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KAUST Innovation

SEMICONDUCTOR INDUSTRY OVERVIEW

Summary

Semiconductor technology is revolutionizing the way we live, powering everything from cars and cellphones to jets and missiles. The ongoing research and development of new chips, technologies and manufacturing processes will continue to drive innovation and change in a wide range of industries, and play a critical role in improving our lives in impactful areas such as energy, computing, data storage, sensors, communication, lighting and photovoltaics.

The global semiconductor industry is expected to double in value to more than $1 trillion by 2030. Drawing on various market reports and studies, the following white paper summarizes the overall strengths and challenges in the industry. Sections cover topics such as the supply trade, geopolitics, materials, trends and market sectors, among other key areas of interest.

Trends

- 5G
- IoT
- Autonomous vehicles
- Artificial intelligence
- China's Dominance
- Materials
- Manufacturing

Artificial Intelligence (AI), 5G, Internet of Things (IoT) and autonomous vehicles are among the promising technologies with the potential to transform all levels of society, including the global semiconductor industry. However, all are still in the early stages of development. Improvements in their capabilities will accelerate the semiconductor field. Thanks to large investments and continuous advancements by major players and start-ups alike, the industry is set to see significant short- and long-term changes.

5G

5G integrated chipsets enable speedier flow and processing of information; data is transferred 10 times faster than 4G – improvements that transform the entire communications ecosystem. Storage, mobile devices and servers, all of which rely on semiconductors, will be able to perform previously impossible activities related to IoT and autonomous vehicles. According to reports published by Next Move Strategy Consulting, the global 5G chipset market size, estimated at $1.53 billion in 2019, is predicted to reach $90.79 billion by 2030, with a compound annual growth rate (CAGR) of 44.95% from 2020-2030.

Internet of Things

From modern automation systems to smart appliances, IoT devices are advancing, requiring their own analytics and microcontrollers to enhance security. The global IoT market size in terms of revenue was estimated at $300.3 billion in 2021 and is anticipated to rise to $650.5 billion by 2026, presenting a CAGR of 16.7%.

Autonomous vehicles

In the automotive industry, self-driving vehicles leverage integrated semiconductor chips to perform different collaborative operations using improved connectivity, enhanced sensors, battery performance in EVs, automation and much more. Automotive artificial intelligence software increases self-driving and semiautonomous vehicles' safety and operational efficiencies. According to reports published by Next Move Strategy Consulting, the global automotive artificial intelligence software market size is predicted to reach $53.98 billion by 2030, with a CAGR of 44.8% from 2020-2030.

Interestingly, demand for consumer electronics is decreasing, with a drop from 2021 to 2022 of 6% and 12% for smartphones and PCs, respectively.

Artificial intelligence

AI, enabled by semiconductors, offers advantages applicable across industries. These advantages include reduced operational costs, improved performance, increased manufacturing speed, enhanced efficiency, decreased response time and greater safety. Demand for AI-based applications and equipment directly impacts growth for semiconductor manufacturers. Furthermore, the massive upsurge in research and development, increased use of autonomous robotics at various industry verticals, and high-tech product launches create new market opportunities, increasing the AI chip market growth rate.

China's dominance

Though not a technology trend, the conflict between the United States (US) and China is expected to continue impacting the semiconductor industry. Over the past few years, China has dominated the global semiconductor industry. It is predicted to maintain this position for the foreseeable future. Chinese companies witnessing high sales are transitioning from a focus on low-cost production to specialized semiconductor design. Continued regulatory restrictions and changes in tech export controls will likely exacerbate the conflict between the US and China, causing price increases throughout the supply chain while the technology war ensues.

Materials

Industry and research institutions have heavily invested in developing advanced materials for semiconductors. Many materials are currently in the experimental phase. For example, scientists see potential in revisiting germanium for use in transistor technology. Electrons move four times faster in germanium than in silicon, providing an opportunity to boost speed. Additionally, manufacturers are experimenting with tin oxide, high-power gallium nitride, antimonide-based and bismuthine-based materials, graphene and pyrite. Most electronic devices depend on rare earth metals, and China has nearly monopolized the production of these metals. However, because of US-China trade disputes, prices for these metals have risen. Inevitably, this impacts subsequent steps in the semiconductor supply chain.

Manufacturing

Though not as financially driven as the trends above, improvements in manufacturing are also expected to impact cost, availability and sustainability of semiconductors. Desires to combat climate change in the geopolitical arena are driving the development of new fabrication techniques that reduce transportation costs (co-location), carbon emissions, water usage, hazardous waste and energy usage. Advancements in these areas may be technologically adjacent to the design and performance of semiconductors. The industry will need to assess adoption holistically, factoring impact on sales.

Overall pain points

- Supply chain disruptions
- Geopolitics
- Changing competitive landscape
- Talent shortages
- Sustainability
- Cybersecurity threats
- Global chip shortage

In 2022, the semiconductor industry hit numerous milestones, including greater investment in R&D, the enactment of the CHIPS and Science Act – a US act that increased funding for semiconductor research and manufacturing – and a projected record number of semiconductors produced and shipped to help combat the global chip shortage. Despite this, it continues to face significant challenges. Global semiconductor sales growth slowed in the second half of 2022 due to the market's cyclical nature, and projections indicate it won't rebound until the second half of 2023. Tensions between the US and China have fueled supply chain disruptions, leading to the enactment of government controls on chip sales to China, the largest global semiconductor market.

Supply chain disruptions

According to an *Accenture* report that surveyed 300 senior semiconductor executives globally, 76% of respondents said they expected industry supply chain challenges to ease by 2024, but that companies should also prepare to withstand other market pressures with investments that drive future growth. The executives cited difficulties that could affect their companies' ability to innovate, including lingering effects of COVID-19 on the supply chain lift, geopolitics, cybersecurity threats, the changing competitive landscape and talent shortages, among others. Two-thirds (65%) of the executives believe that the rate of Moore's law, which refers to the observation that the number of transistors in a dense integrated circuit (IC) doubles about every two years, will slow down by 2024. 56% of the executives believe that promoting strong IP protection and enforcement is one of the best ways to improve the industry's resilience moving forward.

Global chip shortage

The global semiconductor chip shortage was exacerbated by COVID-19 disruption and continues to affect industries reliant on chip technology, including automotive, electronics and technology manufacturing. The global chip shortages of 2021 became so dire that many automotive production lines shut down. Yet the demand for semiconductor chip technology is steadily increasing. As a result, the global shortage is predicted to last many years.

Changing competitive landscape

In the coming years, the market is expected to undergo significant changes in terms of companies' influence on the market. Many large tech companies, including Apple, Google and Amazon, plan to produce their own chips, overcoming the shortage and differentiating themselves from the competition. The changing competitive landscape will influence the direction in which applications of semiconductor technology develop due to the impact new technology will have on availability to the wider market.

Sustainability

There is a drive across industries to implement sustainable practices, and the semiconductor market is expected to adopt some of these to keep up with changing regulations and consumer expectations. Many companies and consumers have felt the push to act in a more sustainable manner due to the documented human impact on climate change.

Some companies in the semiconductor space have explored ways of reducing water usage in the production process by leveraging recycling technologies. Companies have also adopted renewable energy practices throughout their manufacturing processes to reduce the environmental impact of their operations.

Geopolitics

In recent years, there has been a push toward nationalization of semiconductor technology, which has implications for supply chains, talent acquisition and access to government subsidies. The US has instituted wider restrictions on what chips can be sold to China and who can work for Chinese companies. Of the $52 billion dedicated to semiconductor manufacturing through the US 2022 CHIPS Act, $39 billion will be used to subsidize building factories domestically.

However, chip manufacturing costs in the US are currently 50% higher than in Taiwan, and many other countries, including Taiwan, Japan and South Korea, are passing laws to give local semiconductor companies tax breaks. China is expected to focus on setting up their domestic chip industry in response to the increased regulations, providing support packages and generous subsidies for domestic companies in 2023.

Talent shortages

Over the next three years, talent shortages will also pose a large issue for the semiconductor industry. From a survey of 151 semiconductor executives, 71% anticipate increasing their global workforce in 2023. 67% of these executives believe talent development and retention is one of their top three priorities. Yet there is a shortage of laborers who are sufficiently trained to meet this demand. The need exists for universities and companies to upskill talent across areas of expertise to feed the growing semiconductor industry.

Cybersecurity threats

Only 15% of executives rank the need to mitigate cybersecurity risk as a "top three" strategic priority, yet cyberattacks continue to grow, putting assets and businesses at risk.

Technology pain points

The following examples of long-term pain points, or perceived challenges, are drawn from the IEEE International Roadmap for Devices and Systems (IRDS).
There is a short-term challenges list, but the long-term is almost the same and is more comprehensive.

Long-term challenges

Application benchmarking

- Big data analytics
- Feature recognition

Systems and architectures

- IoT
- Personal augmentation
- Cloud
- Cyber-physical systems

Outside system connectivity

- RF analog technology

More Moore

- Logic device scaling
- DRAM and 3D NAND flash memory

Lithography

- EUV lithography for 7nm node Logic and beyond

Factory integration

- Responding to business requirements
- Re-emergence of 200mm production line

Yield enhancement

- Detection of multiple
- Killer defects

Beyond CMOS

- Emerging memories and logic devices

Packaging integration

- Packaging technology

Metrology

- Measurement of complex 3D structures
- Measurement of complex material Stacks and interfacial properties

Environment, safety, health, and sustainability (ESHS) (also long-term challenges)

- Material challenges

More than Moore

- Smart sensors and energy
- Flexible electronics

Previous gains in graphic processing performance mainly came from improvements in algorithms and memory bandwidth, but processor performance did not seem to have a first-order impact. Larger memory bandwidth, lower latency and higher bandwidth of global networks that can use optical links are essential for future technology development. The main challenges with deep neural networks (DNN) hardware concern in-memory digital or analog computation. There is a need for analog memory devices, as well as low-power, high-bandwidth, moderate-precision and area-efficient analog-to-digital (A/D) converters.

Many systems and architectures bridge application benchmarks and component technologies, including IoT, personal augmentation, cloud technologies and cyber-physical systems. Many IoT devices will include AI capabilities in the future, which must be provided at very low energy levels, including convolutional neural networks, neuromorphic learning, low-cost energy harvesting, energy storage and management, low power sensing, computing and communication and automatic network configuration. Personal augmentation devices rely on further advances in communication, computation, capture, battery capacity and display technologies. Newer cloud technologies will require high bandwidth memory and large socket thermal power dissipation using improved packaging and cooling. Cyber-physical systems need high reliability in both hardware and software, security and storage capacity.

There is an increasing need for outside systems connectivity, which requires development of circuits for cancellation of 5G mm wave noise, reconfigurable directional multiple-input multiple-output (MIMO) antennas capable of reconfiguring and synchronizing signals, agreement on optical technology standards, communication between systems with different wavelengths, and increasing the efficiency of RF technologies by >10GB/s communication for mobile devices in a cost-efficient manner. 6G frequencies are projected to be above 100GHz, and new technologies and circuits are needed to improve energy efficiency, reduce latency of communication between CPUs and memory in data centers, convert between electrical and photonic signals and reduce the cost for mobile devices.

Power scaling remains a long-term challenge with a current lack of manufacturable candidates. Novel architectures such as vertical gate-all-around (VGAA) devices, 3D stacking, and possible cointegration of complementary metal-oxide-semiconductor (CMOS) and beyond CMOS technologies will be required for improving performance. These new technologies require good management of thermal challenges, yield and cost, along with introduction of alternatives to copper interconnects with low resistance and good reliability. Lithography limits are projected to be reached by 2030, but there are many new 3D device structures being introduced into manufacturing that will likely solve this issue. These new patterning techniques will face challenges in cost, yield, defectivity, etch and deposition of sub-10nm structures, implementing patterning on 450mm wafers and optimization of complex 3D structures.

Factory integration also remains a significant long-term challenge, with issues including flexibility, extendibility, scalability, environmental concerns such as material recycling and substitution, future global regulations, management of novel device types replacing conventional CMOS, and the impact of new manufacturing requirements on factory design. There is also a need for exploring new alternative technologies that can meet inspection requirements to discriminate defects of interest, including high-speed scanning probe microscopy, near-field scanning optical microscopy, interferometry, scanning capacitance microscopy and e-beam lithography.

Beyond CMOS technologies are facing research challenges, including nanoscale volatile and nonvolatile memory technologies to replace traditional static random access memory (SRAM), dynamic random access memory (DRAM) and flash memory, and new computing paradigms, including neuromorphic or quantum computing, novel architectures, device technology breakthroughs using charges and alternative or hybrid state variables. In semiconductor packaging, current challenges include reliable interconnects and substrates for wearable electronics, bio-compatible systems for miniaturized implants, efficient integration of electronic and optical components, and integration of cooling systems for quantum computing. Nondestructive wafer and mask-level metrology with better precision for novel device architectures are also needed.

Materials characterization and metrology methods are needed for control of interfacial layers, dopant positions, defects, size, location, alignment and atomic concentrations relative to device dimensions and for direct self-assembling processes. There are also current challenges relating to the impact of emerging materials on health and the environment, including III-V materials, perfluorooctanoic acid (PFOA) and potential biological interactions with different frequencies. Green chemistry and engineering concepts will become an important asset for future technologies.

> Many application fields for semiconductors, including automotive, healthcare, communication and energy management, require the development of multifunctional smart systems with cooperation across the complete value chain. The More than Moore domain, classified by the integration of digital and non-digital components, leads to the development of generic technology modules and open technology platforms. This opens up new possibilities for innovation, including smart sensors, smart energy, flexible and printed electronics and energy harvesting.

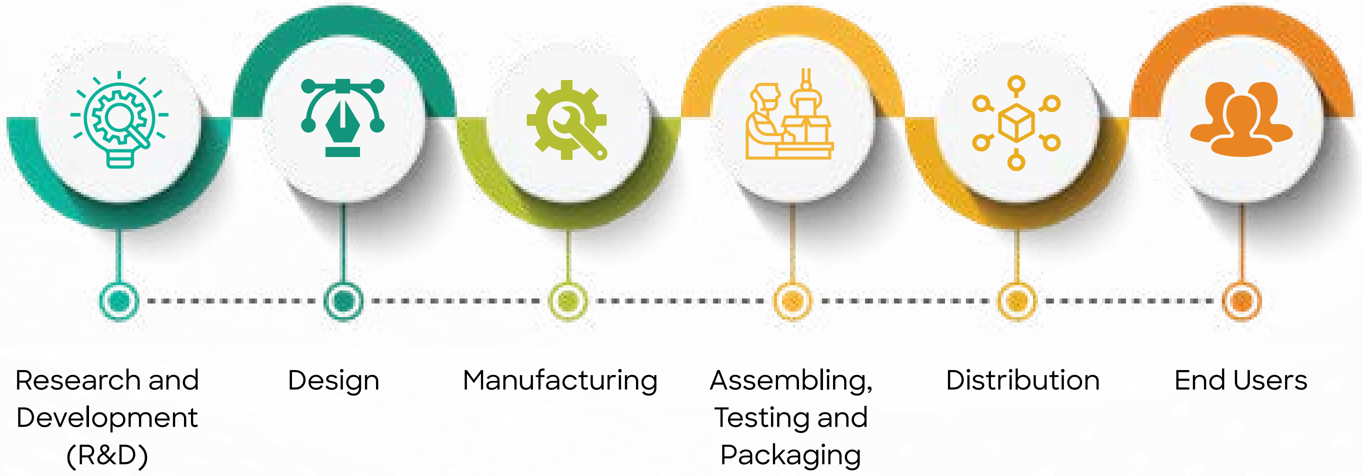
Market structure

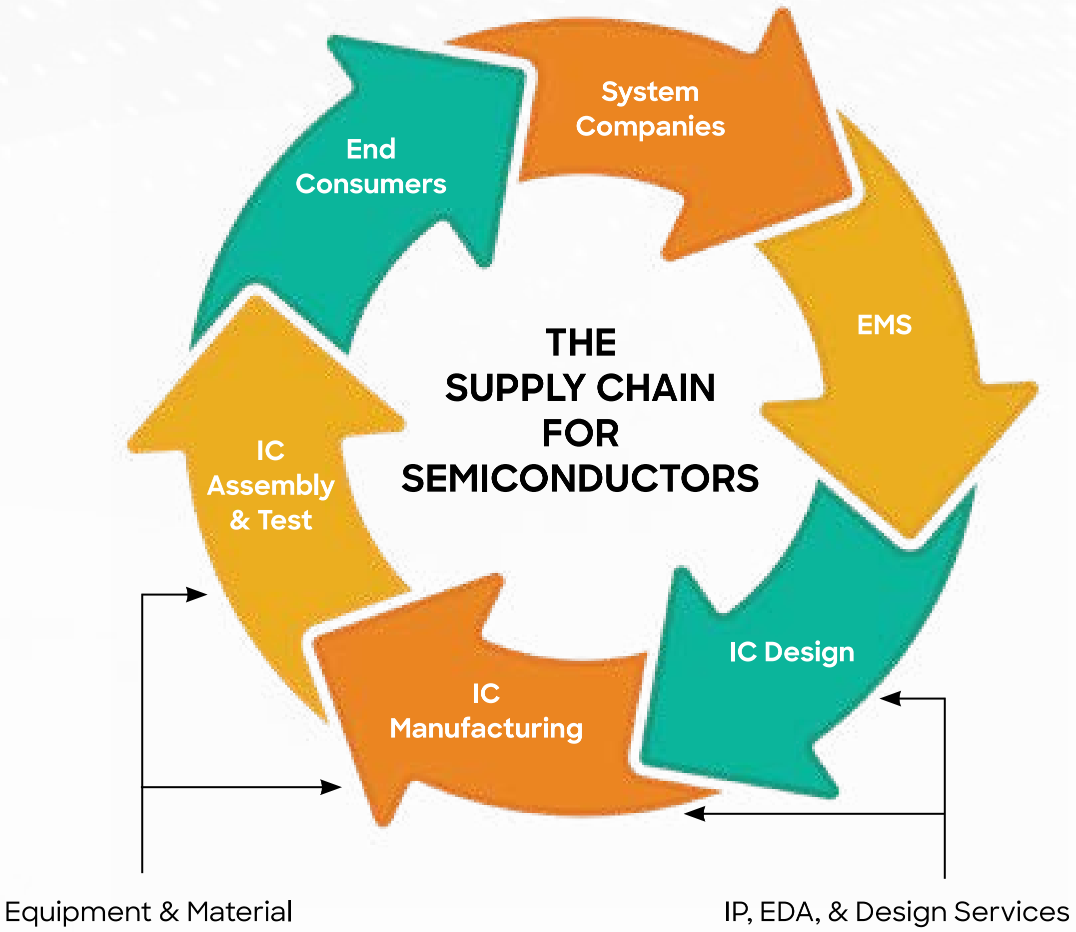
There are several steps involved in the semiconductor production process and value chain. The first step in the creation of an integrated circuit is to design it, including tailoring the design to perform a certain function. This process is usually carried out largely in software involving calculations.

The second step in the process is fabricating the initial design to convert it into a physical product, or "chip." This involves manipulating and applying various raw materials (starting with ultra-pure silicon) to transfer the circuit design into a physical embodiment.

The next step in the process is the assembly, packaging and testing of the completed chip. This involves cutting apart each individual integrated circuit on the wafer and packaging in a suitable manner according to the end application. All these steps require semiconductor manufacturing equipment, which is the capital equipment used by the other market segments to perform and automate their functions.

In terms of value-added for the various steps in the process, the design segment is dominant. According to a 2021 study by the Boston Consulting Group and the Semiconductor Industry Association, the total added value for integrated circuits is estimated at 53%. However, each sector in the semiconductor production process is necessary to achieve a high-quality product. Most companies in the market space have specialized in one of these market sectors and have developed in very different directions.





IC design

The subset of electronics engineering including the required logic and circuit design techniques

Steps in IC Design

- System Specification
- Architectural Design
- Functional Design and Logic Design
- Circuit Design
- Physical Design
- Physical Verification and Signoff
- Fabrication
- Packaging and Testing
- Chip

IC assembly & test

Assembly: The process of packaging the die to provide protection as well as an Interface that connects internal electrical signals to the system through pins.
Test: The process of trying dies to ensure they meet electrical specifications.

IC manufacturing

The process when electronic circuits are created on a wafer using photolithographic and chemical procedures.

The terms “fab” and “fabless” refer to different approaches in semiconductor manufacturing. A “fab” is short for “fabrication facility,” a manufacturing plant that produces semiconductor chips. In a fab operation, the company owns and operates its own manufacturing facility, which includes the equipment, materials and expertise needed to produce semiconductor chips. The manufacturing process is typically complex and requires a high level of expertise in areas such as lithography, etching and wafer processing.

A “fabless” company designs and markets semiconductor chips but outsources the manufacturing process to a fab. This allows fabless companies to focus on design and marketing components rather than invest in expensive manufacturing facilities.

Building and operating a fab requires a significant amount of capital investment, including the cost of equipment, materials and labor. Fabs also necessitate ongoing maintenance and upgrades to keep up with advances in semiconductor technology.

In contrast, fabless companies typically have lower capital requirements, as they do not need to invest in a manufacturing facility. Fabless companies have more flexibility in their manufacturing operations, as they can choose from a variety of fabs to produce their chips. This allows them to adapt to changes in demand and technology more easily, shifting production to different fabs as needed.

In a fab operation, the company is limited to producing chips in its own facility, which can make it more difficult to respond to changes in demand or to produce specialized chips for specific applications, yet it also has more control over the manufacturing process and can ensure that its designs are not copied or stolen. Semiconductor chip designs are often closely guarded intellectual property, as they can give a company a competitive advantage in the market. A fabless company must rely on a fab to maintain confidentiality and protect its intellectual property.

> **“The main difference between fab and fabless semiconductor operations is that fabs own and operate their own manufacturing facilities, while fabless companies outsource the manufacturing process to third-party fabs. Both approaches have their advantages and disadvantages, and the choice between fab and fabless operations will depend on a variety of factors, including the company’s financial resources, expertise and strategic goals.**

Product/component sectors

- Analog IC
- Microprocessors and memory
- Discrete
- FPGAs
- ASICs
- AI
- System-on-chip (SoC)
- Graphics processing units

Many types of semiconductor technology comprise the larger market, with the largest sector being analog, a type of semiconductor commonly used in vehicles, consumer goods and computers. Analog had the highest annual growth rate at 7.5%, reaching $89 billion in 2022 sales. Discrete semiconductors also saw an increased growth rate in 2022, largely due to the strong demand from the automotive sector and industrial end markets for applications in electric vehicles, industrial automation and energy transition. Nonmemory revenue grew 5.3% in 2022, but individual sector performance varied across the different device categories.

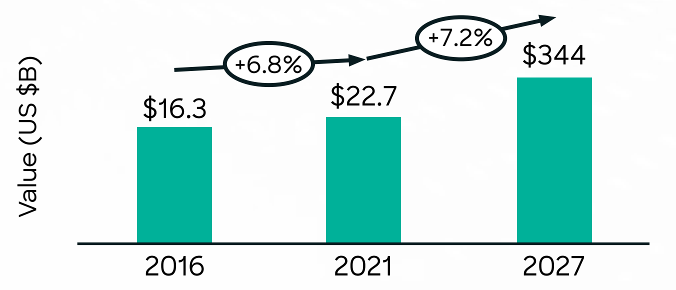
Memory chips are specialized chips that are used to store data, such as computer programs and user data. These chips come in different types, including DRAM, SRAM and flash memory. Memory chips typically have a feature size of around 10 to 50 nm and can contain billions of memory cells. Memory, which accounted for around 25% of semiconductor sales in 2022, was the worst-performing device category, experiencing a 10% revenue decrease. The memory market showed signs of a significant collapse in demand in 2022 as original equipment manufacturers (OEMs) depleted memory inventory they had been holding in anticipation of stronger demand. Most memory companies have announced capital expenditure (CAPEX) reductions for 2023, and some have cut wafer production to reduce inventory levels and try to bring the market back into balance.

Microcontrollers are small, low-power chips that contain a central processing unit (CPU), memory and input/output (I/O) interfaces. They are used in a wide range of embedded systems, such as sensors, motors and consumer electronics. Microcontrollers typically have a feature size of around 40 to 90 nm and can contain up to several hundred thousand transistors. In addition to their size and complexity, semiconductor chips also have different performance characteristics, such as power consumption, speed and reliability. These factors depend on the specific application and can be optimized through the design and manufacturing process.

Field-programmable gate arrays (FPGA) are programmable chips that can be reconfigured to perform different functions. They are used in a wide range of applications, such as telecommunications, data centers and aerospace. FPGAs typically have a feature size of around 7 to 28 nm and can contain millions to billions of transistors. The FPGA market is projected to grow from $8 billion in 2022 to $15.5 billion by 2027, with an expected CAGR of 14.2% during that period. The growth of this market is driven by increasing adoption of robotics and industry 4.0, rising demand for FPGAs in advanced driver assistance systems (ADAS) and increasing penetration of data centers across the globe.

Application-Specific Integrated Circuits (ASICs) are customized integrated circuit chips that are designed for a particular function. The future of the ASIC chip market shows opportunities in data processing, consumer electronics, telecommunication systems, industrial automation and other industries. The global ASIC chip market is expected to reach an estimated $34.4 billion by 2027, with a CAGR of 7.2% from 2021 to 2027. The major drivers for this market are increasing advancement in chip technology, demand for customizable ICs and usage in consumer electronic devices. Emerging trends include advanced 7-nm technology for ASIC fabrication and structured ASICs for 5G, AI, cloud and edge workloads and development of ultra-small, case size capacitors for portable electronic devices.

Trends and forecast for the Global ASIC chip market (US $B) (2016-2027)



Source: Lucintel

Top companies in ASIC chip market

- Advanced Micro Devices
- ON Semiconductor
- Intel Corporation
- Infineon Technologies AG
- Samsung Electronics

Opportunities for ASIC chip by product, technology, and end user industry

Product	Technology
Semi-based custom Programmable logic device Full custom	Data processing system Consumer electronics Telecommunication system Industrial Others

Artificial Intelligence training and inference tasks are largely handled in mega data centers run by major cloud providers. In recent years, the semiconductor industry has spawned the emergence of AI chips that can work in data centers and also edge devices as diverse as assisted driving vehicles and even portable MRI machines. The global artificial intelligence chip market size was estimated at $16.86 billion in 2022, and it is expected to reach $227.48 billion by 2032. AI memory devices alone will account for $60 billion in 2025, up from $20 billion in 2019, and processors will account for $68 billion in 2025, up from $22 billion in 2019. This includes semiconductors in systems that run AI functions, including memory and processing devices within those systems.

System-on-chips (SoCs) are highly integrated chips that contain multiple components, including a central processing unit (CPU), memory, graphics processing unit (GPU) and I/O interfaces, on a single piece of silicon. They are used in a wide range of applications, such as smartphones, tablets and other mobile devices, as well as in automotive and industrial systems. SoC chips typically have a feature size of around 5 to 10 nm and can contain billions of transistors.

GPUs are specialized chips that are designed to perform complex calculations related to computer graphics, such as rendering 3D images and videos. They are used in a wide range of applications, including gaming, virtual reality and machine learning. GPUs typically have a feature size of around 7 to 16 nm and can contain tens of billions of transistors.

Market sectors

- Automotive
- Consumer electronics (e.g. computers, phones, etc.)
- Data processing (cloud computing)
- Energy transition
- Industrial automation
- Networking & communications (IoT)
- Government (defense & military)
- Artificial intelligence

2021 DEMAND BY END-USE

End-Use Category	Computer	Communication	Automotive	Consumer	Industrial	Government
Annual Growth	23.1	24.0	37.9	28.9	26.6	26.4
Total Value ($B)	**175.0**	**170.6**	**69.1**	**68.4**	**66.9**	**5.8**

In 2021, the semiconductor industry saw record sales of $555.9 billion across all market sectors and record unit shipments of $1.15 trillion. The automotive sector of the semiconductor market is predicted to reach $200 billion annually by the mid-2030's and surpass $250 billion by 2040. As of 2023, wireless communication – long seen as the industry's most important revenue driver – has slipped into second place behind the automotive sector. Currently, IoT, cloud computing and artificial intelligence each rank third, fourth and fifth in terms of importance.

Currently, around 70% of all memory, logic and processor chips are produced for the computer market, and the market sector for computers is valued at $175 billion. Industrial automation is growing in importance with the emergence of artificial intelligence and robotics technology, and that market sector is currently valued at $66.9 billion. While government applications of semiconductor technology only occupy 1% of the total market demand share, there are still important advancements being made in that sector, which is valued at $5.8 billion.

Market size

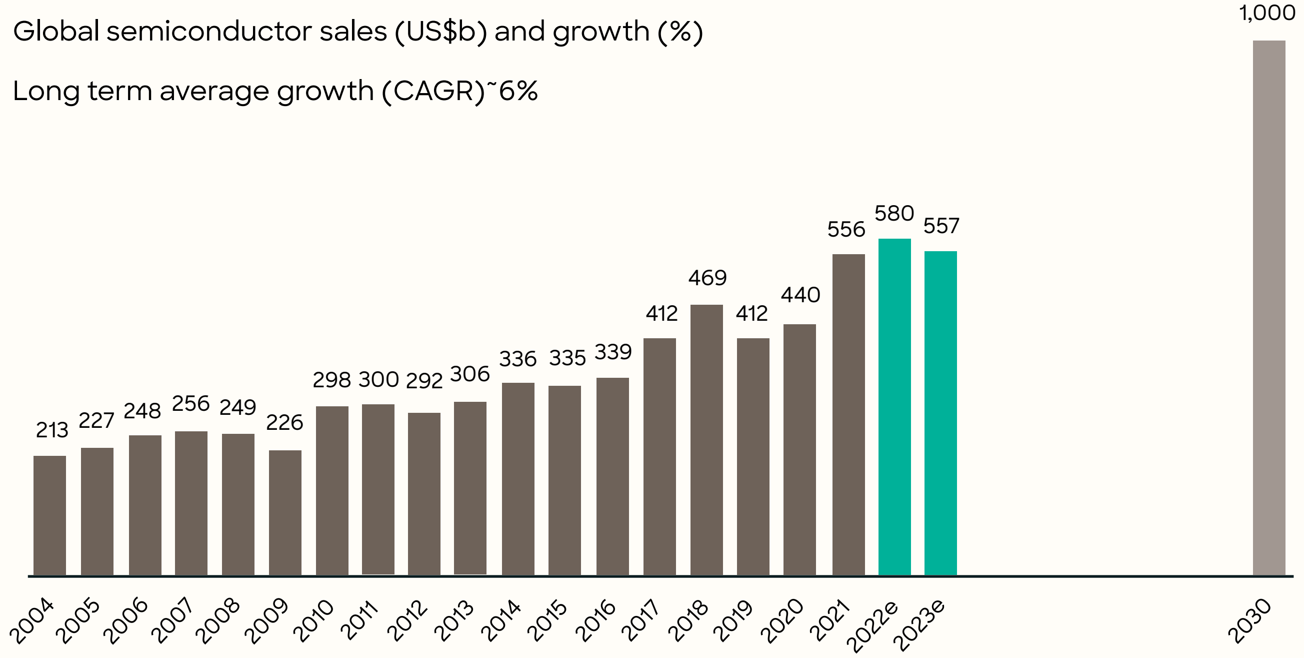
The US semiconductor industry ranked second to the US pharmaceutical and biotechnology industries for the rate of R&D spending as a percentage of sales.
Global semiconductor revenue increased 1.1% in 2022 to $601.7 billion, up from $595 billion in 2021. According to a report by McKinsey & Company, the global semiconductor market is expected to grow at a CAGR of 6-8% from 2025 to 2035, reaching a total revenue of $1.5 trillion by 2035. This growth will be driven by demand from various industries such as automotive, healthcare and telecommunications.
The Semiconductor Industry Association (SIA) announced that global semiconductor industry sales totaled $573.5 billion in 2022, the highest-ever annual total and an increase of 3.2% compared to 2021. However, sales slowed during the second half of the year, with fourth-quarter sales of $130.2 billion being 14.7% less than the total from the fourth quarter of 2021, and 7.7% lower than the total from third quarter of 2022. Global sales for the month of December 2022 were $43.4 billion, a decrease of 4.4% compared to November 2022.
According to a report by IC Insights, semiconductor capital expenditures are projected to increase from $96.4 billion in 2021 to $102.3 billion in 2022, reflecting a 6.1% increase. This growth is expected to continue in the coming years, driven by increased investments in new fab construction and equipment upgrades.

On a regional basis, American sales saw the biggest increase (16.0%) in 2022. China remained the largest individual market for semiconductors, with sales totaling $180.3 billion in 2022, a decrease of 6.3% compared to 2021. Annual sales also increased in 2022 in Europe (12.7%) and Japan (10.0%). The Asia-Pacific region is expected to continue to dominate the global semiconductor market, driven by the growing demand for electronic devices and the increasing adoption of emerging technologies in countries such as China, South Korea and Taiwan. According to a report by Research and Markets, the Asia-Pacific semiconductor market is projected to grow at a CAGR of 7.1% from 2021 to 2026.

Adoption of emerging technologies, such as 5G, AI and autonomous vehicles, is expected to drive the growth of the semiconductor industry in the coming years. According to a report by MarketsandMarkets, the AI chipset market is expected to grow at a CAGR of 40.1% from 2021 to 2026, while the autonomous vehicle semiconductor market is projected to reach $8.4 billion by 2025.

> **“ Overall, the semiconductor industry is expected to continue its growth trajectory in the coming years, driven by various factors, such as increasing demand for electronic devices, the adoption of emerging technologies and geographical growth. However, the industry also faces challenges, including supply chain disruptions and increasing competition, which may impact its growth trajectory.**

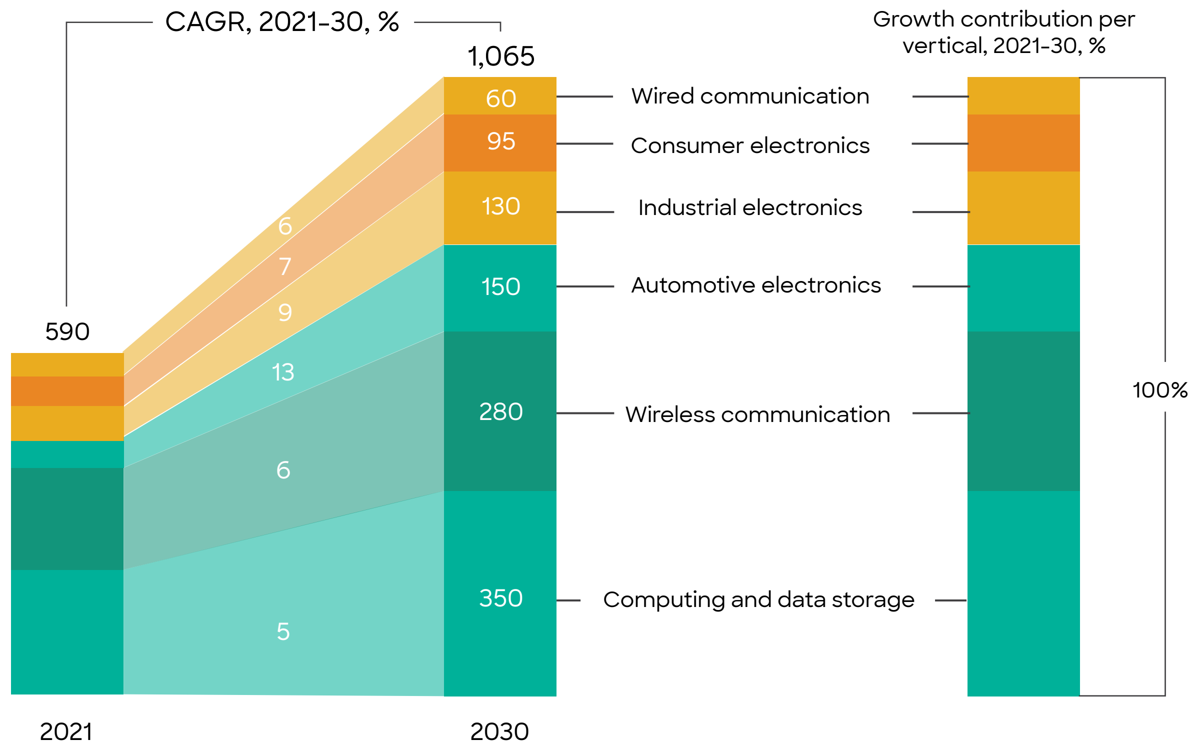
Figure 1: Semiconductor market to become a trillion-dollar market by 2030



Source: WSTS Blue Book data and WSTS forecast, 29 November 2022

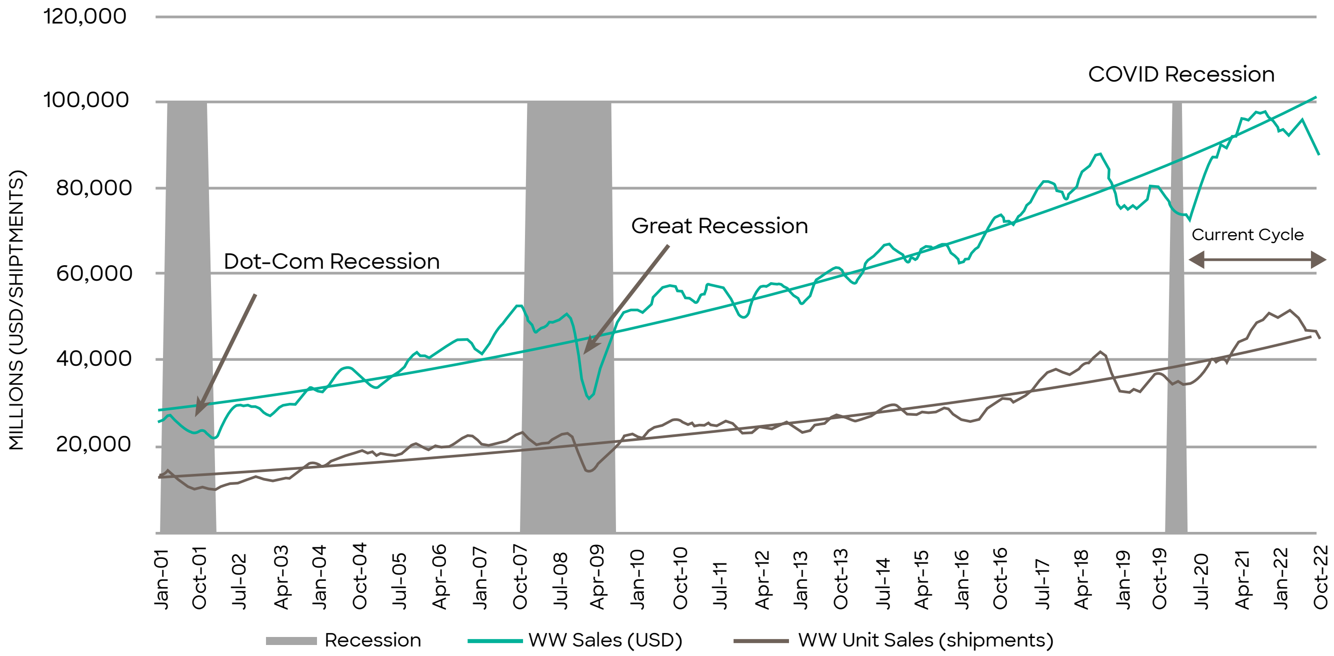
The overall growth in the global semiconductor market is driven by the automotive, data storage and wireless industries.

Global semiconductor market value by vertical, indicative, $ billion



Note: Figures are approximate.

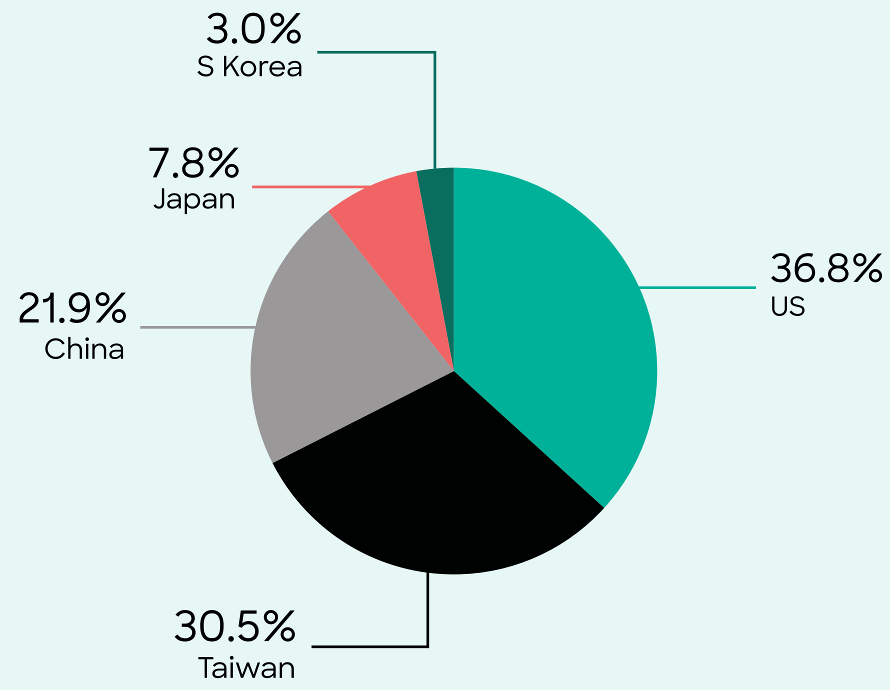
McKinsey & Company



Major players

- Memory chips
- Logic and microprocessors
- Analog and mixed-signal
- Other semiconductor products

The US and Taiwan dominate global chip market value, with China coming in third. However, if weighted by revenue or profit, China would have a much lower share. This data is based on the current market value of all chipmakers with capitalization of $1 billion or more. Samsung is excluded because less than 1/3 of its revenue comes from semiconductors. If Samsung were included but weighted according to chip revenue, South Korea's weighting would be around 7% and other countries lowered accordingly.



Source: Bloomberg Opinion

Table 1. Top 10 semiconductor vendors by revenue, Worldwide,2022 (Millions of USD)

2022 Rank	2021 Rank	Vendor	2022 Revenue	2022 Market Share	2021 Revenue	2021-2022 Growth (%)
1	1	Samsung Electronics	65,585	10.9	73,197	-10.4
2	2	Intel	58,373	9.7	72,536	-19.5
3	3	SK Hynix	36,229	6.0	37,192	-2.6
4	4	Qualcomm	34,748	5.8	27,093	28.3
5	5	Micron Technologies	27,566	4.6	28,624	-37
6	6	Broadcom	23,811	4.0	18,793	26.7
7	7	AMD	23,285	3.9	16,299	42.9
8	8	Texas Instruments	18,812	3.1	17,272	8.9
9	9	MediaTek	18,233	3.0	17,617	3.5
10	10	Apple	17,551	2.9	14,580	20.4
		Others (outside top 10)	277,501	46.1	271,749	2.1
		Total Market	**601,694**	**100.0**	**594,952**	**1.1**

For a further breakdown of the top five companies based on their innovation activities, see the *Innovation Matrix from Discovery*.

The semiconductor industry is a diverse and complex market with many sub-sectors and applications. The memory chip sector includes DRAM, SRAM and NAND flash memory used in various applications such as computers, mobile devices and data centers.

Leading companies by revenue and market share:

- **Samsung Electronics:** $58.7 billion (43.9% market share)
- **SK Hynix:** $27.1 billion (20.3% market share)
- **Micron Technology:** $21.4 billion (16.0% market share)
- **Western Digital:** $7.2 billion (5.4% market share)
- **Kioxia (formerly Toshiba Memory):** $5.8 billion (4.3% market share)

The **logic and microprocessors sector** includes CPUs, GPUs and other types of processors used in computing, mobile devices, gaming consoles and other applications.

Leading companies by revenue and market share:

- Intel: $71.9 billion (16.4% market share)
- Samsung Electronics: $56.4 billion (12.9% market share)
- Qualcomm: $20.4 billion (4.7% market share)
- AMD: $9.8 billion (2.2% market share)
- MediaTek: $8.7 billion (2.0% market share)

The **analog and mixed-signal sector** includes various types of analog and mixed-signal ICs used in a wide range of applications such as audio, video, sensors and power management.

Leading companies by revenue and market share:

- Texas Instruments: $14.3 billion (19.1% market share)
- Analog Devices: $6.2 billion (8.3% market share)
- STMicroelectronics: $5.5 billion (7.4% market share)
- Infineon Technologies: $4.9 billion (6.5% market share)
- NXP Semiconductors: $4.8 billion (6.4% market share)

The **optoelectronics and sensors sector** includes various types of optoelectronic and sensor ICs used in applications such as automotive, consumer electronics and industrial automation.

Leading companies by revenue and market share:

- Broadcom: $6.8 billion (21.7% market share)
- STMicroelectronics: $2.2 billion (6.9% market share)
- AMS AG: $1.7 billion (5.5% market share)
- On Semiconductor: $1.3 billion (4.1% market share)

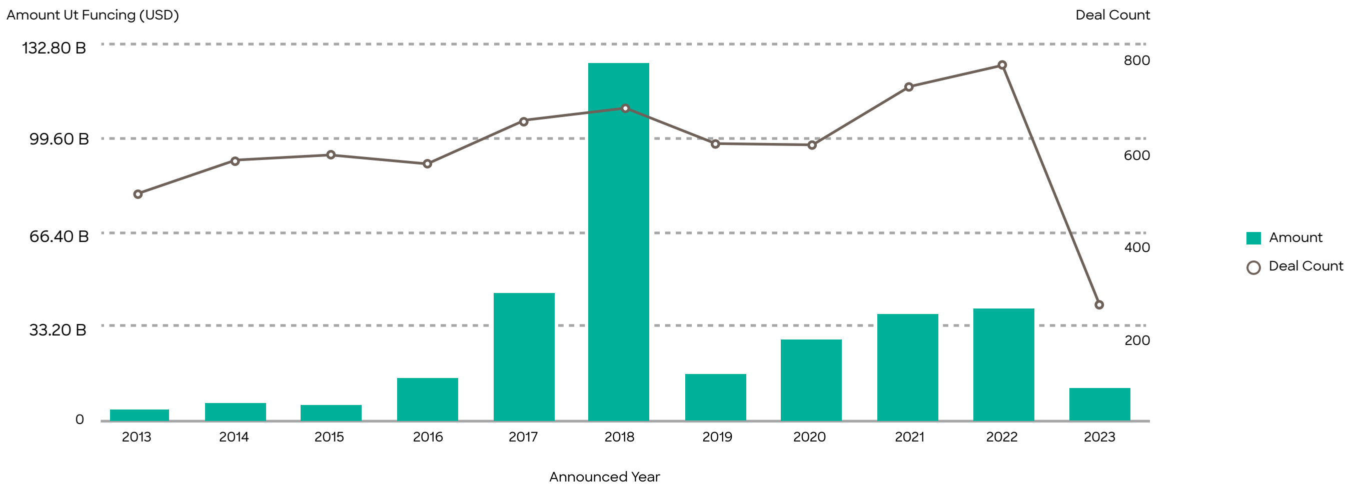
The **other semiconductor products sector** includes various other types of semiconductor products such as discrete components, power devices, and RF ICs.

Leading companies by revenue and market share:

- Infineon Technologies: $4.4 billion (14.8% market share)
- NXP Semiconductors: $2.4 billion (8.2% market share)
- ON Semiconductor: $1.7 billion (5.9% market share)
- Renesas Electronics: $1.6 billion (5.5% market share)
- Vishay Intertechnology: $1.2 billion (4.0% market share)

Deal activity

After the large market correction to adjust for the mismatch in supply and demand in 2018, the venture community was slow to return to the semiconductor industry. The steady ramp up has been predominantly in China. The Chips Act may provide for greater opportunities in the US, but for now, China is seeing the greatest venture investment trend.



Source: discovery.parsena.com

The merger and acquisition sector has also been active over the last 10 years, with more than $8K deals yielding hundreds of billions of dollars. The most active acquiring companies include some of the top innovators in the industry, such as Intel, Hitachi, Samsung and Toshiba.

Forecast

- The Metaverse
- Digital Health
- Mobility
- Sustainability
- Artificial Intelligence (AI) Chips

The Metaverse
Based on a survey of more than 300 semiconductor industry executives, two-thirds (67%) believe that semiconductors are the most critical technology to the development of the Metaverse, and 44% of executives expect to allocate more than 20% of their semiconductor production budget to the Metaverse by 2024.

Digital health
Fitness trackers and smart watches also represent a major growth opportunity for the industry, as these devices will benefit most from improved connectivity enabled by semiconductors.

Sustainability
Most executives (90%) believe that sustainability initiatives will have a positive impact on profitability, creating more sustainable consumer products and playing a large role in the semiconductor value chain within the next five years.

Mobility
The mobility sector has suffered the effects of constrained semiconductor supply, with The mobility sector has suffered the effects of constrained semiconductor supply, with new vehicles containing anywhere from 1,000-3,500 chips. 93% of executives believe that car manufacturers should partner with semiconductor and technology businesses to develop next-generation mobility technologies, including improved electric vehicles, autonomous vehicles, drone delivery and air taxis.

Artificial intelligence chips
Artificial intelligence chips are a relatively new development in the semiconductor industry that can function in data centers and also devices, including assisted driving vehicles, portable MRI machines and advanced security systems. Many of these applications require large amounts of power and high-bandwidth volatile memory, which can be accomplished through a few different methods that have been recently developed.

Some new technologies place the memory closer to the computation core by enabling processing parallelism with dedicated memory cells for each processing core, and some move early stages of data computation into the memory in a technique called processing in memory (PIM). Another new approach is using new memory technologies that allow easy back-end silicon integration or volatile performance.

Recent disruptions to the global semiconductor supply chain significantly impacted industries that rely heavily on chips to manufacture their goods. These disruptions, including the COVID-19 pandemic, highlighted the need to strengthen the domestic chip industry by expanding manufacturing capacity and reinforcing the need for innovation in the industry.

CHIPS Act

- Transitioning and scaling pathfinding research
- Research infrastructure
- Development infrastructure
- Collaborative development
- Workforce development
- Industry advancement

On August 9, 2022, Congress enacted the bipartisan Creating Helpful Incentives to Produce Semiconductors (CHIPS) and Science Act of 2022, which provided $52 billion in critical semiconductor manufacturing incentives and research investments designed to strengthen the US economy, national security, supply chain resiliency and technology leadership. The CHIPS Act also provides an investment tax credit for semiconductor manufacturing and semiconductor equipment manufacturing.

The CHIPS Act is expected to impact several key areas of the semiconductor R&D ecosystem in a positive way. The CHIPS Act supports pre-competitive research into future technologies that are 5-15 years away from volume production. Under this act, there will be a National Semiconductor Technology Center (NSTC) established, which will serve as a public-private consortium engaging with government, industry and universities to innovate across all aspects of semiconductor technology.

The CHIPS Act is also expected to provide additional funding to upgrade or expand access to existing research and development tools and equipment. The National Advanced Packaging Manufacturing Program (NAPMP) is a federal R&D program designed to strengthen advanced Assembly, Test and Packaging (ATP) capabilities. The CHIPS Act aims to bring together companies in the semiconductor industry for full stack and collaborative innovation to accelerate development of key technologies, tools, industry standards and methodologies.

Three Manufacturing USA Institutes will be established in partnership with government, industry and academia to focus on research in several areas, including automation of the semiconductor industry and development of ATP capabilities. There is also projected growth in the number of programs designed to increase the size and skill development of the US workforce in semiconductor R&D. $2 billion from the CHIPS Act is designated for the CHIPS Defense Fund, which will supplement investments in university-based prototyping and workforce training.

The impact of the US CHIPS Act on different industries will depend on a variety of factors, including the specific applications of semiconductor chips in those industries, the extent to which those chips are currently manufactured domestically or overseas and the availability of funding and resources to support research and development.

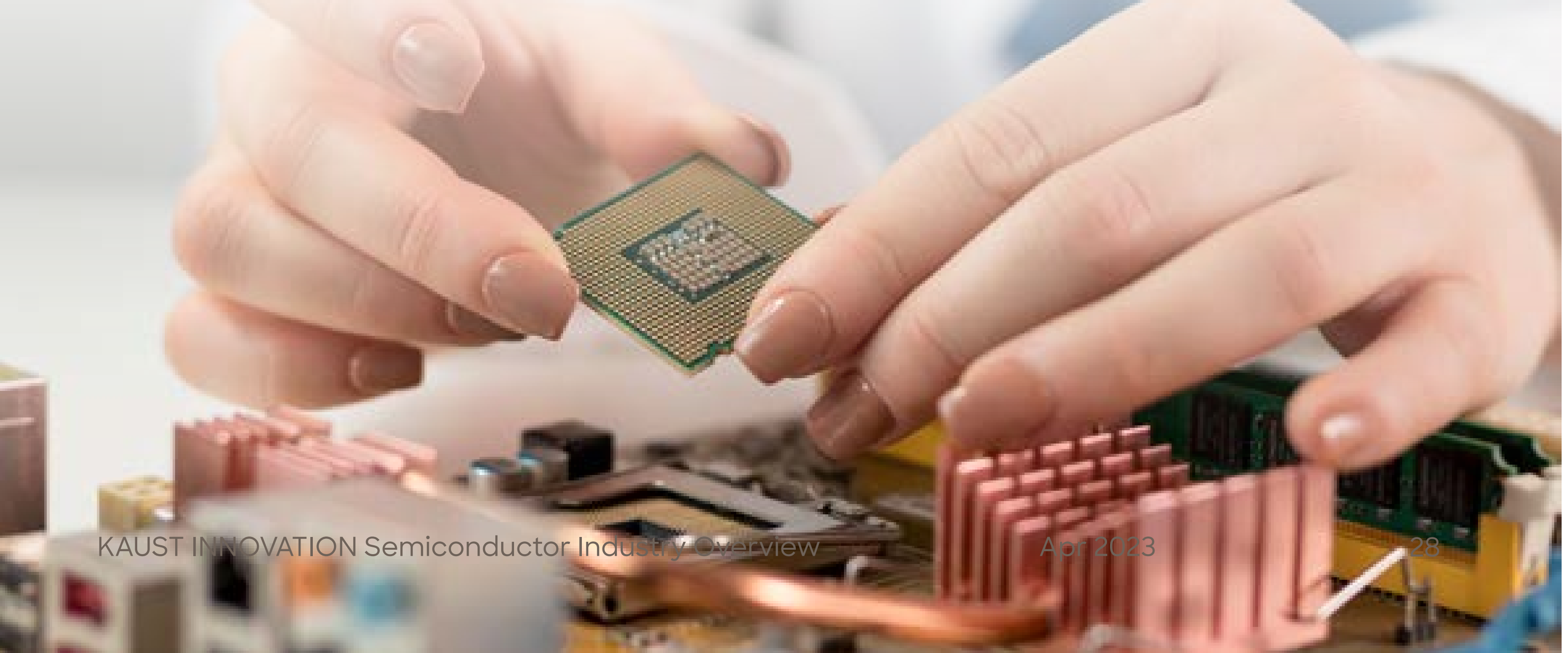
The consumer electronics industry, which includes products such as smartphones, laptops and gaming consoles, relies heavily on semiconductor chips. The US Chips Act could encourage domestic chip manufacturing and research into advanced chip technologies, which could help to increase the supply of chips and reduce dependence on overseas manufacturers. This could lead to more stable prices and availability of chips for consumer electronics manufacturers, which could in turn benefit consumers.

The automotive industry also relies heavily on semiconductor chips, particularly for Advanced Driver Assistance Systems (ADAS) and other safety features. The shortage of chips has led to production slowdowns and disruptions in the automotive industry. The US Chips Act could encourage domestic manufacturing of chips for automotive applications, reducing the risk of future shortages and supply chain disruptions.

Aerospace and defense industries use semiconductor chips in a wide range of applications, such as guidance and control systems for missiles and spacecraft, as well as communication and surveillance systems. The US Chips Act could support research and development in advanced chip technologies that are specifically tailored to the needs of these industries, which could help to improve performance and reliability in critical applications.

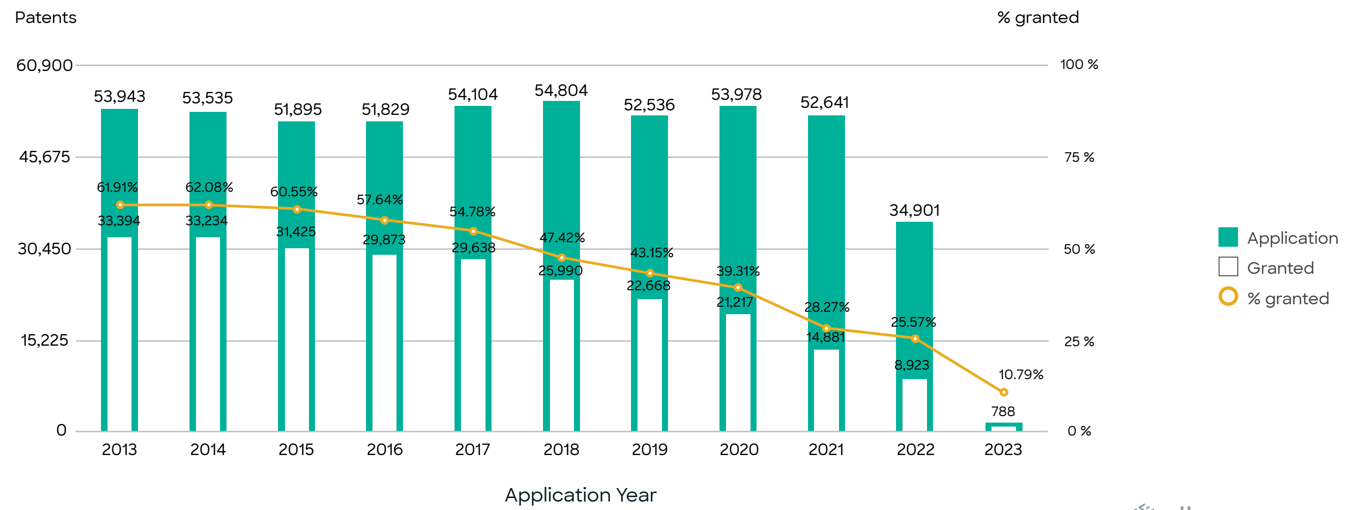
Data centers, which are used to store and process large amounts of data for businesses and organizations, rely heavily on semiconductor chips for processing power and memory. The US Chips Act aims to support research and development in advanced chip technologies for data center applications, improving energy efficiency and reducing costs.

> **“ The US Chips Act is likely to have a positive impact on the semiconductor industry and industries that rely on semiconductor chips. By supporting research and development and incentivizing domestic manufacturing, the act could improve the availability and reliability of chips, as well as drive innovation in advanced chip technologies. However, it will take time to see the full effects of the act on these industries, as research and development in semiconductor technology is a long-term process.**



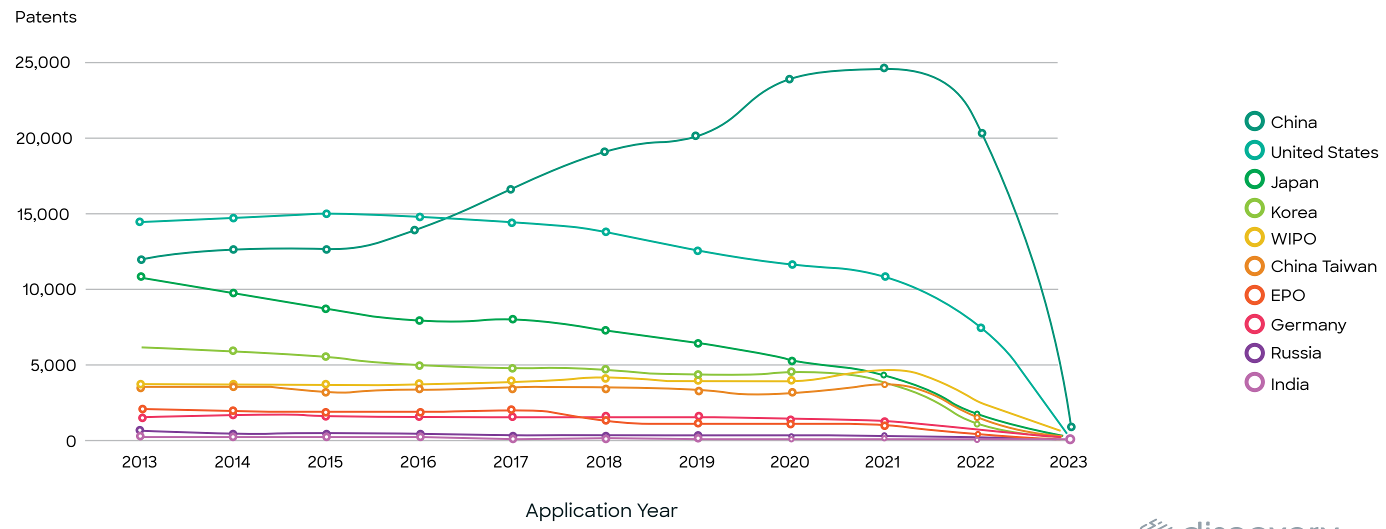
Patent research

Because semiconductors are foundational to many innovations, search results for patent activity can vary greatly depending on the parameters used. For example, one search for all patent activity containing semiconductor as a key word identified $80K patents issued in 2020, while another that focused more specifically on semiconductor technology identified just over $21K. For purposes of this analysis, the later search criteria will be used.



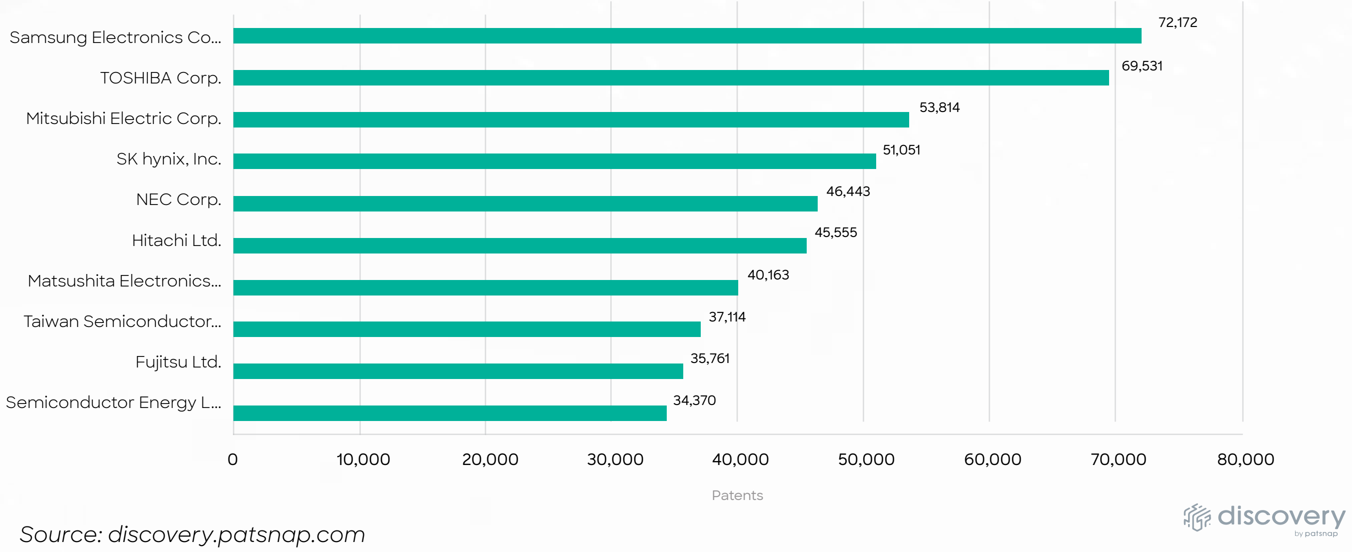
Source: discovery.patsnap.com

According to PatSnap, the global patent and innovation database, patent activity is shifting to Asia. In the last 5 years, China has expanded its investments in patents as well as manufacturing, and that trend is likely to continue.

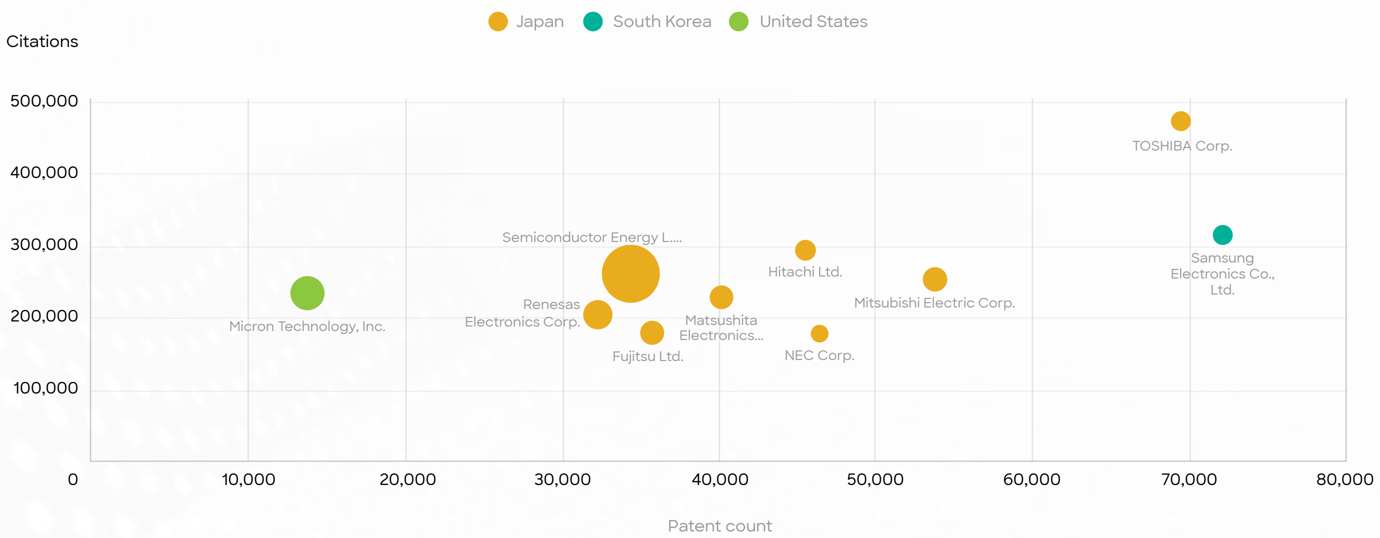


Source: discovery.patsnap.com

The most prolific assignees have been and continue to be Asian companies, dominated by Japan and Korea in the past, though China is increasing in activity. The patents from these central players tend to be highly relevant, as exemplified by their high citation rates.



Source: discovery.patsnap.com



Source: discovery.patsnap.com

The companies with the fastest growing number of filings in the last five years are primarily from Asia and already have large portfolios, showing a significant continued investment trend. Note that in the image below, Kioxia is the renamed Toshiba Memory Corp.

Taiwan Semiconductor Manufacturing Co., Ltd.
Taiwan Province, China
Patent: 15,857

Samsung Electronics Co., Ltd.
South Korea
Patent: 10,669

Semiconductor Energy Laboratory Co., Ltd.
Kanagawa-ken, Japan
Patent: 5,655

KIOXIA Corp.
Tokyo-to, Japan
Patent: 4,815

ChangXin Memory Technologies, Inc.
Anhui Sheng, China
Patent: 4,182

Mitsubishi Electric Corp.
Tokyo-to, Japan
Patent: 4,077

SK hynix, Inc.
South Korea
Patent: 2,911

Sony Semiconductor Solutions Corp.
Fukushima-ken, Japan
Patent: 2,727

Fuji Electric Co., Ltd.
Tokyo-to, Japan
Patent: 2,653

Applied Materials, Inc.
California, United States
Patent: 2,560

Universities have also been very prolific, with MIT as the only US university in the top 10.

University of Electronic Science & Technology of China
Sichuan Sheng, China
Patent: 1,597

Tsinghua University
Beijing Shi, China
Patent: 1,321

Massachusetts Institute of Technology
Massachusetts, United States
Patent: 1,168

Tohoku University
Miyagi-ken, Japan
Patent: 1,117

Korea Advanced Institute of Science & Technology
South Korea
Patent: 865

Institute of Semiconductors of Chinese Academy of Sciences
Beijing Shi, China
Patent: 824

Fudan University
Shanghai Shi, China
Patent: 788

Zhejiang University
Zhejiang Sheng, China
Patent: 737

University of Tokyo
Tokyo-to, Japan
Patent: 720

Peking University
Beijing Shi, China
Patent: 611

PatSnap patent research

In the past five years, there have been many patent applications filed in the semiconductor sector in countries around the world. As semiconductors are a key technology that underlies many different industries, including consumer electronics, automotive, aerospace and telecommunications, among others, there is keen interest in developing new semiconductor technologies and applications and protecting those through patents.

According to data from the World Intellectual Property Organization (WIPO), approximately 55,000 patent applications were filed in the field of semiconductor technology in 2020 alone. This represents a significant increase from previous years and is likely due, in part, to the growing demand for semiconductor chips in a wide range of industries, as well as the increasing focus on research and development in advanced chip technologies.

Patent activity in the last 20 years for the semiconductor sector has been dominated by filings in the US (where market share still leads). The US Patent and Trademark Office (USPTO) grants patents for semiconductor inventions that are deemed to be novel, non-obvious and useful. According to data from the USPTO, there were approximately 32,000 patent applications filed in the field of semiconductor technology in 2020, with roughly 22,000 patents granted.

Some key areas of semiconductor technology with high patent activity include:

- Advanced chip architectures, such as 3D stacking and heterogeneous integration
- Emerging technologies, such as quantum computing and neuromorphic computing
- AI and machine learning applications, such as optimizing chip design and manufacturing processes
- Power management and efficiency, particularly for applications such as data centers and electric vehicles
- Sensor technologies, such as those for autonomous vehicles and smart homes

> “ The semiconductor sector is a highly competitive and dynamic field, and patents are a key tool for companies and individuals to protect their intellectual property and gain a competitive edge in the market.

Patent filings

The top international patent codes related to the semiconductor industry based on the number of global filings as of 2021:

- **H01L29/66** - Semiconductor devices specially adapted for rectifying, amplifying, oscillating or switching and having at least one potential jump barrier or surface barrier
- **H01L21/00** - Processes or apparatus specially adapted for the manufacture or treatment of semiconductor or solid-state devices or components
- **H01L27/146** - Devices consisting of a plurality of semiconductor or other solid-state components formed in or on a common substrate
- **H01L31/00** - Semiconductor devices sensitive to infra-red radiation, light, electromagnetic radiation of shorter wavelength or corpuscular radiation and specially adapted either for the conversion of the energy of such radiation into electrical energy or for the control of electrical energy by such radiation
- **H01L21/28** - Manufacture of electrodes on semiconductor bodies using processes or apparatus not provided for in groups H01L21/20-H01L21/268158
- **H01L23/00** - Details of semiconductor or other solid-state devices
- **H01L33/00** - Semiconductor devices with at least one potential-jump barrier or surface barrier specially adapted for light emission
- **H01L27/08** - Devices consisting of a plurality of semiconductor or other solid-state components formed in or on a common substrate including semiconductor components specially adapted for rectifying, oscillating, amplifying or switching and having at least one potential-jump barrier or surface barrier
- **H01L25/00** - Processes specially adapted for the manufacture or treatment of semiconductors or other solid-state devices or components
- **H01L27/12** - Devices consisting of a plurality of semiconductor or other solid-state components formed in or on a common substrate, including semiconductor components specially adapted for voltage generation

Top companies

Here are the top five companies filing semiconductor-related patents in the United States in the past three years, organized by company and year, based on data from the USPTO:

Samsung Electronics

- 2020: 9,415 patent applications filed
- 2019: 8,607 patent applications filed
- 2018: 8,491 patent applications filed

Intel Corporation

- 2020: 3,031 patent applications filed
- 2019: 2,728 patent applications filed
- 2018: 2,735 patent applications filed

TSMC (Taiwan Semiconductor Manufacturing Company)

- 2020: 2,862 patent applications filed
- 2019: 2,307 patent applications filed
- 2018: 2,185 patent applications filed

Micron Technology

- 2020: 1,900 patent applications filed
- 2019: 1,802 patent applications filed
- 2018: 1,521 patent applications filed

Qualcomm Incorporated

- 2020: 1,629 patent applications filed
- 2019: 1,344 patent applications filed
- 2018: 1,325 patent applications filed

It is worth noting that these numbers only reflect the number of patent applications filed, and do not necessarily reflect the quality or importance of the patents themselves. Additionally, there are many other companies and individuals filing semiconductor-related patents in the United States and around the world, and the competitive landscape of the industry is constantly evolving.

Top universities

The top five universities that filed semiconductor-related patents in the United States over the past three years, organized by year and the number of patent applications filed, based on data from the USPTO:

University of California System

- 2020: 614 patent applications filed
- 2019: 652 patent applications filed
- 2018: 668 patent applications filed

Massachusetts Institute of Technology (MIT)

- 2020: 345 patent applications filed
- 2019: 308 patent applications filed
- 2018: 320 patent applications filed

Stanford University

- 2020: 326 patent applications filed
- 2019: 273 patent applications filed
- 2018: 301 patent applications filed

University of Texas System

- 2020: 255 patent applications filed
- 2019: 229 patent applications filed
- 2018: 206 patent applications filed

Georgia Tech Research Corporation

- 2020: 244 patent applications filed
- 2019: 225 patent applications filed
- 2018: 229 patent applications filed

It is worth noting that these numbers only reflect the number of patent applications filed, and do not necessarily reflect the quality or importance of the patents themselves. Additionally, there are many other universities and research institutions filing semiconductor-related patents in the United States and around the world, and the competitive landscape of the industry is constantly evolving.

Granted patents

The number of semiconductor-related patents granted in the United States over the past three years, as well as the top ten owners of granted patents for each year, based on data from the USPTO:

2020

Total number of semiconductor-related patents granted: 22,049

Top ten owners of granted patents:

- System specification
- Architectural design
- Functional design and logic design

2019

Total number of semiconductor-related patents granted: 21,670

Top ten owners of granted patents:

- Samsung Electronics Co Ltd: 6,469
- International Business Machines Corp (IBM): 2,651
- Taiwan Semiconductor Manufacturing Co (TSMC): 1,942
- Qualcomm Inc: 1,270
- Intel Corp: 1,185
- Micron Technology Inc: 1,050
- SK Hynix Inc: 797
- United Microelectronics Corp (UMC): 598
- LG Electronics Inc: 512
- Texas Instruments Inc: 444

2018

Total number of semiconductor-related patents granted: 20,751

Top ten owners of granted patents:

- Samsung Electronics Co Ltd: 6,024
- International Business Machines Corp (IBM): 2,774
- Taiwan Semiconductor Manufacturing Co (TSMC): 1,762
- Qualcomm Inc: 1,276
- Intel Corp: 1,062
- Micron Technology Inc: 949
- SK Hynix Inc: 768
- United Microelectronics Corp (UMC): 578
- LG Electronics Inc: 477
- Texas Instruments Inc: 444

It is worth noting that the number of patents granted does not necessarily reflect the quality or importance of the patents themselves, and there may be many other companies and individuals who are also granted valuable semiconductor-related patents.

Venture capital investment trends

Highlights of trends in venture capital investment in the semiconductor-related sectors over the past five years, based on data from various sources, including PitchBook, Crunchbase and Semiconductor Engineering:

2020

Total amount of venture capital investment in semiconductor-related sectors: $9.9 billion

Top recipients of funding:

- SambaNova Systems: $676 million
- Cerebras Systems: $433 million
- Fungible: $200 million
- Lightmatter: $80 million
- Nuvia: $73 million

2019

Total amount of venture capital investment in semiconductor-related sectors: $6.5 billion

Top recipients of funding:

- SambaNova Systems: $150 million
- Syntiant: $35 million
- Lightelligence: $31 million
- Lightmatter: $28 million
- Untether AI: $20 million

2018

Total amount of venture capital investment in semiconductor-related sectors: $5.3 billion

Top recipients of funding:

- Cerebras Systems: $112 million
- Graphcore: $107 million
- SiFive: $65 million
- Lightelligence: $33 million
- Untether AI: $20 million

2017

Total amount of venture capital investment in semiconductor-related sectors: $3.6 billion

Top recipients of funding:

- Graphcore: $60 million
- SiFive: $50.6 million
- Lightelligence: $18 million
- Mythic: $8.8 million
- Flex Logix: $7.4 million

2016

Total amount of venture capital investment in semiconductor-related sectors: $3.5 billion

Top recipients of funding:

- Mythic: $8.2 million
- Ayar Labs: $5.5 million
- SiFive: $5.1 million
- Rockley Photonics: $3.2 million
- Mojo Vision: $2.6 million

It is worth noting that these numbers only reflect publicly announced funding rounds and do not include undisclosed or unreported investments, and that the industry's competitive landscape is constantly evolving.

Establishing a new integrated circuit (IC) manufacturing plant in the United States involves significant costs, timelines, challenges and logistics. Here are some key considerations:

Estimated Costs

Building a new IC manufacturing plant can cost billions, with estimates ranging from $10 billion to $20 billion. The costs include land acquisition, facility construction, equipment procurement, labor and other expenses. Additionally, ongoing operational costs, such as materials, energy and maintenance, must be considered.

Timelines

The timeline for building a new IC manufacturing plant can range from three to five years or more, depending on various factors such as site selection, facility design and construction, equipment installation and regulatory approvals. The semiconductor industry is also subject to rapid technological advancements and evolving market demands, which can impact timelines and require ongoing investments in R&D.

Challenges

The semiconductor industry is highly competitive, and establishing a new IC manufacturing plant requires significant expertise and experience in semiconductor design, manufacturing and supply chain management. Furthermore, the industry is subject to various challenges, such as intellectual property protection, geopolitical risks and supply chain disruptions, which can impact the success and profitability of a new plant.

Logistics

Establishing a new IC manufacturing plant requires significant logistical planning, including site selection, transportation infrastructure and supply chain management. Also, regulatory approvals and compliance with environmental and safety regulations are critical considerations requiring coordination with government agencies and local communities.

In summary, establishing a new IC manufacturing plant in the United States involves significant costs, timelines, challenges and logistics. The success of a new plant depends on various factors, such as market demand, technological advancements, regulatory compliance and supply chain management, among others.

Enforcement through Litigation

Recent high-profile patent infringement cases involving intellectual property in the semiconductor industry:

Apple vs. Qualcomm: This legal battle involved a dispute over patents related to wireless communications technologies used in Apple's iPhones. Apple accused Qualcomm of abusing its market dominance to charge excessive royalties for its patents, while Qualcomm claimed that Apple was using its technology without paying for it. The case was settled in 2019, with Apple agreeing to pay Qualcomm $4.5 billion in royalties and license fees.

VLSI Technology vs. Intel: In 2021, VLSI Technology, a company owned by IP investment firm Fortress Investment Group, won a $2.18 billion patent infringement lawsuit against Intel. The case involved two patents related to computer processor technology. VLSI claimed that Intel had infringed on its patents and that it was owed damages for lost profits.

Samsung vs. Tela Innovations: In 2020, Samsung was ordered to pay $400 million in damages to Tela Innovations for infringing on its patents related to semiconductor manufacturing processes. Tela Innovations claimed that Samsung had used its technology without permission, resulting in lost profits and market share.

GlobalFoundries vs. TSMC: In 2019, GlobalFoundries, a US-based semiconductor manufacturer, filed multiple lawsuits against TSMC, a Taiwan-based chipmaker, for allegedly infringing on 16 of its patents related to semiconductor manufacturing processes. GlobalFoundries sought to ban the import and sale of products containing TSMC's allegedly infringing chips. The case is still ongoing.

Infineon vs. Fairchild: In 2016, German semiconductor company Infineon won a patent infringement lawsuit against US-based Fairchild Semiconductor. The case involved a patent related to power transistor technology. Infineon claimed that Fairchild had copied its technology, resulting in lost profits and market share. The court awarded Infineon $12 million in damages.

It's important to note that other patent infringement cases in the semiconductor industry may have occurred in the past five years. Additionally, the outcome of these cases may vary based on a variety of factors, including the jurisdiction and the specific patents involved.

Additional market research

Semiconductor demand drivers

2023 | https://www.semiconductors.org/wp-content/uploads/2022/11/SIA_State-of-Industry-Report_2022.pdf

Over the next decade, further innovation in semiconductors will enable a host of transformative technologies, including artificial intelligence (AI), autonomous electric vehicles, and the internet of things (IoT). Indeed, long-term growth drivers for semiconductor demand are firmly in place. The relationship between semiconductors and the markets they serve is truly symbiotic, as innovations in semiconductors themselves help to spur further market demand and open up new markets entirely. For example, successive generations of cellular technology were made possible by advances in semiconductors themselves, leading to 5G.

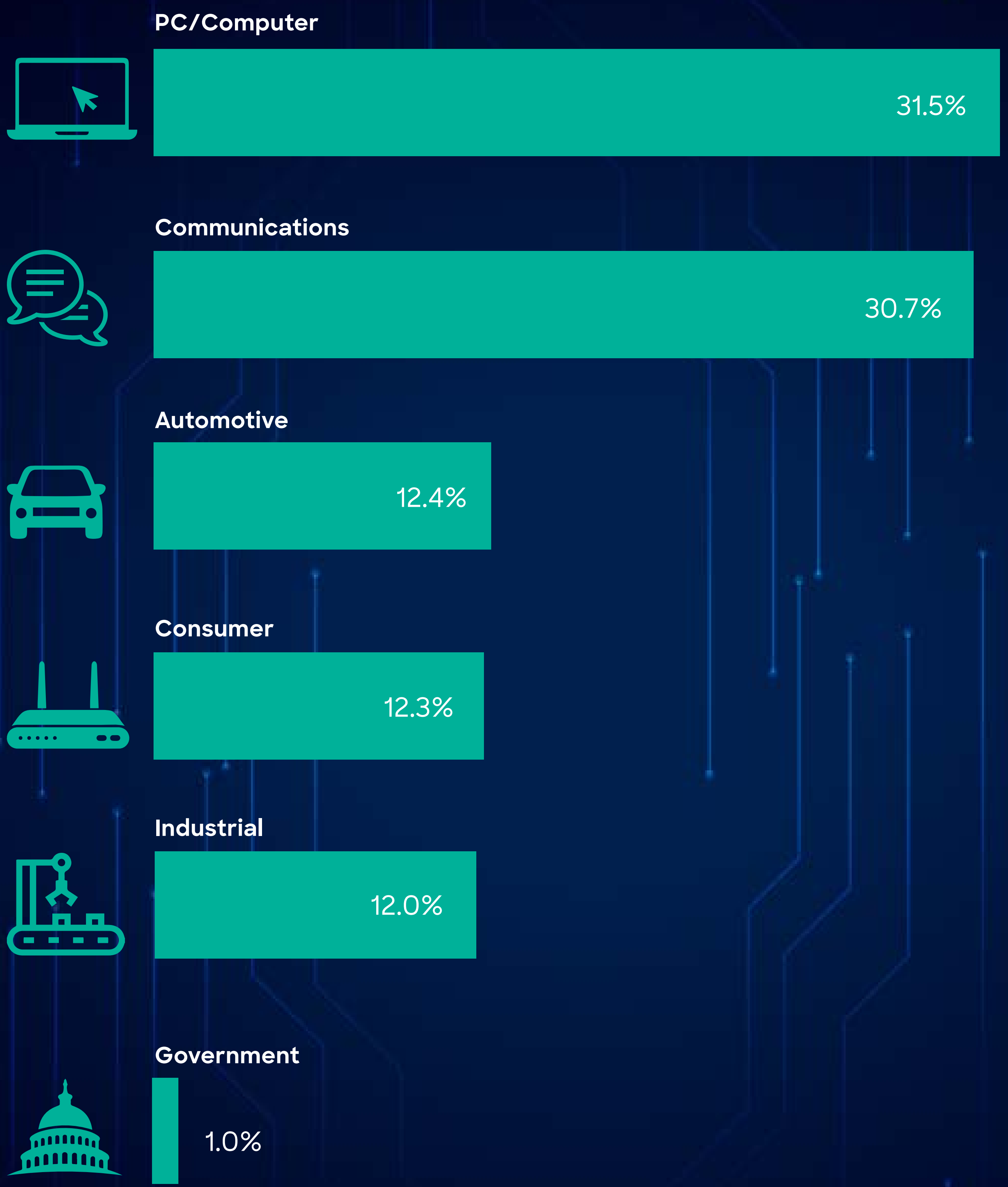
End-use drivers reflect shifts from COVID-19 demand shock

While demand drivers in the short-term experienced unexpected shifts brought on by societal changes due to the pandemic, in many ways, these shifts resulted in an overall increase in demand, as society has recognized and leaned on the semiconductor-enabled technologies more than ever.

2021 DEMAND BY END-USE

End-Use Category	Computer	Communication	Automotive	Consumer	Industrial	Government
Annual Growth	23.1	24.0	37.9	28.9	26.6	26.4
Total Value ($B)	**175.0**	**170.6**	**69.1**	**68.4**	**66.9**	**5.8**

2021 TOTAL GLOBAL SEMICONDUCTOR DEMAND SHARE BY END USE



2023 semiconductor industry outlook: signposts for the future

2023 | https://www2.deloitte.com/us/en/pages/technology-media-andtelecommunications/articles/semiconductor-industry-outlook.html

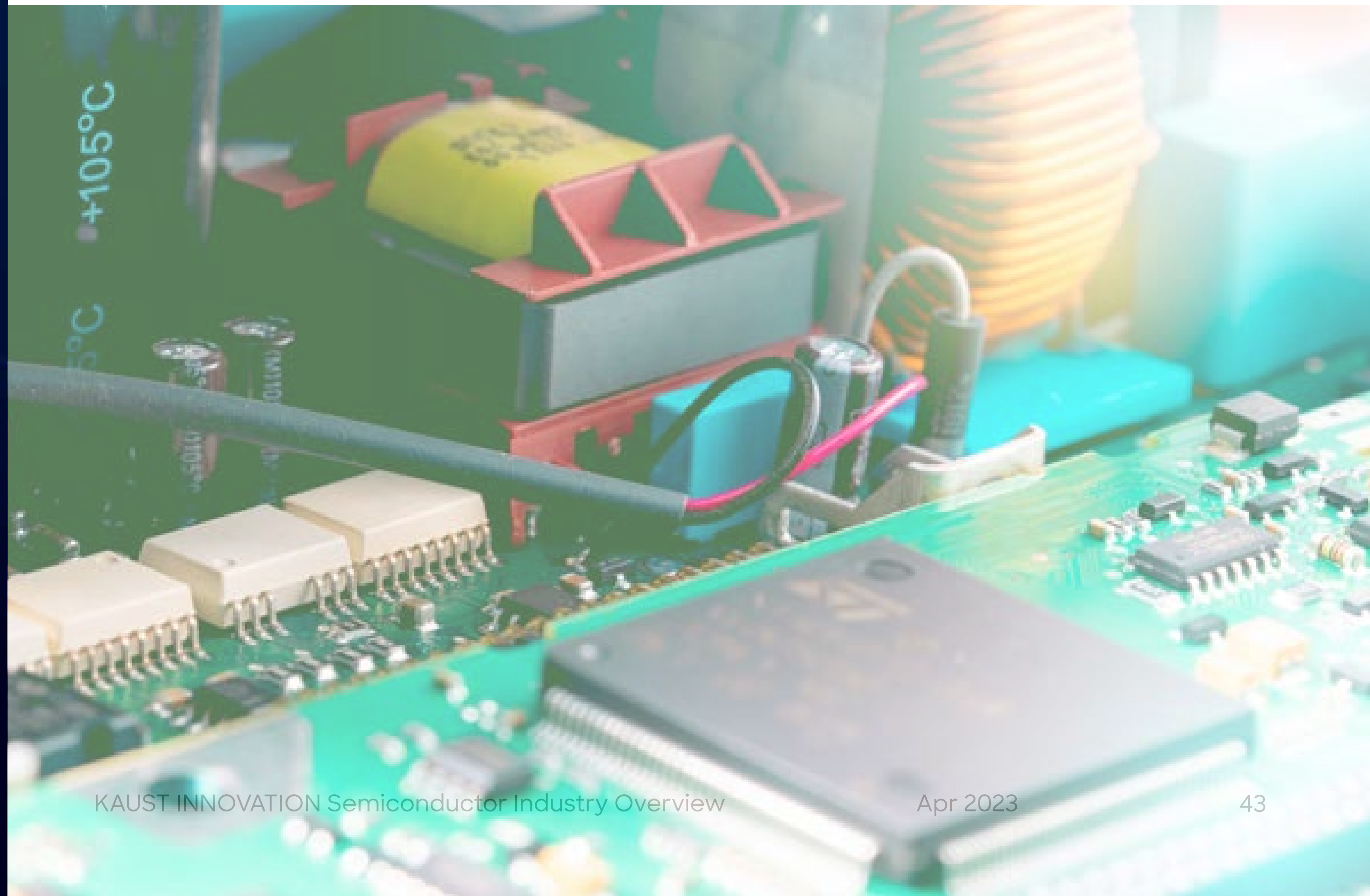
For 2023, we recommend that semiconductor industry executives consider these signposts:

- Macroeconomic indicators: Reduction in inflation, hard or soft economic landing, central banks slowing or stopping increasing interest rates, signs of renewed consumer demand for smartphones and PCs, and a rise in the market capitalization of the sector.
- Inventory levels for end customers and distributors, plus manufacturing cutbacks: Inventories are almost certain to be reduced in H1 2023, but will we see orders begin to flow in the second half, and will we see reductions in wafer starts being reversed? Memory prices can often be leading indicators for the chip cycle. Prices bottoming or even rising will be an important bellwether.

Capex plans are being reduced or deferred—a key signpost may be companies publicly raising guidance.

Regulatory/political issues can change quickly: US attitudes on semi-technologies and China could change (we are still waiting to see how China responds), the war in Ukraine could shift toward diplomatic solutions or could escalate, and environmental regulators could announce new rules.

As the war for talent continues (plus high inflation, low unemployment and the need to ramp up new plants in the United States and Europe as well as Southeast Asia), will chipmakers see costs rise much faster than usual?



Value chain

Sep 2021 | https://www.forbes.com/sites/georgecalhoun/2021/09/30/the-semiconductor-scoreboard-part-1-the-basic-value-chain-and-the-value-added/?sh=1ccbfe89738a

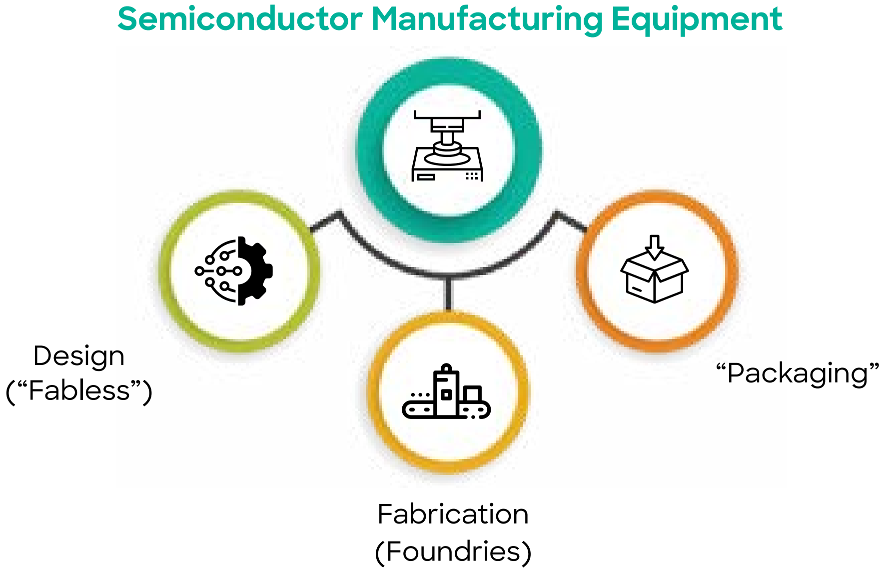
Design: The first step in the creation of an integrated circuit, as with almost every manufactured product, is to design it – in this case, to design a circuit that will perform a certain function, usually involving a calculation of some sort; this process is carried out largely "in software" (all the other functions are much more about hardware).

Fabrication (Foundries): The fabrication process converts the design into a physical product – a "chip," which involves manipulating and applying various raw materials (starting with ultra-pure silicon) to transfer the circuit design into its physical embodiment.

Assembly/Packaging/Test: The fab process usually results in a "wafer" that has been printed with several hundred individual integrated circuits, which must be cut apart, or diced, and each IC packaged in a suitable manner. As this step is often overlooked in rough industry surveys (for reasons that will become apparent in later installments), it is worth quoting the Wikipedia definition at length:

"A semiconductor package is a metal, plastic, glass or ceramic casing containing one or more discrete semiconductor devices or integrated circuits. Individual components are fabricated on semiconductor wafers (commonly silicon) before being diced into die, tested and packaged. The package provides a means for connecting it to the external environment, such as a printed circuit board, via leads such as lands, balls or pins; and protection against threats such as mechanical impact, chemical contamination and light exposure. Additionally, it helps dissipate heat produced by the device, with or without the aid of a heat spreader."

Semiconductor Manufacturing Equipment: Often overlooked as an ancillary segment, this category refers to the capital equipment used by the other segments to perform and automate their functions. Again, due to recent developments, the critical importance of this segment is increasingly recognized. (For example, it was the embargo on the use of equipment in this category that truly closed the door on Huawei's access to US semiconductor technology.)



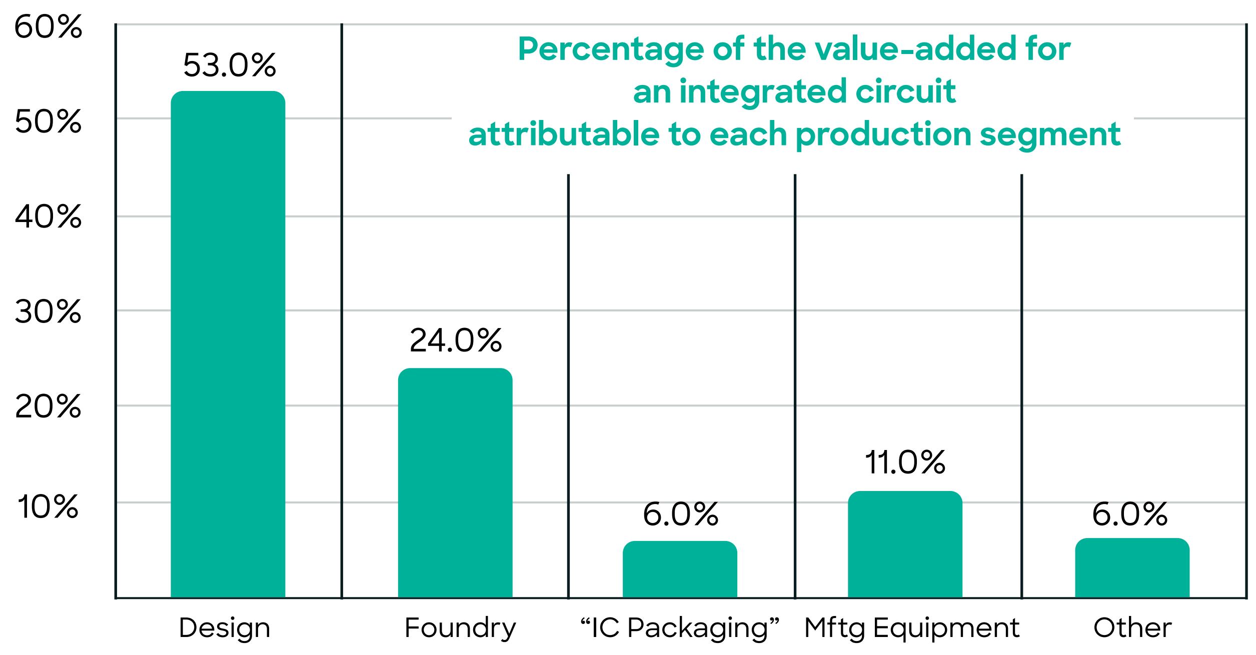
The Basic Categories of the IC Production Value-Chain

Value-added metrics

The first metric is the percentage of end-product's value that is added by each segment. In some ways, this is the most primordial, definitive and also determinative of the results we shall see when we apply many of the other metrics to follow. In other words, if the microprocessor in your smartphone cost Apple $50, the question is: What portion of that $50 can be attributed to, or was captured by, the company that provided the design of the chip? How much is attributable to the foundry that fabricated the chip? How much to the company that "packaged" it? And how much to the company that built the amazing and complex hardware that enabled the designer, foundry and packager to carry out their functions? Which companies add the most value in the semiconductor industry?

A study by the Boston Consulting Group and Semiconductor Industry Association, published in April, 2021, offers an answer: Value-Added by Segment of the Semiconductor Industry

Source: https://www.forbes.com/sites/georgecalhoun/2021/10/11/the-us-still-dominates-in-semiconductors-china-is-vulnerable-pt-2/?sh=3de2d82b70f7



Source: BCG/SIA Report, 2021

Value-added by segment of the semiconductor industry

Here then is the first important stylized fact about semiconductors: **the design segment is dominant in terms of real value-creation.**

This basic fact will help explain many of the other facts that will come to light, as we apply other metrics to these categories. It will also help us understand the larger economic and geopolitical characteristics of the industry.

Semiconductor chips: applications and impact of shortage

Jan 2023 | BCC Research

- The global market for semiconductor chips is estimated to increase from $585.4 billion in 2022 to $882.1 billion by 2027, at a CAGR of 8.5% from 2022 through 2027.
- The Asia Pacific semiconductor chips market is estimated to increase from $409.5 billion in 2022 to $624.3 billion by 2027, at a CAGR of 8.8% from 2022 through 2027.
- The North American semiconductor chips market is estimated to increase from $126.9 billion in 2022 to $196.1 billion by 2027, at a CAGR of 9.1% from 2022 through 2027.

Summary figure:

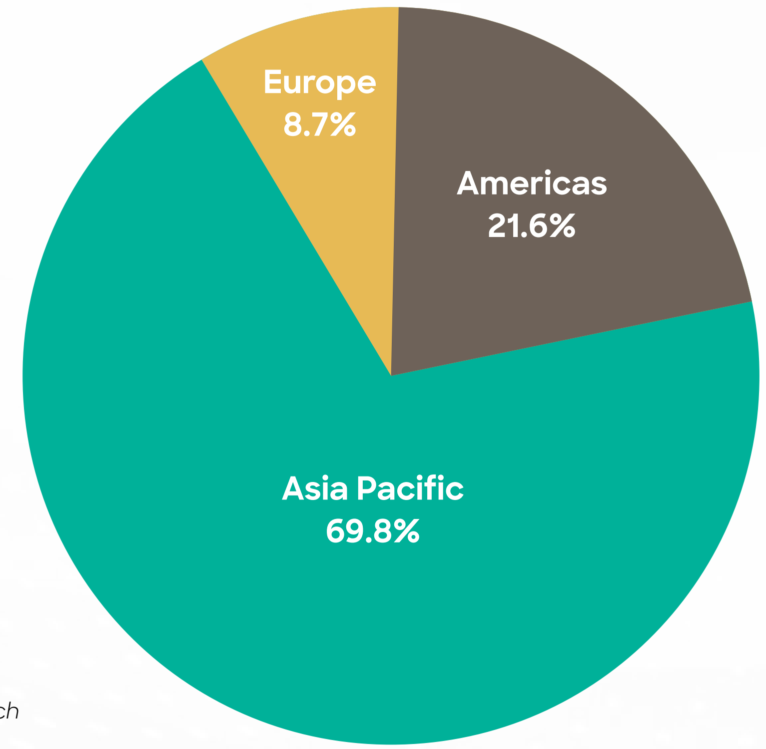
Stages in semiconductor value chain

Source: BCC Research

Summary figure:

Global market shares of semiconductor chips, by region, 2021

(%)



Source: BCC Research

Market restraints

Lack of trained/skilled individuals and scientists

A persistent labor shortage could dampen projected growth in the semiconductor industry as US policymakers seek to boost funding for domestic manufacturing. For example, Taiwanese chip design company, MediaTek, is looking to expand its presence in the US However, plans are hampered by a shortage of skilled workers.

The global semiconductor chip industry currently occupies a market of over $500 billion, but the shortage of skilled workers remains a problem for semiconductor companies. Expanding semiconductor manufacturing facilities outside Taiwan, China and South Korea exacerbates the ongoing skill shortage. The higher demand for software skills to program and integrate chips into fast-growing markets will exacerbate the shortage.

According to a whitepaper by Eightfold.ai, the US alone will need around 70,000 to 90,000 additional employees by 2025 to meet the most critical workforce needs in new fab facilities. The research reveals that many existing semiconductor manufacturing roles and skills rapidly lose prevalence in the modern workforce.

One of the industry's biggest shortages is the lack of scientists in the field. In China, the demand for scientists continues to increase. The average salary in China's semiconductor industry increased by 9% in 2021 amidst the ongoing China/US tech rivalry. Peking University and Shenzhen Technology University have set up a semiconductor school to train chip engineers and technicians to address this shortfall. As initiatives strengthen domestic semiconductor education pathways and career prospects, new incentives for trusted international partners to pool talent will help combat the labor shortages, offering a more direct solution in addition to public and private investment.

Global political, economic and financial crises

Numerous systemic political, economic and financial crises in recent years have severely impacted global business, including the semiconductor industry and markets. Since 2018, several of the world's major economies have faced political and commercial issues. These conflicts have resulted in the imposition of tariffs, non-tariff trade barriers and sanctions, including the imposition of export controls and sanctions against specific countries and companies.

The semiconductor industry and related areas have been particularly hard hit by these trade barriers and other measures. Prolonged or increasing use of trade barriers and similar measures might hinder the growth of the semiconductor chips market, inducing market turbulence, which frequently results in decreases in electronic device sales, from which semiconductor companies earn revenue through goods and services.

Additionally, increases in the use of export control restrictions and sanctions to target specific countries and entities, any expansion of the extraterritorial jurisdiction of export control laws or any complete or partial prohibition of semiconductor product sales to certain entities could affect not only a company's ability to continue supplying products to its customers, but also the demand for products.

Table 10

Global Market for Semiconductor Chips, by End Use, Through 2027 ($ Billions)

End Use	2021	2022	2023	2027	CAGR% 2022-2027
Wireless communications	167.8	183.2	200.3	292.1	9.8
Computing	158.1	168.9	180.6	241.5	7.4
Consumer electronics	72.8	79.5	87.2	128.1	10.0
Automotive	60.1	65.0	70.5	98.7	8.7
Industrial	62.7	66.8	71.3	94.1	7.1
Others	20.6	22.0	23.1	27.6	4.6
Total	542.1	585.4	633.0	882.1	8.5

NOTE: Other end users include networking equipment and government

Source: BCC Research

Market ranking of market players by operating model ranking of semiconductor Integrated device manufacturers

Table 22

Top five semiconductor integrated device manufacturers, 2021

Rank	Company	Headquarters	Revenue ($ Millions)	Net Income/ Loss ($ Millions)
1	Intel	US	79,024	19,868
2	Samsung	South Korea	235,102	26,042
3	SK Hynix	South Korea	36,154	8,086
4	Micron Technology	US	30,758	8,687
5	Texas Instruments	US	18,344	7,769

Source: BCC Research

Today, Intel is the world's leading integrated device manufacturer (IDM), with $79 billion in revenue by 2021. Intel is a leading manufacturer of microprocessors, offering chipsets, networking and memory chips for PCs and mobile devices. In 2021, Intel's R&D spending was about $1 billion and net income was about $19.8 billion. As of the end of 2021, the company's total assets were $168.4 billion, of which, $63.2 billion was property, plant and equipment.

As the industry has been very cyclical, IDMs often have the excess manufacturing capacity to sell. Today, most IDMs provide chip manufacturing or foundry capacity to companies that do not have fabrication facilities. For instance, Samsung is one of the leading foundry service providers. Although Samsung surpassed Intel as the world's largest chipmaker by revenue in 2021, it is still behind in terms of chip production.

Key IDMs are transitioning toward the fabless model. Over the next couple of years, the shift of IDM products to foundries will be zooming ahead in high gear. IDMs will spend billions of dollars on silicon foundry services in the coming years. For instance, in March 2021, Intel entered into a $90 billion foundry business with its IDM 2.0 strategy focused on reinforcing its manufacturing capabilities. Intel will not only retain its fabs but will also invest $20 billion into two new fabs and launch a new Intel Foundry Services (IFS) company. This new company will offer Intel manufacturing to external customers.

Ranking of semiconductor foundry/fab companies

Table 23

Top Five Semiconductor Foundry/Fab Companies, 2021

Rank	Company	Headquarters	Revenue ($ Millions)	Net Income/ Loss ($ Millions)
1	TSMC	Taiwan	56,824.5	21,526.1
2	Samsung	South Korea	24,551.8	1,490
3	UMC	Taiwan	7,678.8	1,823.3
4	GlobalFoundries	US	6,585.1	(253.9)
5	SMIC	China	5,443.1	1,775.2

*Samsung foundry revenue is not disclosed; hence considered Samsung DS division revenue which covers foundry business.
Source: BCC Research

The foundry industry is highly concentrated. Leading company, TSMC, maintained its position in the global semiconductor foundry industry with over 55% market share in 2021. After TSMC, Samsung and UMC rank in the top two and three, with around 14% and 7% of the market share, respectively. 80% of the major foundries are located in Asian countries like Taiwan, South Korea and China. Pure-play foundries accounted for 85% of total foundry revenue in 2021.

TSMC's growth was mainly driven by the continued expansion of 5G and high-performance computing (HPC)-related applications. TSMC is, by far, the world's largest chip manufacturer and most valuable company, with a market cap of over $600 billion, supplying chips to the likes of Apple, Intel, MediaTek, Nvidia, Qualcomm, Nvidia, AMD and Marvell.

TSMC and Samsung are the only companies capable of producing the latest 5nm chips that power the iPhone. Samsung's main customers, Qualcomm, Nvidia and Tesla, trusted the company to produce 8nm and 14nm chips. Samsung has won new orders for the Snapdragon 888 series from Qualcomm and Ampere and GeForce chips from Nvidia. At the end of 2021, Samsung increased its wafer prices by up to 20. TSMC announced a smaller price increase.

UMC, the world's third-largest foundry, is one step ahead, aiming to produce 3nm chips by 2022, offering cutting-edge foundry technology. Following TSMC and Samsung, UMC raised its wafer prices by 14% in 2021. At the country level, Taiwanese and South Korean companies hold the largest share of the global semiconductor foundry market.

Growth in the foundry industry surged during the US/China trade war, disrupting sales of imported chips to Chinese companies. Because of this trade war, the US blacklisted 60 Chinese companies and SMIC.

Intel's entry into the fab industry in March 2021 sent a major shock to the foundry industry. It will take Intel about three years to gain market share in the face of fierce competition from TSMC and Samsung Foundry. In connection with the escalating geopolitical cold war between the US and China, Intel could be among the top three as its first customer may be a US company.

Ranking of semiconductor fabless companies

Table 24

Top Five Semiconductor Fabless Manufacturers, 2021

Rank	Company	Headquarters	Revenue ($ Millions)	Net Income/ Loss ($ Millions)
1	Apple	US	3,65,817	94,680
2	Qualcomm	US	33,566	9,043
3	Broadcom	US	27,450	2,724
4	Nvidia	US	26,914	9,752
5	MediaTek	Taiwan	17,805	4,037

Source: BCC Research

Due to increasing difficulty in the semiconductor process and due to growing investment costs, the number of fabless semiconductor companies is growing. The foundry business is responsible for consignment semiconductor production for such fabless companies. Many IDMs have drifted toward the fab-lite and fabless model during the last few years. This has been possible because of pure-play foundries' increased capacity and capabilities. The growth of pure-play foundries, in turn, mainly results from the rise of new fabless semiconductor manufacturers that focus on chip design.

Today, almost 70% of all memory, logic and processor chips are produced for the PC market. The emergence of independent pure-play foundries, including TSMC and UMC, radically changed the picture. Fabless firms that never had wafer manufacturing capability have emerged as important semiconductor firms (Qualcomm, Broadcomm, Apple and Nvidia).

Strategic analysis
Companies use strategic analysis based on results from studies performed on company profiles of key players in the global market for semiconductor chips.

Product launches and developments
Some companies operating in the semiconductor chips market focus on new products, new features for existing products and new technology to enhance business offerings and maintain presence in the continually evolving semiconductor chips market.

Agreements, collaborations and partnerships
Many companies enter into distribution and R&D agreements, collaborations and partnerships to benefit from the market reach of major market players and product offerings to compete with other players, or to expand product reach to a wider geography or a new type of customer.

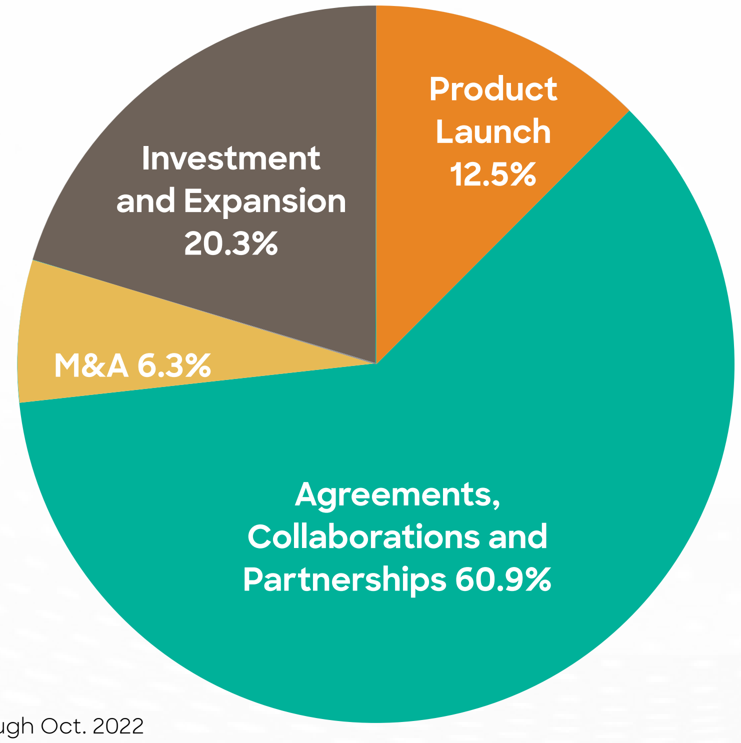
Mergers and acquisitions (M&A) and expansion
M&As are inorganic strategies adopted by companies that include acquiring other companies, or merely a product line, to increase the breadth and depth of the acquirer's product portfolios or customer bases. Companies use M&A to include some or all business segment(s) of acquired companies in the product/services portfolio. Companies use business expansion to grow global presence.

Investments and funding
Companies often turn to outside investors or third-party funding to expand R&D activities, enter new business areas or expand their global presence. Investments in semiconductor chips offer a better and more interactive advertising experience for brands and advertisers.

Figure 20

Strategies implemented by semiconductor chips manufacturers, 2021-2022*

(%)



Note: *Developments through Oct. 2022

Source: BCC Research

Table 25

Product launches, April 2021-Sept. 2022

Date	Strategy	Description
Sept. 2022	Product launch	DB HiTek developed a 0.13 micrometer BCDMOS 120V process platform mainly used for automotive and industrial power semiconductors. BCDMOS was developed to meet the increasing demand in the sector, worldwide, amid the rapid growth in the global electric vehicle and self-driving car market.
Sept. 2022	Product launch	Qualcomm launched the first integrated automotive super-compute class system-on-chip (SoC), Snapdragon Ride Flex system-on-chip super-compute family. This product is to be used by carmakers to integrate sensing and other functions for digital cockpits, automated driving, autonomous driving, networking and computer vision.
July 2022	Product launch	Qualcomm unveiled a new suite of premium wearable platforms, Snapdragon W5+ Gen 1 and Snapdragon W5 Gen 1. Based on hybrid architecture, this purpose-built platform is comprised of a 4nm-based SoC and 22nm-based highly integrated always-on co-processor.
June 2022	Product launch	AMD launched the new Ryzen Embedded R2000 Series, second-generation mid-range SoC processors, optimized for a wide range of industrial and robotics systems, machine vision, IoT and thin-client equipment. This SoC provides up to 2X more cores, enhanced Radeon graphics, Windows 11 support and versatile, multi-display configurability.
May 2022	Product launch	GlobalFoundries launched GF Labs, a new program that extends the development horizon of innovative, differentiated semiconductor technology and broadens the company's portfolio of feature-rich and enablement solutions. GF Labs focuses on advancing new technology and long-term roadmap differentiation that enables GF customers to develop innovative products and accelerate time-to-market.
May 2022	Product launch	Tower Semiconductor expanded its power management platforms with the release of the second generation of its state-of-the-art 65nm Bipolar-CMOS-DMOS (BCD) expanding operation to 24V and reducing drain-source on-resistance (RDSon) by 20%. It is also adding deep trench isolations to its 180nm BCD platform, enabling up to 40% die size reduction for voltages up to 125V.
March 2022	Product launch	MediaTek launched SoCs called Dimensity 8100 and Dimensity 8000 to bring flagship level technology (connectivity, displays, gaming, multimedia and imaging features) to premium 5G smartphones. Both chips borrow the advanced technology from MediaTek's powerful flagship (Dimensity 9000) platform and package it into the new Dimensity 8000 series, built on the ultra-efficient TSMC 5nm production process with an octa-core CPU.
April 2021	Product launch	DB HiTek introduced 110nm-based global shutter and SPAD (single photon avalanche diode) processes and plans to expand its specialized image sensor business. This product has light shield and light guide technologies.

Source: Company website and press releases

Table 26

Agreements, collaborations and partnerships, Jan. 2021 to Oct. 2022

Date	Strategy	Description
Oct. 2022	Partnership	Qualcomm partnered with Razer and Verizon to introduce the ultimate 5G handheld gaming device equipped with the latest processing power from the Snapdragon G3x and Razer's industry-leading gaming hardware.
Oct. 2022	Partnership	The US National Science Foundation entered into a cross-sector partnership with Micron to develop transformative solutions to address semiconductor manufacturing challenges and workforce shortages. NSF and Micron will each invest $5 million in support of research, education, infrastructure capacity building and workforce development for semiconductor design and manufacturing.
Sept. 2022	Partnership	Nvidia partnered with TSMC to develop new gaming chips that use artificial intelligence (AI) for video games. With TSMC's 4N chip manufacturing technology Nvidia will develop gaming chips.
Sept. 2022	Collaboration	Avalanche Technology, the leader in next generation Magnetoresistive Random-Access Memory (MRAM) technology and United Microelectronics Corporation (UMC) announced immediate availability of new High-Reliability Persistent SRAM (P-SRAM) memory devices through UMC's 22nm process technology for aerospace applications.
Aug. 2022	Agreement	GlobalFoundries extended its long-term agreement with Qualcomm to secure the US supply through 2028. GlobalFoundries has been manufacturing Qualcomm's feature-rich, high-performance chips for many years, reaching across its global footprint.
Aug. 2022	Collaboration	UMC and Cadence Design Systems Inc. collaborated on Cadence analog/mixed-signal (AMS) IC design flow for UMC's 22ULP/ULL process technologies. This flow optimizes process efficiency and shortens design cycle time, accelerating the development of 5G, IoT and display application designs to meet increasing market demand.
Aug. 2022	Agreement	Intel signed an agreement with Brookfield Asset Management (one of the largest global alternative asset managers) to jointly invest up to $30 billion in leading-edge chip factories in Ariz. Intel announced a first-of- its-kind Semiconductor Co-Investment Program (SCIP) that introduces a new funding model to the capital-intensive semiconductor industry. As part of its program, Intel signed a definitive agreement with Brookfield to tap into a new pool of capital below its cost of equity.
July 2022	Agreement	GlobalFoundries signed a memorandum of understanding with STMicroelectronics to create a new, jointly-operated 300mm semiconductor manufacturing facility adjacent to ST's existing 300mm facility in Crolles, France. The new facility will support a broad range of technologies, including GF's market-leading FDX technology and STMicroelectronics' comprehensive technology roadmap, down to 18nm for automotive, industrial, IoT and communications infrastructure applications.
July 2022	Partnership	Intel partnered with TSMC to boost its contract manufacturing unit. Intel boosted its Intel Foundry Services (IFS) division with a TSMC veteran.
July 2022	Collaboration	Cadence Design Systems Inc. collaborated with Tower Semiconductor to advance automotive and mobile IC development. Through the collaboration, the companies are developing a new, comprehensive automotive reference design flow using the Cadence Virtuoso Design Platform and Spectre Simulation Platform to provide customers with a faster design cycle, maintaining comprehensive design verification for advanced automotive IC product development.
July 2022	Partnership	Intel and MediaTek entered into a strategic partnership to manufacture chips using Intel Foundry Services (IFS) advanced process technologies. The agreement will help MediaTek build a more balanced, resilient supply chain through the addition of a new foundry partner with significant capacity in the US and Europe.
July 2022	Collaboration	STMicroelectronics collaborated with CARIAD, the software unit of Volkswagen Group, to launch the joint development of an automotive system-on-chip (SoC). The new co-developed SoC aims to complement STMicroelectronics' high-performance Stellar microcontroller family.
June 2022	Partnership	Advanced Micro Devices' (AMD) Versal AI Core series, with AMD AI Engine technology, was selected by Canon for its Free Viewpoint Video System, expected to revolutionize the viewing experience for live sport broadcasts and webcasts. This single-chip Versal solution enables delivery of powerful Machine Learning (ML)-based video processing at the edge for Canon camera systems.
June 2022	Collaboration	AMD and NIO formed a collaboration to sell chips to NIO, the Chinese electric automobile manufacturer. NIO would employ AMD's EPYC series of processors, which will fasten the AI deep learning training and cut down product development cycles.
May 2022	Agreement	GlobalFoundries entered into a long-term agreement with Motorola Solutions, a global leader in public safety and enterprise security, to safeguard the supply of innovative chip solutions for Motorola Solutions' radios, which are widely used by public safety, critical infrastructure and enterprise organizations, across the world.
May 2022	Agreement	GlobalFoundries signed a $117 million agreement with the US Department of Defense (DoD) to provide a strategic supply of US- made semiconductors that are critical to national security systems. GlobalFoundries Fab 8 plant in Malta, N.Y., will securely manufacture the chips that will be used in some of the nation's most sensitive defense and aerospace applications.
April 2022	Collaboration	DENSO Corp., a leading mobility supplier and United Semiconductor Japan Co. Ltd. (USJC), a subsidiary of UMC, agreed to collaborate on the production of power semiconductors at USJC's 300mm fab to serve growing demand in the automotive market. An insulated-gate bipolar transistor (IGBT) line will be installed at USJC's wafer fab, the first in Japan to produce IGBTs on 300mm wafers.

Date	Strategy	Description
April 2022	Collaboration	Qualcomm collaborated with the Ministry of Electronics and Information Technology's (MeitY) Centre for Development of Advanced Computing (C-DAC) to support Indian semiconductor startups. As a part of the government and the industry's ongoing efforts to encourage innovation in the semiconductor space in India, Qualcomm will support a group of promising semiconductor design startups.
March 2022	Collaboration	GlobalFoundries collaborated with Broadcom, Cisco Systems Inc, Marvell and Nvidia, along with photonic leaders including Ayar Labs, Lightmatter, PsiQuantum, Ranovus and Xanadu, to deliver innovative, unique, feature-rich solutions to solve some of the biggest challenges facing data centers, today.
Feb. 2022	Agreement	Tower Semiconductor entered into a merger agreement with Intel for $53 per share in cash, representing a total enterprise value of approximately $5.4 billion. The transaction awaits regulatory approval from China's State Administration for Market Regulation (SAMR) and is expected to close in 2023.
Jan. 2022	Collaboration	Qualcomm collaborated with Microsoft to expand and accelerate the adoption of augmented reality in both the consumer and enterprise sectors. This collaboration focuses on designing custom augmented reality (AR) chips and integrating software platforms to usher in new gateways to the metaverse.
Dec. 2021	Agreement	Advanced Micro Devices (AMD) entered into the First Amendment to the Amended and Restated Seventh Amendment to the wafer supply agreement (WSA) with GlobalFoundries. The updated amendment goes through 2025, with AMD raising 12nm/14nm wafer orders by $500 million to $2.1 billion.
Dec. 2021	Partnership	Huawei partnership with SMIC to build a new fab manufacturing plant in China that will serve its needs either exclusively, or almost exclusively. This plant will help Huawei to avoid the impact of US sanctions that have severely limited its access to crucial chip technologies. Huawei intends to spend as much as $10 billion on the fab.
Dec. 2021	Collaboration	IBM and Samsung Electronics jointly introduced new Vertical Transport Field Effect Transistors (VTFET), a breakthrough in semiconductor design using a new vertical transistor architecture that demonstrates a path to scaling beyond nanosheet. VTFET has the potential to reduce energy use by 85% compared to a scaled fin field- effect transistor (finFET).
Nov. 2021	Agreement	BMW Group, an automotive company, signed a direct supply assurance agreement with high-tech microchip developer, INOVA Semiconductors and Global Foundries. The agreement guarantees the BMW Group a supply of several million microchips per year.
Nov. 2021	Agreement	GlobalFoundries and Ford Motor Company signed a strategic collaboration to advance semiconductor manufacturing and technology development within the US, aiming to boost chip supplies for Ford and the US automotive industry.

Date	Strategy	Description
Nov. 2021	Partnership	Apple partnered with TSMC to produce iPhone modems using the chipmaker's four-nanometer manufacturing process. Modem chips are used by handsets, such as iPhone, to connect to carrier networks. TSMC will mass produce these modern chips in 2023.
Nov. 2021	Collaboration	Broadcom announced that Meta is now deploying the world's highest bandwidth Ethernet switch chip, the Broadcom StrataXGS Tomahawk 4 switch series, in its data center network fabric. A leading-edge 25.6 Tbps Ethernet switch, the Tomahawk4 is now shipping in high volume in Meta's Minipack2 platform, an industry first.
Oct. 2021	Agreement	Qualcomm and SSW Partners, a New York-based investment partnership, entered into a definitive agreement to acquire Veoneer Inc. for approximately $4.5 billion. At closing, SSW Partners will acquire all of the outstanding capital stock of Veoneer, then sell Veoneer's Arriver business to Qualcomm and retain Veoneer's Tier-1 automotive supplier business. Following the close of the Arriver business sale, Qualcomm intends to incorporate Arriver's computer vision, drive policy and driver assistance technologies into Qualcomm's Snapdragon automotive platform in order to deliver an open and competitive ADAS platform for automakers and Tier-1 automotive suppliers. Subject to the satisfaction of closing conditions, the acquisition is expected to close in 2022.
Sept. 2021	Collaboration	Qualcomm and GlobalFoundries announced extension of the successful radio frequency (RF) collaboration on 5G multi-Gigabit speed RF front-end products.
Sept. 2021	Agreement	Tower Semiconductor entered into a definitive agreement with STMicroelectronics to share a 300mm manufacturing fabrication facility in Agrate, Italy, under a collaborative arrangement. Tower Semiconductor Italy S.r.l. (TSIT), a wholly-owned subsidiary of Tower, was incorporated.
Sept. 2021	Collaboration	Tower Semiconductor collaborated with Quintessent, a leader in laser integration with silicon-photonic-integrated circuits to create the world's first Silicon Photonics (SiPho) process with integrated quantum dot lasers, addressing optical connectivity in artificial intelligence/machine learning and disaggregated computing (datacenter) markets.
Aug. 2021	Partnership	STMicroelectronics announced the expansion of an existing multi-year, long-term silicon carbide wafer supply agreement with Cree Inc., a world leader in the development, manufacturing and marketing of electronic devices made from silicon carbide (SiC). The amended agreement, which calls for Cree to supply STMicroelectronics with 150mm silicon carbide bare and epitaxial wafers over the next several years, is now worth more than $800 million.
July 2021	Collaboration	Intel collaborated with Qualcomm to produce some of Qualcomm's future chips. These chips will be built by Intel via 20A technology, which is scheduled to ramp up in 2024. The 20A technology enables faster transistor switching and a more compact design. Intel will work on Intel 7, Intel 4 and Intel 3 CPUs from 2021-2023, before the 20A chips are ready.

Date	Strategy	Description
June 2021	Agreement	STMicroelectronics signed an agreement with Tower Semiconductor: Tower will share a portion of the cleanroom of its new Agrate R3 300mm fab, which is currently under construction, in order to accelerate fab ramp-up to reach a high utilization level and scale.
June 2021	Partnership	STMicroelectronics announced a strategic cooperation with the Renault Group on advanced power semiconductor products for electric and hybrid vehicles. This will bring significant volumes of power modules and wide bandgap power transistors supplied from 2026-2030.
May 2021	Agreement	Advanced Micro Devices (AMD) entered an amended seventh amendment with GlobalFoundries. AMD currently estimates that it will purchase approximately $1.6 billion in wafers from GlobalFoundries from 2022-2024 under the A &R Seventh Amendment.
Jan. 2021	Collaboration	Broadcom's BCM4389 chip is the world's first Wi-Fi 6E phone, a Samsung Galaxy S21 Ultra smartphone. The BCM4389 combines the benefits of the sixth generation of Wi-Fi with the pristine 6 GHz band to power the Galaxy S21 Ultra with Wi-Fi speeds over 2 Gbps.
Jan. 2021	Partnership	Samsung entered into a semiconductor manufacturing agreement with Intel to produce semiconductors starting in the second half of 2021. Intel will produce 15,000 300mm wafers per month at Samsung Austin Foundry Factory.

Source: Company website and press releases

Table 27

Mergers and acquistions, March 2021 to June 2022

Date	Strategy	Description
June 2022	Acquisition	Kioxia completed acquisition of Chubu Toshiba Engineering Corp. (currently Kioxia Engineering Corp.), a provider of engineering services in the fields of development, production and manufacturing semiconductors to further strengthen Kioxia's technology development capabilities.
Feb. 2022	Acquisition	AMD acquired fabless semiconductor company, Xilinx, for $49 billion. The acquisition was originally announced in Oct. 2020, creating the industry's high-performance and adaptive computing leader with significantly expanded scale and the strongest portfolio of leadership computing, graphics and adaptive SoC products. AMD enhanced its portfolio of leadership CPUs, GPUs, FPGAs and Adaptive SoCs to address an approximately $135 billion market opportunity.
Oct. 2021	Acquisition	Texas Instruments acquired Micron Technology's 300mm semiconductor factory in Lehi, Utah, for $900 million. The Lehi fab will be Texas Instruments' fourth 300mm fab, joining DMOS6, RFAB1 and the soon-to-be-completed RFAB2 in TI's wafer fab manufacturing operations.
March 2021	Acquisition	Qualcomm completed the acquisition of NUVIA for $1.1 billion, net of cash acquired. NUVIA has certain in-process technologies and is comprised of a CPU and technology design team with expertise in high performance processors, SoC and power management for compute-intensive devices and applications. NUVIA's technologies are integrated into certain QCT products.

Source: Company website and press releases

Table 28

Investments and expansions, June 2021 to Oct. 2022

Date	Strategy	Description
Oct. 2022	Expansion	Synopsys Inc. collaborated with Samsung Foundry to produce multiple successful test chip tapeouts on Synopsys digital and custom design tools and flows, certified for Samsung Foundry's most advanced processes. This collaboration focuses on continued innovating to drive silicon improvements, driving adoption of Samsung's 3nm gate-all-around (GAA) process technology for mobile, high-performance computing and AI applications.
Oct. 2022	Expansion	STMicroelectronics announced building a silicon carbide wafer plant in Italy with an investment of $728 million (730 million euro) as part of expanding its semiconductor manufacturing. This new integrated silicon carbide (SiC) substrate manufacturing facility would meet increasing demand from automotive and industrial customers amid a transition to electrification.

Date	Strategy	Description
Sept. 2022	Investment	Micron announced plans to invest $15 billion to build a brand-new plant in its home state of Idaho, the CHIPS and Science Act of 2022 was passed and will increase domestic chip manufacturing. This new plant will be the first new memory manufacturing fab built in the US, which will help fuel the data center and automotive industries.
Sept. 2022	Expansion	SMIC broke ground on a $7.5 billion electronic fabrication plant in the port city of Tianjin, China. SMIC began work on the 12-inch wafer fab and is carrying out the project in cooperation with two local government authorities in the Xiqing district in the southwest of the city.
Aug. 2022	Investment	TSMC invested up to $44 billion to expand its chip manufacturing capacity in 2022. The world faces acute chip shortages amid supply chain constraints. TSMC will invest $100 billion over three years, by 2023.
June 2022	Expansion	DB Hitek announced building a next-generation power MOSFET production line at its 8-inch semiconductor fab in the Chungcheongbuk province. This plant will supply 1200V SiC MOSFET for automotive applications, by 2025.
June 2022	Expansion	Samsung Electronics started chip production using its 3nm technology. Samsung hopes to capture a larger slice of the global semiconductor foundry market, which is currently led by TSMC. Samsung claims that second-generation 3nm processes could reduce power consumption by up to 50%, improve performance by 30% and reduce area by 35%.
March 2022	Investment	Intel made an initial investment of over $32.3 billion for R &D and manufacturing in the EU and planned to invest around $79 billion in the EU over the next decade, along the entire semiconductor value chain.
Feb. 2022	Expansion	UMC plans to build a new advanced manufacturing facility next to its existing 300mm 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.
Jan. 2022	Expansion	DB HiTek expanded its RF front-end business by securing RF SOI (Silicon- on-Insulator) and RF HRS (High Resistivity Substrate) processes based on 130nm/110nm technology.

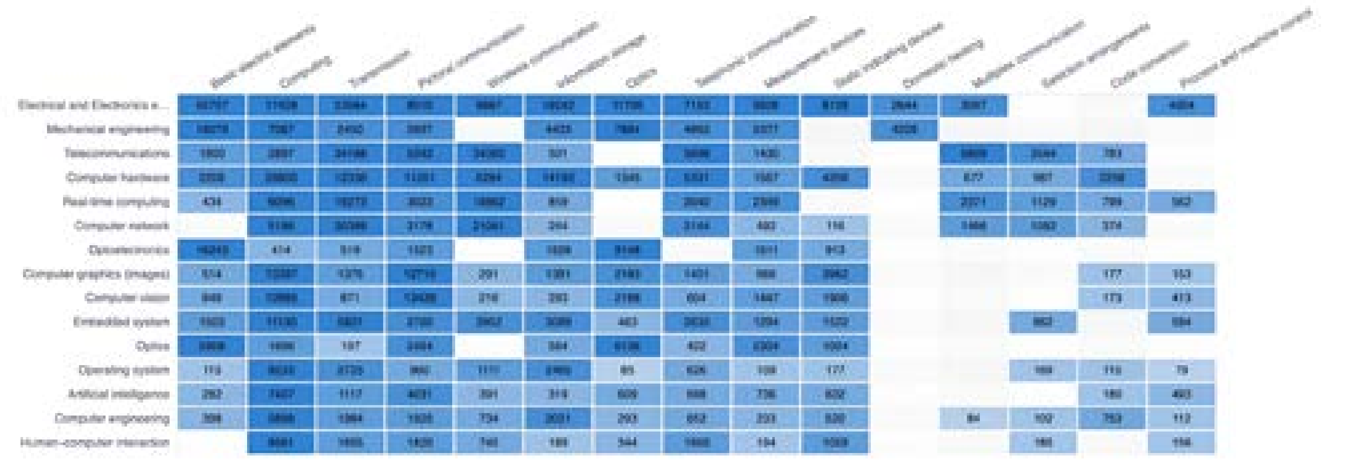
Date	Strategy	Description
Nov. 2021	Expansion	TSMC will build a $7 billion fabrication plant in southern Japan with a subsidiary of Sony Group Corp. becoming a minority shareholder in the venture. TSMC plans to start production by the end of 2024.
Nov. 2021	Expansion	Samsung planned to build a $17 billion semiconductor factory outside of Austin, Texas, amid a global shortage of chips used in cars, phones, tablets, video game consoles and other electronic devices. Samsung said it will start building the plant next year and hopes to begin operations in the second half of 2024.
June 2021	Expansion	TSMC started construction of its chip factory in Ariz., where it plans to spend $12 billion to build a computer chip factory. The planned factory remains on track to start volume production of chips using the TSMC's 5nm production technology starting in 2024.

Source: Company website and press releases

Innovation matrix for top 5 companies

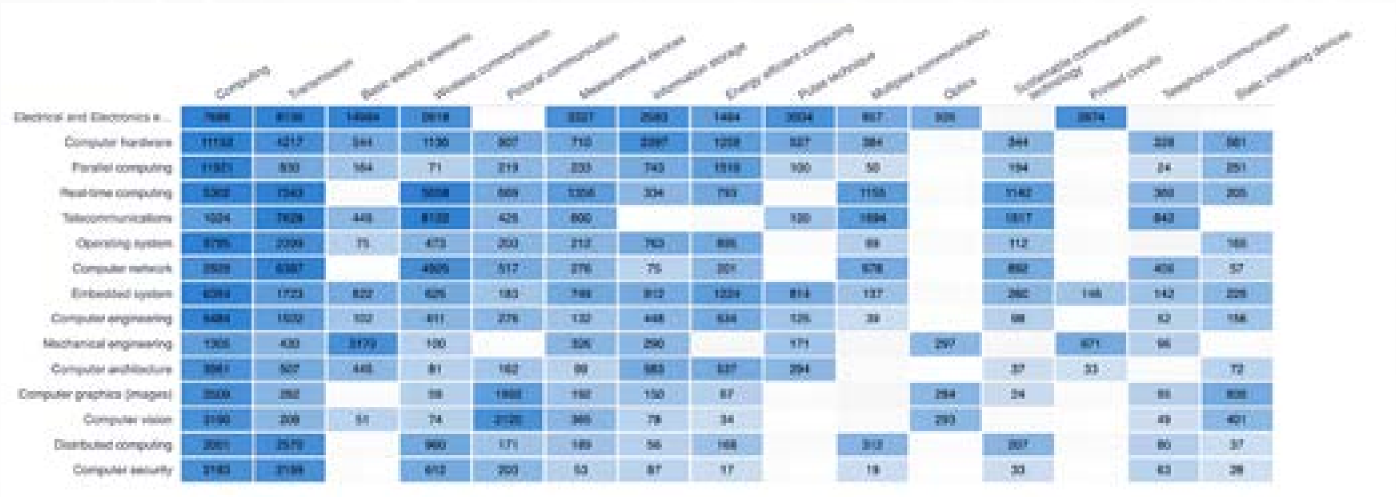
The innovation matrix is helping identify the hot application areas and blank areas by visualizing the technology portfolio across multiple dimensions.

Samsung Electronics



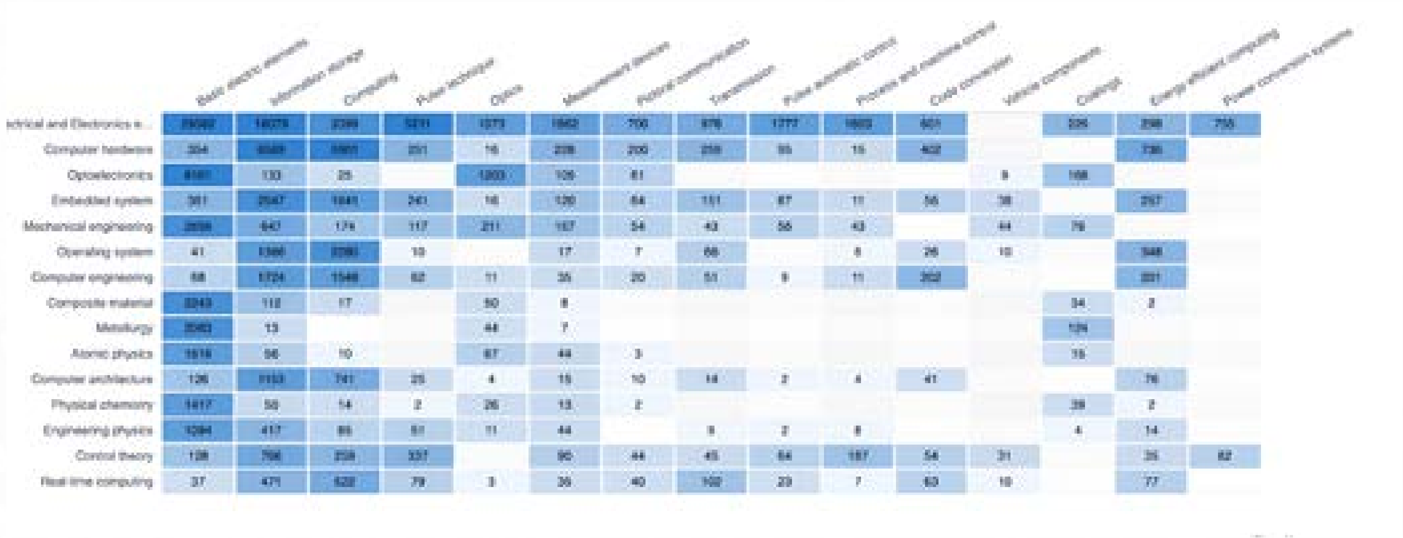
Source: discovery.patsnap.com

Intel



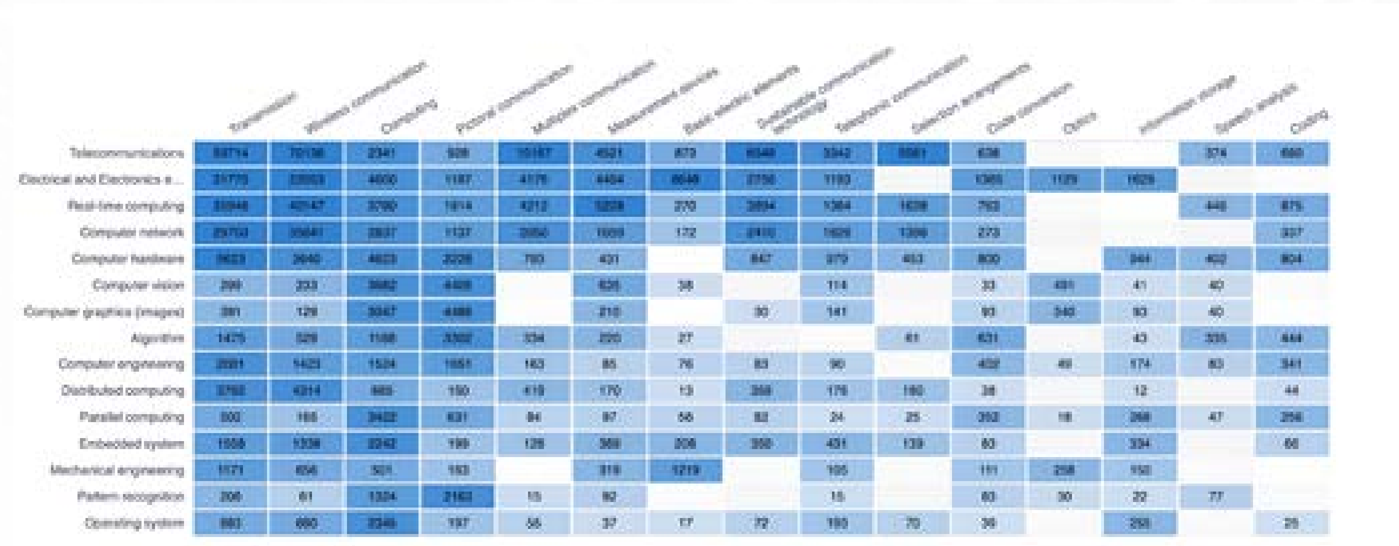
Source: discovery.patsnap.com

SK Hynix



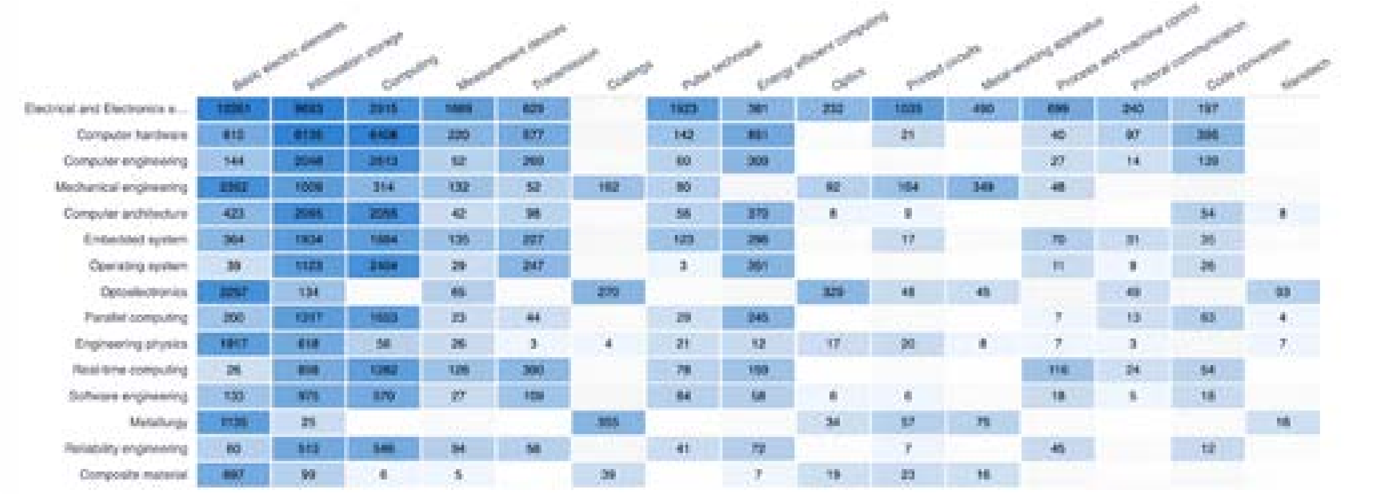
Source: discovery.patsnap.com

Qualcomm



Source: discovery.patsnap.com

Micron Technology



Source: discovery.patsnap.com