an integrated device manufacturer (IDM) that sells the chip—or in separate firms, where a fabless firm designs and sells the chip and purchases fabrication services from a foundry and ATP services from an outsourced semiconductor assembly and test (OSAT) firm. Examples of IDMs are Intel, Samsung, and Texas Instruments while examples of fabless companies are Advanced Micro Devices Incorporated (AMD), Nvidia Corporation, and Qualcomm. In 2022, the three largest foundries were Asian companies (TSMC and UMC of Taiwan and Samsung Electronics of South Korea).

[49] Center for Security and Emerging Technology, "The Semiconductor Supply Chain: Assessing National Competitiveness", January 2021.

Production requires several inputs: materials, semiconductor manufacturing equipment (SME), electronic design automation (EDA), and core intellectual property (IP). The highest value and most technologically complex parts of this process are the design and fabrication segments of production, and the SME element of the supply chain.

Before a semiconductor can be fabricated or manufactured, it needs to be designed. At this stage of the process, the designers work to determine what functions the semiconductor needs to serve, and how the semiconductor can fulfill those functions. The design can influence everything from the materials to the architecture. It is common for a business to design semiconductors with their needs in mind and then send those designs to a fab facility for manufacturing.

Although comparatively small elements, EDA and core IP are also critical and involve great expertise. Firms involved in design of nanometer-scale integrated circuits rely on highly advanced EDA software and IP cores.

Once the IC design is completed, it will enter the production stage, that is, IC manufacturing. In simple terms, IC manufacturing means that the wafer foundry or memory manufacturing facility must transfer the designed circuit diagram to the semiconductor wafer. IC manufacturing plants that manufacture chips need to use a variety IC manufacturing equipment and materials in the process of transferring circuits to wafers. Firms headquartered in Taiwan, South Korea, the United States, Japan, and China produce the vast majority of the world's chips.

Downstream of the Semiconductor Industry: IC Packaging and Testing

IC packaging and testing is labor-intensive and has comparatively the lowest barriers to entry. When the circuit on the design drawing is placed on the wafer to form the IC, it is necessary to test and package it, that is, to test whether these ICs can work, and then cut the IC on the wafer into a piece of die. Because these bare dies are very fragile, if the IC is usable after testing, it must be protected by wrapping it in a shell. This encapsulated die is now the final finished chip.

IC packaging and testing manufacturers use chip testing equipment and chip packaging equipment when conducting chip testing and chip packaging. Chip packaging can use various chip packaging materials, such as IC carrier plates, lead frames, solder balls, gold wire, and molding materials such as packaging glue and packaging shell.[50]

[50] Market Prospects, "What Is the Semiconductor Supply Chain?", July 26, 2021.

Firms headquartered in Taiwan, South Korea, the United States and China are the main providers of ATP services.

Downstream Application

The finished semiconductor devices have been used in a variety of products in everyday life such as personal computers/notebooks (PC/NB), communication devices, consumer electronics products, electric cars; in playing a key role for economic competitiveness, security and defense; and constituting the basic technology for the ongoing digital transformation (see Figure 2).

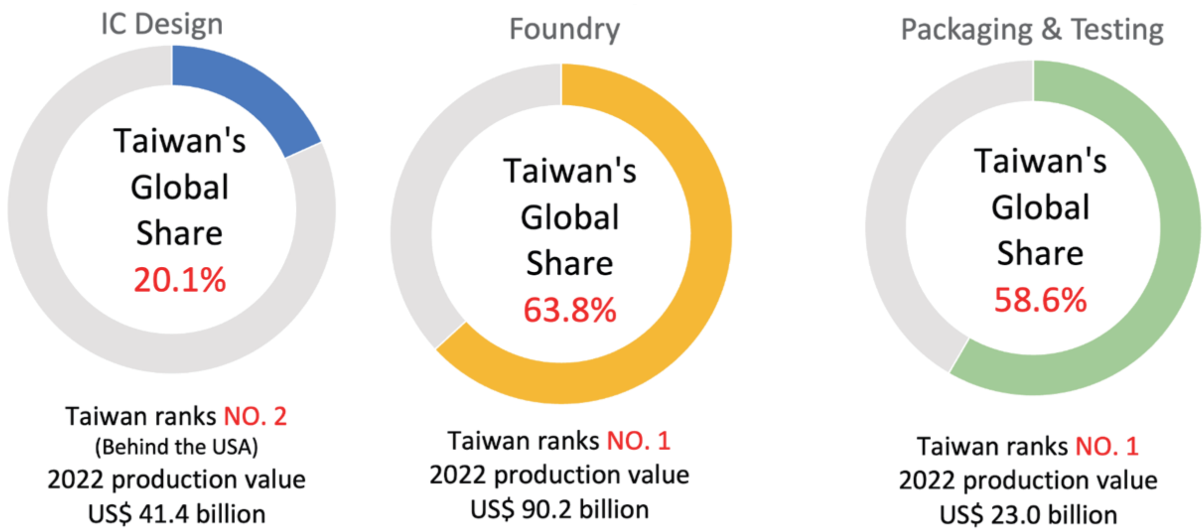
The complex set of steps from design, front-end fabrication to back-end testing and packaging are carried out by different firms and countries that have developed comparative advantages in specific parts of the global supply chain, such that no country has complete end-to-end control of chip manufacturing. The United States dominates R&D and has strong capabilities across all segments. However, it lacks firms in certain key subsectors, especially photolithography tools and foundries to manufacture the most advanced chips. South Korea specializes in all production steps, but also produces significant amounts of materials and some SME. Taiwan is successful in the most advanced manufacturing and IC packaging and testing, and produces some materials. By contrast, Japan specializes in SME and materials, and it produces many mature node semiconductors (generally defined as less advanced chips, above 28 nm), which require older manufacturing processes. Europe (especially the Netherlands, the United Kingdom, and Germany), meanwhile, specializes in SME (especially photolithography tools), materials, and core IP.[51]

[51] Center for Security and Emerging Technology, "The Semiconductor Supply Chain: Assessing National Competitiveness", January 2021.

3. Status of Semiconductor Industry in Taiwan

A. Global Rankings of Semiconductor Industry

Figure 4: Taiwan's Global Share in the Semiconductor Industry

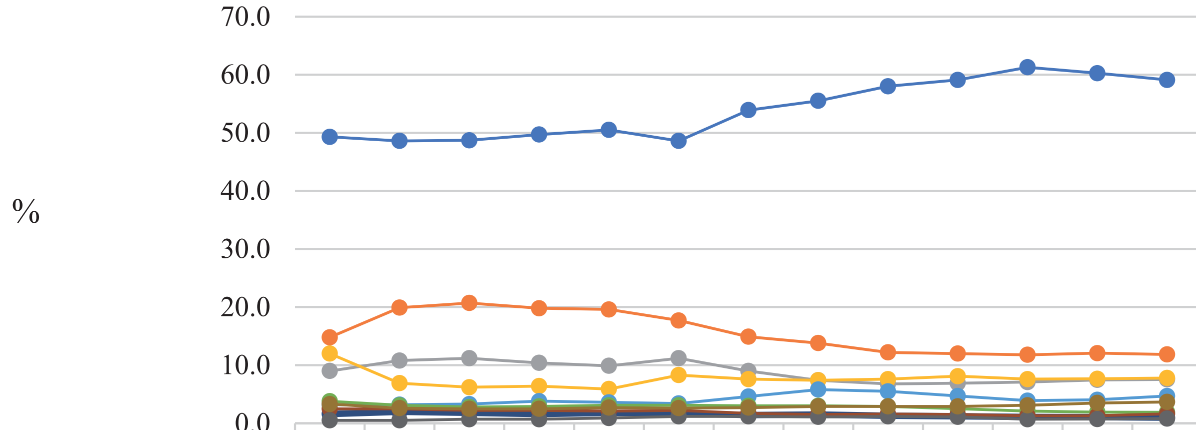


Source: IEK Consulting, ITRI. Industrial Development Bureau (IDB), Ministry of Economic Affairs (MoEA), R.O.C. (Taiwan), July 2023.

The semiconductor industry in Taiwan is a global leader, ranking first by market share in both wafer manufacturing and packaging and testing, and second by market share in IC design (see Figure 4). In 2022, Taiwan produced 63.8% of the world's semiconductors, and accounted for approximately 70% of the global production capacity of advanced chips below 7 nm. Taiwan captured 20.1% of the world's market share in IC design and 58.6% of the global packaging and testing market.

Taiwan's semiconductor industry has already built close business ties with international tech giants, such as Apple, Google and Nvidia, by providing high-end chips used in advanced devices, including high performance computing and artificial intelligence applications.

Figure 5: Share of IC Exports from Taiwan



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
China (Include HK)	49.3	48.6	48.7	49.7	50.5	48.6	53.9	55.5	58.0	59.1	61.3	60.3	59.1
Singapore	14.8	19.9	20.7	19.8	19.6	17.7	14.9	13.8	12.2	12.0	11.8	12.1	11.9
Korea	9.0	10.8	11.2	10.4	9.9	11.2	9.0	7.4	6.8	6.9	7.1	7.5	7.6
Japan	12.0	6.9	6.2	6.4	5.9	8.3	7.6	7.4	7.6	8.1	7.6	7.6	7.8
Malaysia	3.2	3.2	3.3	3.8	3.6	3.4	4.6	5.8	5.5	4.7	3.9	4.0	4.7
Phillipines	3.8	3.1	2.8	2.9	3.1	3.1	3.0	3.0	2.9	2.5	2.1	1.9	1.9
Thailand	1.6	2.0	1.8	1.6	1.8	1.7	1.4	1.5	1.3	1.2	1.1	1.1	1.0
USA	2.5	2.5	2.2	2.2	2.1	2.2	1.7	1.5	1.6	1.5	1.3	1.3	1.6
Germany	0.5	0.5	0.7	0.7	0.9	1.2	1.2	1.1	1.2	1.1	0.7	0.7	0.8
Others	3.3	2.6	2.5	2.5	2.7	2.6	2.7	2.9	2.9	2.9	3.1	3.5	3.7

Source: IEK Consulting, ITRI

Taiwan's semiconductor industry plays an important role in the global chip market. In terms of exports of integrated circuits, Taiwan's top five export destinations included China, Singapore, Japan, Korea and Malaysia. For the year 2022, Taiwan's IC exports to China accounted for 59.1% of its IC export value. This is followed respectively by Singapore (at 11.9% of all IC export value), Japan (at 7.8% of all IC export value), Korea (at 7.6% of all IC export value) and Malaysia (at 4.7% of all IC export value). Other important export markets include Philippines, Thailand, the USA and Germany (See Figure 5).

Additionally, Taiwan's complete industrial supply chain also attracts US semiconductor companies such as Micron and Applied Materials to invest on its shores.[52]

[52] Ministry of Economic Affairs, R.O.C. (Taiwan), "U.S.-Taiwan Cooperation on Global Semiconductor Supply Chain Resilience Industry Forum", April 30, 2022.

The semiconductor industry is a key pillar of Taiwan's economic growth. It is one of its most important industries in terms of output value and share of exports. In 2022, Taiwan's semiconductor output value reached over US$ 160 billion, which was second only to the USA.[53] Furthermore, Taiwan's semiconductor sector has brought tremendous spill-over contribution to its economy. The value-added rate of the semiconductor sector was 74.7%, the highest among Taiwan's manufacturing sector in 2021. In 2022, the output value of Taiwan's semiconductor industry was NT$ 4.89 trillion with employees of 330 thousand. With the spill-over effects of supply chains and induction, this sector created an extra output value of NT$ 4.04 trillion with employees of 703 thousand.[54]

With global supply chains now undergoing major restructuring and commercial 5G services launching around the world, Taiwan's government is leveraging the nation's robust manufacturing and production capabilities to promote industry adoption of smart technology and transform Taiwan into a high-end production hub for Asia. The government also hopes to make Taiwan an advanced manufacturing process center for semiconductors and aims to increase its production value to NT$ 5 trillion (US$ 164.1 billion) by 2030.[55]

As Taiwan builds a comprehensive ecosystem for its domestic semiconductor industry, it relies on the expansion of cooperation between Taiwan and global partners. The strengthening of such an ecosystem can also fully support the needs of the semiconductor industry in various countries around the world and form closer global cooperation.

B. Global Rankings of Sub-Industries in Taiwan

Taiwan is home to the most complete semiconductor industry clusters and specializations in the world, and it has world-class companies in all the various sub-fields of the semiconductor industry.[56] The total number of semiconductor firms operating in Taiwan has hovered around 300, numbering 317 firms in 2010 and 285 in 2021. Of the 285 firms in 2021, 235 (82%) are in IC design, 13 (5%) are in IC manufacturing and 37 (13%) are in IC packaging and testing (see Table 3).

[53] Industrial Development Bureau, Ministry of Economic Affairs, R.O.C. (Taiwan), March 2023.

[54] Stephen Su, ITRI, April 12, 2023.

[55] Executive Yuan, R.O.C. (Taiwan), "Making Taiwan a high-end production hub for Asia and an advanced semiconductor manufacturing center", August 30, 2022.

[56] IEK Consulting, Industrial Technology Research Institute, April 2023.

Table 3: Number of Semiconductor Companies

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
IC Design	266	250	260	250	245	245	240	240	238	238	238	235
IC Manufacturing	14	16	15	15	16	16	16	15	15	15	13	13
IC Packaging and Testing	37	37	37	37	37	37	37	37	37	37	37	37
TOTAL	**317**	**303**	**312**	**302**	**298**	**298**	**293**	**292**	**290**	**290**	**288**	**285**

Source: IEK Consulting, ITRI

Over the years, the semiconductor industry has grown in importance and there has been an increasing number of persons employed in Taiwan's semiconductor industry. The 285 firms in 2021 employed more than 290,000 employees as of the end of that year, in a population of 23.4 million. That is up from 217,465 in 2010 and 225,000 just two years earlier in 2019, according to the Industrial Technology Research Institute (ITRI). The expansion of the number of persons employed in the semiconductor industry looks set to continue apace (see Table 4).[57]

Table 4: Number of Employees in Taiwan's Semiconductor Industry

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
IC Design	38,100	37,000	37,800	39,500	42,000	42,500	42,000	41,000	41,500	41,800	45,010	49,533
IC Manufacturing	85,393	80,614	83,526	83,854	85,674	87,559	88,960	83,392	83,475	83,559	96,628	109,176
IC Packaging and Testing	93,972	91,520	92,000	93,700	94,000	95,100	97,200	98,800	99,200	99,800	114,888	132,893
TOTAL	**217,465**	**209,134**	**213,326**	**217,054**	**221,674**	**225,159**	**228,160**	**223,192**	**224,175**	**225,159**	**256,526**	**291,602**

Source: IEK Consulting, ITRI

Upstream Segment

In 2022, the total production value of Taiwan's IC design industry reached US$ 41.6 billion. Leading Taiwanese chip design firms including MediaTek, Realtek Semiconductor and Novatek

[57] IEK Consulting, Industrial Technology Research Institute, April 2023.

Microelectronics were among the global top ten IC design companies by revenue in 2022, and were respectively ranked 5th, 7th and 8th worldwide. MediaTek is known for its mobile phone application processor (AP), and along with the USA's Qualcomm, is one of the world's largest mobile phone AP suppliers. Realtek is an innovator in wireless network cards while Novatek's strength lies in its display driver chips. Together, the three companies held 12% of the global market share (see Table 5).[58]

Today's IC designs have dramatically increased in function and capability, and the use of pre-verified IP components can make the process of completing chip design more efficient, quality assured and cost-effective. Moreover, with clusters, Taiwanese semiconductor companies can flexibly and quickly develop and produce products in close cooperation with global customers.

Table 5: Global Top 10 IC Design Companies by Revenue, 2021 & 2022

Unit: US$ Billion

2022 Ranking		2021 Revenue	2021 Market Share	2022 Revenue (Est.)	2022 YoY	2022 Market Share
1	Qualcomm (US)	29.3	15%	36.8	26%	17%
2	Broadcom (US)	21.3	11%	26.9	26%	13%
3	Nvidia (US)	25.8	14%	26.5	3%	12%
4	AMD (US)	16.4	9%	23.5	43%	11%
5	MediaTek (TW)	17.6	9%	18.2	3%	8%
6	Marvell (US)	4.5	2%	5.9	32%	3%
7	Realtek (TW)	3.8	2%	3.8	0%	2%
8	Novatek (TW)	4.8	2%	3.5	-27%	2%
9	Willsemi (CN)	3.2	2%	2.6	-19%	1%
10	Cirrus Logic (US)	1.6	1%	2.0	24%	1%
	Total	**128.3**	**68%**	**149.7**	**17%**	**69%**
	Taiwan's Total*	**26.2**	**13%**	**25.5**	**-2.7%**	**12%**

*Excluding TW companies outside the top 10 list

Source: DIGITIMES Research, February 2023

58 DIGITIMES, April 30, 2023.

Midstream Segment

The output value of Taiwan's IC manufacturing in 2022 hit US$ 90.2 billion, accounting for 63.8% of the global wafer foundry industry market. Four listed Taiwanese companies providing foundry services, namely, TSMC, UMC (United Microelectronics Corporation), PSMC (Powerchip Semiconductor Manufacturing Corporation) and Vanguard International Semiconductor Corporation (VIS) were ranked first, third, seventh and eighth respectively among the world's top ten foundry companies by revenue in 2022. Together, the four companies command 65% of the global market share (see Table 6).

Table 6: Global Top 10 Foundry Companies by Revenue, 2021 & 2022

Unit: US$ Billion

2022 Ranking		2021 Revenue	2021 Market Share	2022 Revenue (Est.)	2022 YoY	2022 Market Share
1	TSMC (TW)	56.8	52%	75.9	34%	55%
2	Samsung Electronics (KR)	19.0	17%	22.1	16%	16%
3	UMC (TW)	7.6	7%	9.2	21%	7%
4	GlobalFoundries (US)	6.6	6%	8.1	23%	6%
5	SMIC (CN)	5.4	5%	7.3	34%	5%
6	Hua Hong (CN)	3.0	3%	3.7	25%	3%
7	PSMC (TW)	2.3	2%	2.6	11%	2%
8	VIS (TW)	0.9	1%	1.7	23%	1%
9	Tower Semiconductor (IL)	1.5	1%	1.7	13%	1%
10	DB HiTek (KR)	1.1	1%	1.3	27%	1%
	Total	**104.3**	**96%**	**133.0**	**28%**	**97%**
	Taiwan's Total*	**67.6**	**62%**	**89.4**	**32.2%**	**65%**

* Excluding TW companies outside the top 10 list

Source: DIGITIMES Research, February 2023

TSMC, the world's largest foundry and the most prominent of Taiwan's midstream chipmakers, commands the number one share of the global foundry market and has highly advanced semiconductor processes. It started mass production of chips using its 3-nanometer process technology in the second half of 2022, and continues to research and develop processes below 2 nm.

Meanwhile, UMC, Taiwan's first semiconductor company, is focused on its 22/28 nm process technology and has made great leaps in communication and automotive chips. Recently, it signed a long-term automotive microcontroller control units (MCU) supply contract with Infineon, a major Integrated Device Manufacturer (IDM) manufacturer.[59]

Downstream Segment

In the downstream packaging and testing segment, Taiwan has a host of home-grown packaging and testing firms. Six Taiwanese firm, namely, Advanced Semiconductor Engineering (ASE), Powertech Technology, KYEC, Chipmos, Chipbond and Sigurd are among the world's top ten outsourced semiconductor assembly and test (OSAT) companies by revenue. They were ranked first, seventh, eighth, nineth and tenth in the world. Together, the six companies command about 45% of the world's market share in packaging and testing in 2022 (see Table 7).

ASE ranks first in the global packaging and testing industry. It is also known for system-in-package (SiP), and has actively invested in the construction of heterogeneous integrated packaging platforms in recent years.

In addition, there is also a number of firms that supply the materials needed for packaging and support the development of Taiwan's packaging and testing industry, including Chang Wah Electromaterials (gold wire and leadframes), Unimicron and Kinsus (IC carrier boards), Eternal Materials (molding and filling materials), and Yeh-Chiang Technology and Shenmao Technology (tin lead solder paste).[60]

[59] Infineon press release, "Infineon and UMC extend automotive partnership with long-term agreement for 40nm eNVM microcontroller production", March 7, 2023

[60] Ministry of Economic Affairs, R.O.C. (Taiwan), Key Innovative Industries in Taiwan- Semiconductors, 2022

Table 7: Global Top 10 OSAT Companies by Revenue, 2022

Unit: US$ Billion

2022 Ranking		2021 Revenue	2021 Market Share	2022 Revenue (E)	2022 YoY	2022 Market Share
1	ASE (TW)	11.5	29%	12.2	6%	29%
2	Amkor (US)	6.1	16%	7.0	15%	17%
3	JCET (CN)	4.7	12%	5.0	7%	12%
4	TFME (CN)	2.4	6%	3.1	25%	7%
5	Powertech (TW)	3.0	8%	3.0	1%	7%
6	Huatian (CN)	1.9	5%	1.8	-2%	4%
7	KYEC (TW)	1.2	3%	1.2	2%	3%
8	Chipmos (TW)	1.0	2%	1.0	1%	2%
9	Chipbond (TW)	1.0	2%	0.9	-7%	2%
10	Sigurd (TW)	0.6	2%	0.6	6%	2%
	Total	**33.4**	**85%**	**35.8**	**54%**	**85%**
	Taiwan's Total*	**18.3**	**46%**	**18.9**	**3.3%**	**45%**

*Excluding TW companies not on the top 10 list

Source: DIGITIMES Research, February 2023

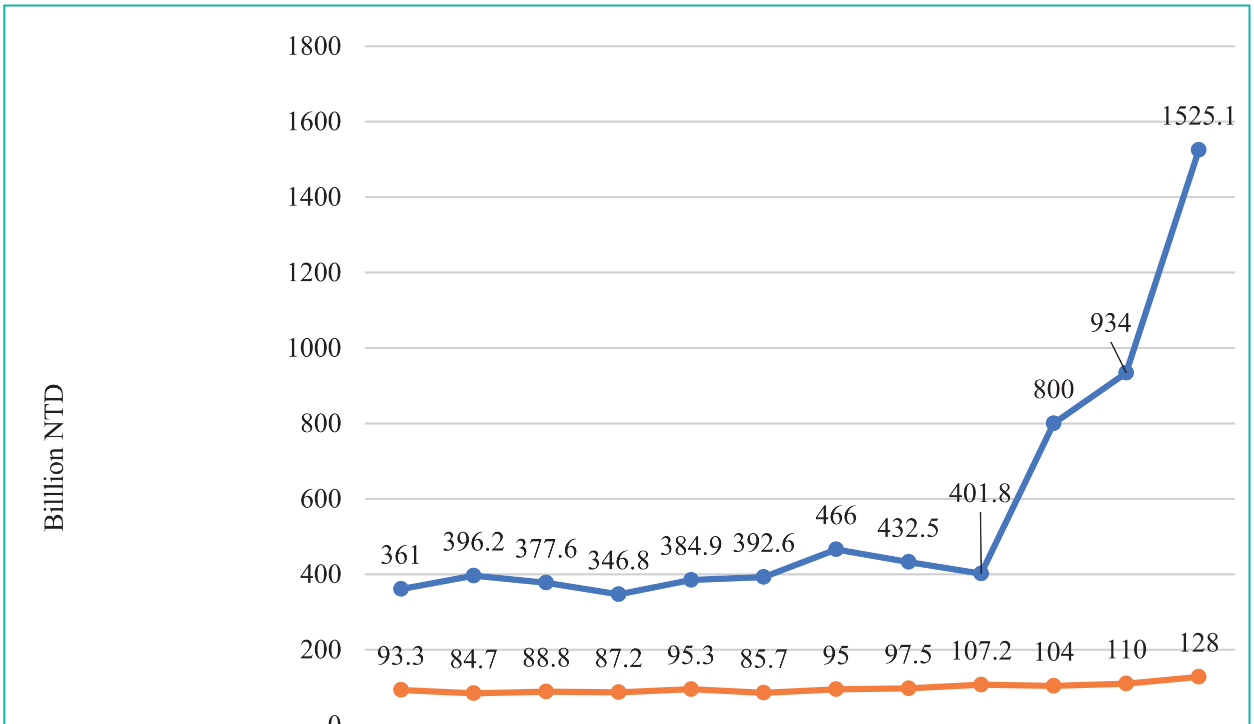
Each segment of Taiwan's semiconductor industry contributes its own irreplaceable value and supports the very high degree of integration among the upstream, midstream and downstream segments of the industry.

C. Capital Expenditure

Capital expense by Taiwan's IC manufacturing companies and IC packaging and testing companies has increased over the years, from NT$ 454.3 billion (US$ 14.67 billion) in 2010 to NT$ 1,653.1 billion (US$ 53.4 billion) in 2021. The increase is particularly significant in the case of IC manufacturing companies. IC manufacturing registered an almost threefold jump in capital expense from NT$ 401.8 billion (US$ 12.98) in 2018 to a whooping NT$ 1,525.1 billion (US$

49.26 billion) in 2021 (see Figure 6). This increase can be attributed to a surge in investment towards advanced process technology.[61]

Figure 6: Capital Expenditure of Taiwan's Semiconductor Industry



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
IC Manufacturing	361	396.2	377.6	346.8	384.9	392.6	466	432.5	401.8	800	934	1525.1
IC Packaging and Testing	93.3	84.7	88.8	87.2	95.3	85.7	95	97.5	107.2	104	110	128

Source: IEK Consulting, ITRI

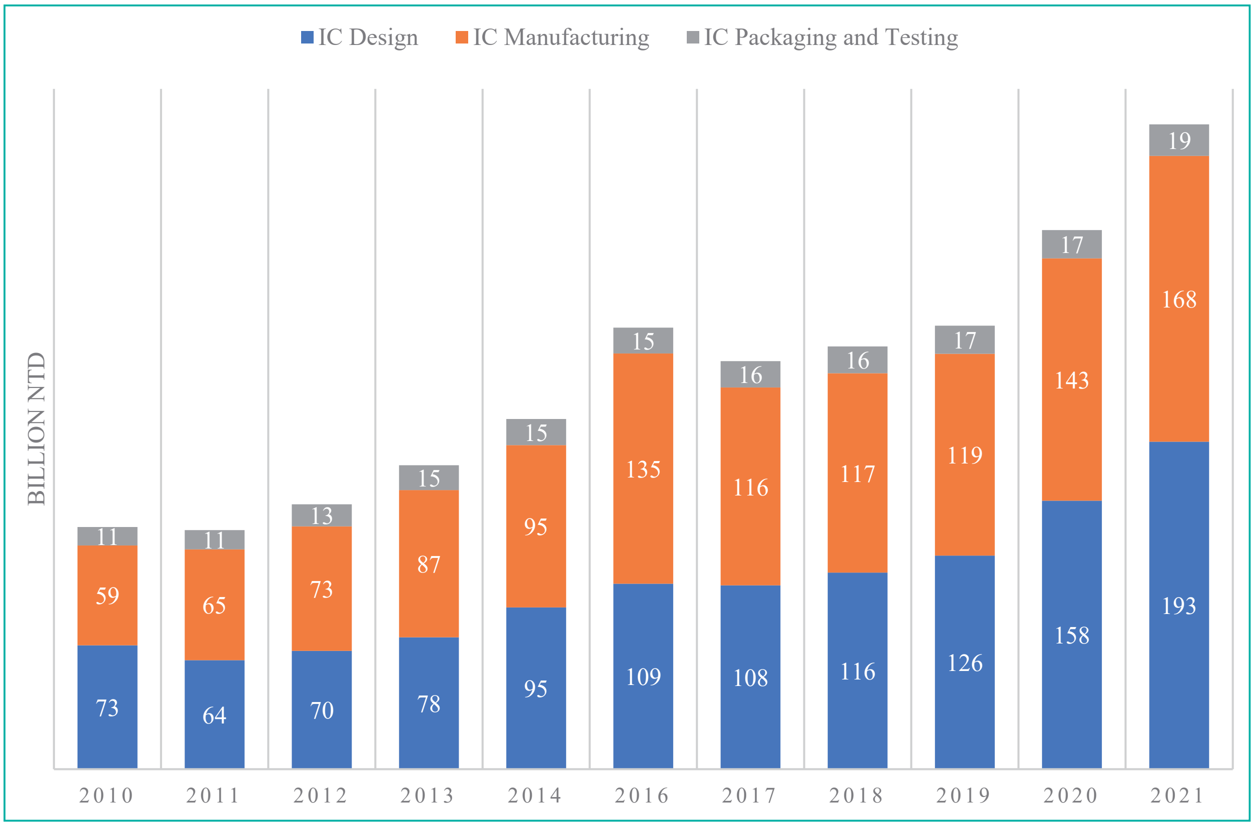
D. R&D Expenditure and Researchers

Businesses in Taiwan are responsible for a large majority of research and development spending. Spending on research and development in the semiconductor industry in Taiwan hit a record high in 2021. From a total spending of NT$ 143 billion (US$ 4.6 billion) in 2010, it increased 122% to NT$ 318 billion (US$ 10.2 billion) in 2020. This spending grew another 19% from 2020 to 2021 to NT$ 380 billion (US$ 12.2 billion). Taiwan IC manufacturing companies invested NT$ 168 billion (US$ 5.4 billion) in R&D in 2021 while its IC packaging and testing

[61] Taiwan Semiconductor Industry Association, Overview on Taiwan Semiconductor Industry (2022 Edition)

and IC design invested NT$ 19 billion (US$ 612 m) and NT$ 193 billion (US$ 6.2 billion) respectively (see Figure 7).[62]

Figure 7: R&D Expenditure of Taiwan's Semiconductor Industry



	2010	2011	2012	2013	2014	2016	2017	2018	2019	2020	2021
IC Design	73	64	70	78	95	109	108	116	126	158	193
IC Manufacturing	59	65	73	87	95	135	116	117	119	143	168
IC Packaging and Testing	11	11	13	15	15	15	16	16	17	17	19
TOTAL	143	140	156	180	205	259	240	249	262	318	380

Source: IEK Consulting, ITRI

Commensurate with the increase in R&D spending, the number of researchers involved in the various segments of the semiconductor industry value chain in Taiwan also reached new

62 Taiwan Semiconductor Industry Association, Overview on Taiwan Semiconductor Industry (2022 Edition)

highs in 2021. In 2010, there were a total of 40,821 semiconductor researchers, with 8,790 in IC design, 8,265 in IC manufacturing and 3,796 in IC packaging and testing. From 2010 to 2021, the total number of researchers increased by 29% to 52,740, with 36,010 in IC design, 10,980 in IC manufacturing and 5,750 in IC packaging and testing (see Table 8).

Table 8: Number of Researchers in Taiwan's Semiconductor Industry

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
IC Design	28,760	27,380	27,518	27,813	29,573	30,277	29,887	29,555	30,005	30,000	32,400	36,010
IC Manufacturing	8,265	8,382	8,473	8,563	8,784	8,907	9,131	8,339	8,414	8,497	9,707	10,980
IC Packaging and Testing	3,796	3,755	3,870	4,000	4,060	4,250	4,200	4,220	4,230	4,250	5,000	5,750
TOTAL	**40,821**	**39,517**	**39,861**	**40,376**	**42,417**	**43,434**	**43,218**	**42,114**	**42,649**	**42,747**	**47,107**	**52,740**

Source: IEK Consulting, ITRI

E. Expansion of Taiwan's Foundries

A number of Taiwan's foundries, including TSMC, Powerchip, UMC and Vanguard International Semiconductor Corporation (VIS) have announced plans to increase their production capability (see Table 9).

TSMC

Taiwan accounted for approximately 70% of the global production capacity of advanced chips below 7 nm in 2022.[63] All these advanced chips are manufactured by a single company, Taiwan Semiconductor Manufacturing Corporation (TSMC).

In 2022, TSMC began mass-producing 4 nm chips, and in December closely followed Samsung's lead to mass-produce 3 nm chips. TSMC is also working to produce cutting-edge 2 nm chips in its Hsinchu and Taichung sites in northern- and central Taiwan by 2025.[64]

63 Industrial Development Bureau, Ministry of Economic Affairs, R.O.C. (Taiwan), March 2023.

64 Bloomberg, "TSMC Starts Next-Gen Mass Production as World Fights Over Chips", December 28, 2022.

On April 1, 2023, TSMC opened an overseas operations office to supervise fabs under construction in the U.S. State of Arizona and Japan's Kumamoto Prefecture. The overseas office is in charge of supervising and managing TSMC Arizona Corp. and Japan Advanced Semiconductor Manufacturing Inc. (JASM).[65]

TSMC will offer 4 nm chips at its new plant in Arizona, USA, which is targeted to begin operations in 2025.[66] It also plans to offer 3 nm at a second US plant in 2026. Through JASM, TSMC is also building an US$ 8.6 billion wafer plant in Kikuyo, Kumamoto Prefecture, using the company's 12/16 nm high-level logic processes as well as 22/28 nm specialty processes, with commercial production expected to start in 2024. Sony Group Corp. and Denso Corp., a major Japanese auto parts vendor, are also investing in the factory while the Japanese government is providing financial aid.[67]

UMC

In February 2022, UMC announced that it would be building a new manufacturing facility next to its existing 12-inch fab (Fab12i) in Singapore. The first phase of this greenfield fab will have a monthly capacity of 30,000 wafers with production expected to commence in late 2024. The new fab (Fab12i P3) will be one of the most advanced semiconductor foundries in Singapore, providing UMC's 22/28 nm processes. The planned investment for this project will be US$ 5 billion. UMC has operated as a pure-play foundry supplier in Singapore for more than 20 years and the location is also the company's designated R&D center for advanced specialty process technologies.[68]

Powerchip and Vanguard

To keep up with demand for their chips, both Powerchip and Vanguard announced their plans to expand in Taiwan in 2021. According to the original announcements, Powerchip plans to offer 1x-50 nm chips in 2024, while Vanguard is expected to offer 90/110 nm+ chips in 2023. However, due to the inventory adjustment throughout the supply chain in 2022, the time frames of the introduction of new production capacity are delayed for both companies.

[65] Overseas Community Affairs Council, R.O.C. (Taiwan), "TSMC opens overseas operations office to supervise fabs in U.S., Japan", April 3, 2023.

[66] Bloomberg, "TSMC Cuts 2023 Outlook Ahead of Delay to Marquee US Project", July 20, 2023.

[67] Japan Times, "TSMC considering second chip plant in Kumamoto", June 6, 2023.

[68] UMC Press Release: "UMC announces new 22nm wafer fab in Singapore", February 24, 2022.

Table 9: Expansion of Taiwanese Foundries

	Company	Announced Month	Major Expansion Plan and Location	Process Node	Yr. of Mass Production	Initial Capacity	8" equivalent wafer capacity
Foundry	TSMC	2020.6	New 12" fab in Arizona, U.S.	5 nm mass production	2024	20,000	45,000
	TSMC	2021.4	Expand 12" fab in Nanjing, China	28 nm mass production	2022	40,000	90,000
	TSMC	2021.10	New fab in Kumamoto, Japan	12-28 nm mass production	2024	55,000	123,750
	TSMC	2021.10	New fab in the former CNPC refinery site in Kaohsiung City	7nm mass production	2024	40,000	90,000
	Powerchip	2021.3	New 12" fab in Miaoli, Taiwan	1x-50 nm mass production	2024	25,000	56,250
	UMC	2021.4	New 12" fab in Tainan Science Park	22/28 nm mass production	2023	27,500	61,875
	UMC	2022.2	Expand 12" fab in Singapore	22/28 nm mass production	2024	30,000	67,500
	Vanguard (VIS)	2021.4	Expand 8" fab through acquisition of AUO's fab in Hsinchu, Taiwan	90/110nm+	2023	40,000	40,000

Source: MIC, Institute for Information Industry, October 2022

4. Opportunities and Prospects

A. Technology Trends

Taiwan's semiconductor industry is well positioned in core technologies and applications fueling innovations in fields essential to future economic growth such as personalized healthcare, robotics, and intelligent products. To meet the needs of the technologies of the future and to stay ahead in the face of global competition, Taiwan is heavily investing in R&D and promoting technological collaborations.

1.4 Nanometer Chip

On July 28, 2023, TSMC launched its global Research and Development Center at its manufacturing base in Taiwan's Hsinchu, where its state-of-the-art facilities are producing ever-smaller silicon wafers that have skyrocketed in demand, especially due to the recent boom in AI-related technology. TSMC will remain "rooted in Taiwan", its chief executive said in a bid to allay concerns that the world's largest contract chipmaker could abandon its island home as it expands abroad. At the launch of the R&D facility, TSMC chairman Mark Liu said the center would "develop world-leading technologies in the semiconductor industry more actively to explore two-nanometer and 1.4-nanometer technology, and even smaller". The company is racing to begin mass production of a 1.4-nanometer chip -- tinier than a fraction of a fingernail -- ahead of its rival Samsung, the world's second-largest producer.[69]

Breakthrough on Applications of 2D Materials

Teams from TSMC and National Yang Ming Chiao Tung University collaborated with the Taiwan Instrument Research Institute (TIRI)'s Atomic Layer Deposition (ALD) Joint Laboratory to develop a high coverage ALD process, successfully producing a device with a two-dimensional material with an effective 1 nm oxidation, in addition to developing a nanosheet gate-all-around (GAA) transistor made with a two-dimensional semiconductor material. Both achievements were jointly reported at the 2022 International Electron Devices Meeting (IEDM) and are critical pieces of research required to achieve "More than Moore" technology.

69 Reuters, "TSMC says it is "rooted in Taiwan" even as it expands abroad", July 28, 2023

Vertically Stacked CFETs by a Low-temperature Bonding Technique

Complementary field-effect transistors (CFETs) can reduce transistors' footprint and are considered the next-generation semiconductor devices' structure. The low-temperature wafer bonding technology developed by the Taiwan Semiconductor Research Institute (TSRI) of the National Applied Research Laboratories (NARLabs) and National Institute of Advanced Industrial Science and Technology (AIST), Japan, can directly bond single crystalline semiconductor substrates with different wafer orientations or materials into one substrate, which can be applied directly to the production of CFET devices. In this technology's double-layer nanosheet stacked structures, the Ge/Si or (111) Ge/(100) Ge for upper pFET/ bottom nFET CFETs constitute a brand-new CFET structure. The results of this research have been published at the International Electron Devices Meeting (IEDM) and IEEE Symposium on VLSI Technology and Circuits (VLSI).

Developing Frontier Semiconductor Process Inspection Equipment

Taiwan Instrument Research Institute (TIRI) plans to develop a field monitoring and inspection module for cluster equipment, which can be applied to the inspection of advanced 2D semiconductor process materials. The technology can also assist domestic semiconductor wafer manufacturers in establishing standards for the use of extreme ultraviolet light components for domestic semiconductor inspection companies to develop the technology. The cluster semiconductor inspection technology and equipment developed will enable the most accurate surface information to be obtained without sample contact with the air.

Custom System-on-Chip Design Platform

Using the Custom System-on-Chip Design Platform developed by the TSRI, research teams from National Taiwan University (NTU) and National Yang Ming Chiao Tung University are developing biomedical chips, self-driving cars, and smart robots. Professor Chia-Hsiang Yang from the NTU Department of Electrical Engineering, his research team, and TSRI have used the platform to design, test, and display three custom systems-on-chips: the "AI Computing Acceleration Chip," which can accelerate computation by four to six times; the "Seven-axis Autonomous Mobile Robot Motion Control Chip," which can increase maximum motion control frequency by 22 times and energy efficiency by 350 times more than recorded in past literature, and the "Next-generation Genetic Sequencing Data Analysis Chip," which is the first in the world to achieve gene variant computation and can reduce analysis time from several days to half an hour or less. All three systems-on-chips were selected for presentation at the International

Solid-State Circuits Conference (ISSCC).[70]

3DIC Technology for Next-generation HPC and Mobile Applications

As the development of silicon process slows down after 10 nm, 3DIC technology becomes a “new Moore’s law” to continue driving performance boost of semiconductor systems. 3DIC technology integrates several chiplets or wafers using vertical stacking or bonding processes. This technology provides tremendous flexibility as designers could "mix and match" technology IP blocks with various memory and I/O elements in novel device form factors. For high-performance computing (HPC), 3DIC offers great advantages of power, performance, and area (PPA).

TSMC is one of the leaders in 3DIC technology with its own CoWoS (Chip on Wafer on Substrate), InFo (Integrated Fan-out), and SoIC (System-on-Integrated-Chips) technology. To help customers overcome the rising challenges of system-level design complexity with 3DIC technology, TSMC introduced the new 3DFabric Alliance in 2022, a significant addition to TSMC’s Open Innovation Platform (OIP). Meanwhile, TSMC established a 3DIC R&D center in Japan to pursue research into the next generations of three-dimensional silicon stacking and advanced packaging technologies in materials science.

Advancement of Third-Generation Semiconductor Devices

Third-generation semiconductor devices usually refer to devices made with silicon carbide (SiC) or gallium nitride (GaN). Owing to its Wide Band Gap (WBG) nature, third-generation semiconductor is suitable for high temperature, high frequency, radiation resistant and high-power devices such as electric vehicles, data centers, and renewable energy production.

Based on a market analysis[71], the output value for third-generation power semiconductors is expected to grow at 48% CAGR (compound annual growth rate) from US$ 980 million in 2021 to US$ 4.71 billion in 2025. In Taiwan, there are several companies working on third-generation semiconductor including TSMC, Episil Technology, WIN Semiconductors, and Mosel Vitelic. It is expected that these companies will enjoy robust global demand for third-generation semiconductors for power grids, electric vehicles and telecom base stations in recent years.

[70] National Applied Research Laboratories (NARLabs), TSRI Develops Custom System-on-Chip Design Platform, May 2023.

[71] TrendForce, “8-inch Substrate Mass Production in 2H22, 3rd Gen Power Semiconductor CAGR to Reach 48% by 2025, Says TrendForce,” March, 2022.

B. Application Trends

AI-Generation Trend (IoT, 5G, Smart City)

Today's artificial intelligence (AI) applications can not only process data but also learn from experience and apply that experience to improve how they function. With AI applications gaining traction in the industrial, retail, health care, military, research, and consumer sectors, demand for specialized sensors, integrated circuits, improved memory, and enhanced processors is increasing. This demand is changing the semiconductor supply chain by directly impacting design and manufacturing decisions.[72]

A McKinsey report[73] projects that, by 2030, internet of things (IoT) products and services will create between US$ 5.5 trillion and US$ 12.6 trillion in value. The growing penetration of internet usage across residential and commercial space as a result of a higher disposable income and improvements in the IT sector, the increasing demand for connected wearable devices, and the rising trend of industrial automation are creating growth opportunities for the IoT chip market.

Semiconductors are involved in every level of 5G from the network infrastructure (antennae, base stations, switches) to mobile phones and other connected devices. According to a report by the Global System for Mobile Communications Association (GSMA), global 5G adoption will reach 17% by 2023, and by 2030, it is expected to contribute a staggering US$ 1 trillion to the global economy.[74]

Both 5G and the internet of things have the potential to transform cities into smart cities, with artificial intelligence technologies used to reduce traffic congestion, improve public safety and protect the environment.[75] In addition, Taiwan will play a very important role in the development of beyond fifth-generation (B5G) networks and sixth generation (6G) wireless communication networks, particularly MediaTek and WIN Semiconductors Corp.

[72] Institute of Electrical and Electronics Engineers, International Roadmap for Devices and Systems (2020 Edition).

[73] McKinsey, "IoT value set to accelerate through 2030: Where and how to capture it", November 2021.

[74] Global System for Mobile Communications Association, "The Mobile Economy 2023", March 2023.

[75] Schroders Wealth Management, "Semiconductors - key to smart, green cities of the future", June 2020.

Automotive Applications (EVs, Smart Cars)

With increasing demand for advanced driver assistance systems, growing electrification of vehicles, and advancements in autonomous technologies, automotive semiconductors will become indispensable components. The automotive semiconductor market is expected to grow by more than 9% annually through 2030.[76] New semiconductor technologies will be driven by the demand for comfort, safety, and convenience features.

Automobiles have about 1,200 chips in a standard internal combustion engine and 3,000 chips in a fully electric vehicle. Experts estimate that 8% of annual chip production goes to automobiles. According to Hsiao-Lu Lee, a partner leading McKinsey and Company's semiconductor practice in Asia, 66% of consumers are willing to change car brands based on their autonomous driving function. She believes that there will be more semiconductor complexity, and purpose-built chips will be more prevalent.[77]

A Digitimes Asia report highlighted that TSMC dominates the global chip foundry market, and high-performance computing chips for self-driving capability must be made using advanced processes. TSMC is in pole position in 28 nm and below processes needed to make automotive chips. The automotive segment accounted for about 5% of TSMC's overall company sales in 2022. In the first quarter of 2023, the percentage rose to 7%. The automotive segment could generate as much as NT$ 140 billion (US$ 4.56 billion) in sales in 2023 for TSMC on an estimated overall company sales of NT$ 2 trillion (US$ 32.1 billion) for the year.[78]

C. Stock Market

The semiconductor industry is also considered the core of Taiwan's stock market. In end-2022, the market value of the semiconductor industry was about NT$15.77 trillion (US$ 514.68 billion), accounting for more than 30% of the value of the Taiwan stock market.[79]

Compared with other securities markets in the world, Taiwan's price-to-earnings (P/E) ratio of about 10.39 times in 2022 is slightly higher than Singapore's and comparable to Hong Kong's,

[76] Boston Consulting Group, "Automotive Industry Semiconductor Outlook", October 2022.

[77] AmCham Taiwan, "EV Industry Drives Chip Growth, Green Future", November 30, 2022.

[78] Digitimes Asia, TSMC growing presence in EV sector, May 5, 2023.

[79] Taiwan Stock Exchange, April 2023.

but is lower than that of other securities markets. The P/E ratio of Taiwan's semiconductor industry at the end of 2022 is about 10.99, low when compared to other securities markets, indicating that Taiwan stocks have a price advantage. In terms of yield rate, Taiwan's overall market yield reached 4.88% while that of the semiconductor industry is 3.93 (see Table 10).

The profit on Taiwan's 2021 cash stocks reached a record high of NT$ 2.19 trillion (US$ 70.31 billion), an increase of more than 50% compared with 2020. Dividends are significantly better than major markets such as the United Kingdom, Hong Kong, China, Japan, South Korea, and the United States. In addition, in 2022, the turnover rate of Taiwan's transaction value was 115.44%, and the turnover rate of semiconductor transaction value was 114.71%. Overall, Taiwan's turnover rate was better than Singapore and Hong Kong, and comparable to the United States.

Table 10: Comparison of 2022 Global Stock Exchange PE Ratio and Yield Rate

Stock Exchange	End of 2022		
	P/E Ratio	Yield (%)	Turnover Ratio (%)
Taiwan	**10.39**	**4.88**	**115.44**
- Semiconductor	**10.99**	**3.93**	**114.71**
Singapore	9.22	4.09	35.38
United Kingdom	17.00	3.76	35.76
Hong Kong	10.31	3.37	61.64
Shanghai	12.78	2.77	204.79
Japan	14.40	2.27	107.12
United States	19.18	2.07	121.74
South Korea	10.76	1.97	165.24
Shenzhen	23.44	1.23	383.24

Sources: Taiwan Stock Exchange, Bloomberg, and indicators of the securities and futures market.

Note:

1. The turnover ratio of semiconductor is based on statistics from the official website of the stock exchange and calculated by dividing the transaction value by the market value.
2. Data date: December 30, 2022

Overall, Taiwan stocks have the characteristics of comparatively low price-to-earnings ratio and high yield rate, and are also highly tradeable and liquid. The long-term growth prospects for the semiconductor industry remain very promising and this will continue to boost the performance of Taiwan's stock market.

D. Talent Cultivation

In terms of human resources, more than 10,000 people graduate from IT-related programs in Taiwan and join the workforce every year.[80] As countries pledge billions for domestic chip production and companies scramble to build new plants, the need for semiconductor talents to design, manufacture and test chips has intensified globally.

The semiconductor workforce, which is estimated at more than two million direct semiconductor employees worldwide in 2021, will need to grow by more than one million additional skilled workers by 2030, according to Deloitte's 2023 semiconductor industry outlook. That means adding about more than 100,000 workers annually, the report said.[81]

Addressing the chip talent shortage is a top priority for Taiwan. To this end, Taiwan passed the National Key Fields Industry-University Cooperation and Skilled Personnel Training Act in May 2021 to allow companies and national universities to jointly develop talent in key sectors. The first four national universities including National Taiwan University, National Tsing Hua University, National Yang Ming Chiao Tung University, and National Cheng Kung University, have set up semiconductor colleges in 2022, each with a quota of about 100 master's and doctorate students.[82] To date, thirteen universities in Taiwan have semiconductor colleges or departments.

The Taipei Representative Office in Singapore (TRO) is currently working with the following eight universities in Taiwan which offer degree programs to broaden the pool of talented candidates for positions in the global semiconductor industry:

1. National Cheng Kung University
2. National Sun Yat-sen University

80 Ministry of Economic Affairs, R.O.C. (Taiwan) – Key innovative Industries in Taiwan: Semiconductors

81 Deloitte 2023 Semiconductor Industry Outlook

82 Ministry of Education, R.O.C. (Taiwan) – Semiconductor Research Department Introduction

3. National Taipei University of Technology
4. National Taiwan University
5. National Tsing Hua University
6. National Yang Ming Chiao Tung University
7. Lunghwa University of Science and Technology
8. Minghsin University of Science and Technology

[A copy of the brochure (and any updates) will be made available on the TRO website]

Talent development is critical for a world run by semiconductors and for developing an indigenous semiconductor industry. Just as it takes years to build semiconductor fabrication facilities, it takes time to develop talent for the industry. Besides racing to set up specialized "chip schools" that run year-round to train its next generation of semiconductor engineers, Taiwan is also introducing chip courses into high school curricula to spur the interest of high school students in choosing STEM (science, technology, engineering and mathematics) programs at the university level.

E. Resilience of the Global Supply Chain and Peace across the Taiwan Strait

Semiconductors produced in Taiwan are essential components of the world economy. As semiconductor technologies expand into every aspect of industry and daily life, or as enablers for new services, the semiconductor industry is the foundation for not just Taiwan's but the world's future. A semiconductor supply chain disruption involving Taiwan will be devastating to not only Taiwan but the rest of the world as well. To conclude, countries committed to economic growth and technological innovation have an enormous stake in the resilience of the global semiconductor supply chain as well as in the stability and peace across the Taiwan Strait.

Antony J. Blinken, US Secretary of State (July 14, 2023)

The United States also seeks to maintain peace and stability in the Taiwan Strait, which is in the interest of all nations. Fifty percent of global commerce goes through that strait every single day. Some 70 percent of the semiconductors made for the world are made in Taiwan. We continue to oppose unilateral changes to the status quo by either side.[83]

[83] US Department of State, press release: "Secretary Antony J. Blinken at a Press Availability", July 14, 2023.

UK's foreign secretary, James Cleverly (April 25, 2023)

"A war across the Strait would not only be a human tragedy, it would destroy world trade worth [US]$ 2.6 trillion, according to Nikkei Asia. No country could shield itself from the repercussions."

"Distance would offer no protection from this catastrophic blow to the global economy – and to China most of all."[84]

U.S. Director of National Intelligence Avril Haines (May 5, 2023)

Director Haines presented what she called a "general estimate" during testimony before the [US] Senate Armed Services Committee:

She noted that the advanced semiconductor chips produced by Taiwan Semiconductor Manufacturing Company Ltd (TSMC) are used in 90 percent of "almost every category of electronic device around the world." If a Chinese invasion stopped TSMC from producing those chips, " it will have an enormous global financial impact that I think runs somewhere between [US]$ 600 billion to [US]$ 1 trillion on an annual basis for the first few years," she said.[85]

F. Forging Partnership with Taiwan

The semiconductor industry is a cornerstone of global economic development in the digital age. Every effort will be made by the Taiwan government to support foreign investment and collaboration with Taiwan in the semiconductor industry. Taiwan's Ministry of Economic Affairs has outlined three areas of partnership, namely, 1) joining Taiwan's core cluster, 2) exploring the growing market for semiconductor equipment and materials, and 3) establishing operations and research centers to tap into the fast-growing Asia market.[86]

Joining the Core Cluster of the Global Semiconductor Industry

The complete semiconductor industry chain, production clusters, and R&D capability in Taiwan generates potential synergies for foreign businesses that set up R&D centers or production sites in Taiwan.

[84] The Guardian, "If China invaded Taiwan it would destroy world trade, says James Cleverly", April 25, 2023.

[85] Reuters, "Taiwan chip production would be 'enormous' global economic blow", May 5, 2023

[86] Ministry of Economic Affairs, "Key Innovative Industries in Taiwan-Semiconductors", 2022

In terms of human resources, more than 10,000 people graduate from IT-related programs in Taiwan and join the workforce every year. OECD data shows that Taiwanese students are ranked 4th in the world in science education. The Taiwan AI Academy was also established in 2017 to cultivate talent for the AI industry. Taiwan has a big competitive advantage in edge computing and AI chips, and Taiwan has succeeded in building up a very complete supply chain ecosystem.

In addition, Taiwan also passed the National Key Fields Industry-University Cooperation and Skilled Personnel Training Act in May 2021 to allow companies and national universities to jointly develop talent in key sectors, in addition to efforts by private universities. Thirteen universities have set up semiconductor colleges or engineering departments and begun recruitment to strengthen basic research and the partnerships necessary for semiconductor development.

The AI on Chip Taiwan Alliance (AITA) formed in July 2019 is composed of local and foreign semiconductor and ICT vendors, local universities, and national research institutions such as ITRI. Four "key technology committees" in AITA focus on AI system applications, heterogeneous integration, emerging architectures, and AI system software. AITA will be building on Taiwan's existing advantages by moving from horizontal division of labor to vertical integration. It will also help the industry reduce its R&D costs for AI chips by 90% and shorten their development time by over 6 months.

In addition, information security has become critical as the globe embraces smart manufacturing and digitalization. SEMI, an international semiconductor industry association, published the first information security standards for semiconductor wafer equipment in Taiwan in December 2021 and organized the inauguration of the Semiconductor Supply Chain Information Security Alliance. The event was attended by representatives of major semiconductor plants in Taiwan and foreign countries such as TSMC, ASE, and Applied Materials. Information security standards were jointly decided by semiconductor companies in Taiwan, which demonstrates Taiwan's key position in the global semiconductor industry.

Going forward, Taiwan looks forward to foreign companies forming technical partnerships with Taiwanese businesses to invest in the development, growth and resilience of the semiconductor industry.

Exploring the Growing Market for Semiconductor Equipment and Materials

IoT, AI, 5G, industrial and service robotics, smart city initiatives, smart lifestyle products, automotive electronics, and high-speed computing applications all require the support of the semiconductor industry. The future growth potential is considerable, and further growth in demand for semiconductor products is expected.

According to global semiconductor trade association SEMI, semiconductor material spending worldwide hit a new high of US$ 72.7 billion in 2022. Due to the large number of foundries and packaging plants, Taiwan has been the largest consumer of semiconductor materials in the world for 13 consecutive years. Taiwan spent US$ 20.1 billion on semiconductor materials in 2022, putting it ahead of South Korea and China.[87]

Currently in the field of semiconductor materials, high-performance photoresists, metal target materials, coating agents, and specialty reactive gases used in IC production processes, as well as wire bonding, molding, and filling materials used in IC packaging, are all imported. IC companies are hoping international vendors can produce those materials in Taiwan. In addition, the 5 nm and 7 nm IC production process recently began mass production in Taiwan as R&D for 2 nm technology continues. Apple and Intel are expected to commence trial production by the end of 2024, and mass production is expected to commence in the second half or the end of 2025.

Taiwan has a high demand for high-level IC production and packaging materials and hopes to enhance cooperation with foreign vendors. Among front-end wafer process materials, items in strong demand include metal sputtering deposition materials (target materials, parts/accessories), EUV photoresists, cleaning chemicals, and CMP slurry. As for back-end packaging and testing process materials, there is demand for high-end solid-state/liquid-state molding compounds, IC substrate materials with a low thermal expansion rate and a high heat dissipation rate, high-definition/low-stress buildup materials, die attach materials, flip chip underfill, and solder resist ink.

In terms of semiconductor equipment, the industry has benefited from growth in the demand of semiconductor front-end-of-line processes including wafer manufacturing, wafer plants facilities, and mask equipment, as well as rear-end-of-the-line assembly, packaging, and testing equipment. By 2022, Taiwan had the second highest equipment expenditure in the world, with spending amounting to US$ 26.82 billion, and is expected to return to the global lead soon.

Taiwanese vendors are capable of supplying equipment for conventional packaging processes and components for wafer production equipment and also has many leading global chip manufacturers. This makes Taiwan a great experimental site for the latest equipment, and Taiwan

[87] Focus Taiwan, "Taiwan ranked No. 1 semiconductor material buyer in 2022", June 14, 2023

can update equipment suppliers on the latest changes in the semiconductor industry. The aim is to cooperate with international upstream equipment vendors on advanced packaging equipment and equipment for 12-inch wafer processes. Foreign vendors in the following areas are therefore invited to invest in Taiwan:

1. *Front-end wafer production equipment*

   Deposition technology, dry etching technology, DUV and EUC exposure technology, photoresistor coating and developing technology, chemical mechanical polishing technology.

2. *Advanced packaging process equipment*

   Exposure technology, copper-plating technology, deposition technology, and dry etching technology.

Establishing Operations and Research Centers

Taiwan is home to the most complete semiconductor industry clusters and specializations in the world. As an active, innovative economy, Taiwan is an attractive destination for foreign-funded R&D centers. Coupling this with the growth of the Asian semiconductor industry, Taiwan has attracted top global semiconductor companies such as Intel, Nvidia, Qualcomm, NXP, Synapsys, Cadence, ASML, Lam Research and ULVAC to set up operations, R&D, logistics, testing and/or training centers on its shores. As recent as May 2023, American Applied Materials (AMAT) announced the establishment of a semiconductor process technology and manufacturing equipment cooperative research and development center in Taiwan to accelerate the development and commercialization of basic technologies that are essential to the global semiconductor and computing industries.

The global semiconductor industry is moving in the direction of regionally defined development, with specific foundries in different regions churning out specific types of wafers. At the same time, this trend is generating demand from manufacturers for after-sales service. China, Taiwan and South Korea remain the top three countries for equipment expenditures in 2022. Beyond that, the production in the semiconductor industry is expected to take on a role of greater importance in Japan. Countries of Southeast Asia will continue to develop stronger packaging and testing capabilities.

In light of the trends described above, foreign firms with increasing numbers of customers and devices in Taiwan and neighboring Asian countries can look at using Taiwan as a services hub. Foreign firms can set up equipment repair and refurbishment facilities, training facilities, or experimental sites in Taiwan. In addition, given that Taiwan is one of the largest semiconductor equipment and material markets in the world and also a major exporter of semiconductor components, international semiconductor manufacturers can also look at setting up global logistics centers in Taiwan. Several prominent global semiconductor companies are currently in negotiations with Taiwan's Ministry of Economic Affairs on this matter.