Economic analysis of the EU and International semiconductor ecosystem

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1. Overview of the semiconductor industry in the world

1.1 Overall contextualization

i. Geopolitical context

A race between the USA and China towards self-sufficiency

The semiconductor industry has witnessed considerable geopolitical upheavals over the past few decades. Since the beginning of the semiconductor industry, the United States are the only country in the world that has built and maintained comprehensive control over their entire value chain.

In the 1980s, Japan became a major player in the global semiconductor industry, driven by the emergence of consumer applications, challenging the US leadership. However, Japanese growth gradually dried up during the 1990s, so that the Japanese industry has been on the defensive since the early 2000s.

The 2000s decade saw the rise of China, Taiwan, and South Korea as major semiconductor countries, especially focused on semiconductor manufacturing.

A new turning point occurred in 2015, when the Chinese government officially announced its plan China Manufacturing 2025, setting the goal to develop total control of its semiconductor value chain, in a manner similar to the United States.

The announcement from China occurred after two decades of offshoring of semiconductor manufacturing facilities from US companies towards Asia, and especially Taiwan and China, placing back-end and advanced front-end facilities serving the US market at the risk of dependency on China. The US government reacted in 2016 already, with the first Chinese semiconductor companies added to the entity list of the Bureau of Industry and Security (BIS)[1]. Since then, the number and the scope of US unilateral interdiction of exports of specific products towards China and Chinese players has skyrocketed. European companies are bound by the US government to conform to these bans. These measures have led to countermeasures from the Chinese government, such as the recent restriction on exports from China of gallium and germanium[2].

Although these trade sanctions against China have delayed the implementation of the "China Manufacturing 2025" plan, they have also encouraged the Chinese government to develop independent production capacities at each stage of the value chain with some success:

[1] Every company added to this entity list is associated with a list of products. The embargo covers the list of products described for every company on the entity list.
[2] For more details: https://www.csis.org/analysis/understanding-chinas-gallium-sanctions

- Since 2022, Semiconductor Manufacturing International Corporation (SMIC) successfully produces 7nm chips thanks to DUV lithography techniques.
- In October 2023, less than 10 years after the first ban imposed on the European company ASML from exporting its products to China, China's semiconductor manufacturer SMIC canceled a significant order from ASML totaling several billion euro, signaling its intent to achieve self-sufficiency in lithography. ASML is therefore likely to face an increased competition from Chinese lithography manufacturers in the coming decades that might progressively challenge its leadership position.

The COVID crisis and the global shortage of semiconductors

From late 2020 to 2022, the recovery of the economic activity following the COVID crisis combined with the priority given by the manufacturers to their main markets - namely consumer markets[3] - led to a shortage of chips, in particular for so-called "embedded" market segments: automotive, industrial and robotics, health, energy, etc. The automotive industry, for example, was compelled to reduce its production by an estimated 15 million vehicles over these two years due to the scarcity of semiconductors[4]. This led to an estimated loss of more than USD 200 billion for the global automotive sector.

This chip shortage has underscored vulnerabilities within the global supply chain, highlighting a dependency on a few suppliers and concentrated manufacturing regions.

Alliances & cooperation: a new paradigm

The semiconductor sector has always been heavily subsidized and with strong ties with the public sector. Examples are numerous, such as the funding of TSMC by the Taiwanese government, or the strong links between the US main chips companies and the US military sector (Texas Instrument, GlobalFoundries, Intel...). However, from the 1990s to the 2010s, international investment plans and alliances within the semiconductor industry were mainly shaped by corporate strategies and private investments.

The US-China trade war and the supply chain disruptions witnessed since 2020 with the COVID crisis and the chip shortage have accelerated a paradigm shift: Governments are now acting to bolster their semiconductor sector and also build alliances and cooperation to secure their value chains[5]:

[3] The demand of semiconductors for phones and consumer PCs even rose significantly in 2020 during the COVID crisis to support the needs of teleworking.

[4] According to AutoForecast Solutions

[5] Chip Diplomacy: Analysis of technology partnerships, Stiftung Neue Verantwortung, Julia Hess and Jan-Peter Kleinhans, October 2023.

- The Chinese government continues its efforts to develop state-of-the-art capabilities across the entire semiconductor value chain, products, and technologies. In this regard, China is open to cooperation with third countries to reach this goal.
- The US are seeking cooperation with three main objectives:
    - Identify the value chain levels at risk of dependency towards China and relocate manufacturing capacities on the US soil for these segments: advanced processors, advanced packaging, back-end in general, PCB…
    - Building alliances with most relevant third countries to prevent China from creating alliances with these countries and benefit from their ecosystems.
    - Finally, building alliances on specific advanced technologies with relevant third countries.
- Other Asian countries (Japan, South Korea, Taiwan, India, Vietnam…) are open to cooperation and are already engaged in cooperation with the US in this regard. They aim at:
    - Securing their security & defense alliance with the US and against China (Taiwan, South Korea, Japan).
    - Building a national ecosystem of semiconductors (India, Vietnam, Malaysia…), or reinforcing their existing ecosystem through investment in specific technologies (Taiwan, South Korea, Japan).

The European Union finds itself in a challenging situation in terms of cooperation. The EU could cooperate with China in several areas on which common interests are shared. However, this exposes the EU to a risk of technological leakage to China which should be monitored. But above all, the EU could face sanctions from the US government in the event of cooperation with China. On the other hand, failing to cooperate with China leads to heavy economic losses for the EU, as evidenced by the recent cancellation of the contract with ASML by SMIC for an amount of several billion euro. According to DECISION, the EU semiconductor industry has already lost at least €15B since 2014 because of the US sanctions and the lack of cooperation with China.

The EU has many opportunities for cooperation with the US. However, the EU is in a situation of strategic dependency on the US in most value chain segments, whereas the US faces almost no strategic dependency towards the EU. Indeed, EUV lithography could be considered as a field where the US face a strategic dependency towards the EU, however the main shareholders of ASML are US funds and 20% of ASML's employees are located in the US[6]. Secure chips and advanced research are two other topics where the EU benefits from players with know-how that cannot be found in the

[6] The United States are therefore the second country in terms of location of ASML's employees, after the Netherlands.

US[7], however that cannot represent a strategic dependency as such given the presence of significant competitors in the US (Microchip for secure chips, and a flourishing ecosystem of R&D). The only segment where the US might be strategically dependent on the EU might be SOI substrate, although they might find alternative suppliers for instance in South Korea. Finally, the US ecosystem is also in competition with the EU ecosystem in most segments, with many large US companies having better capacities than EU companies to derive market applications from R&D innovations (time-to-market).

The EU could also develop cooperation with other Asian countries, especially to reduce shared strategic dependencies towards either China or the US. However, most of these countries are already engaged in cooperation with the US.

This report describes the investment and international cooperation strategies of the countries dominating the global semiconductor industry and identifies opportunities for cooperation between the EU and these countries: The US, China, Japan, South Korea, Taiwan, India, and Singapore. Insights are provided for Malaysia.

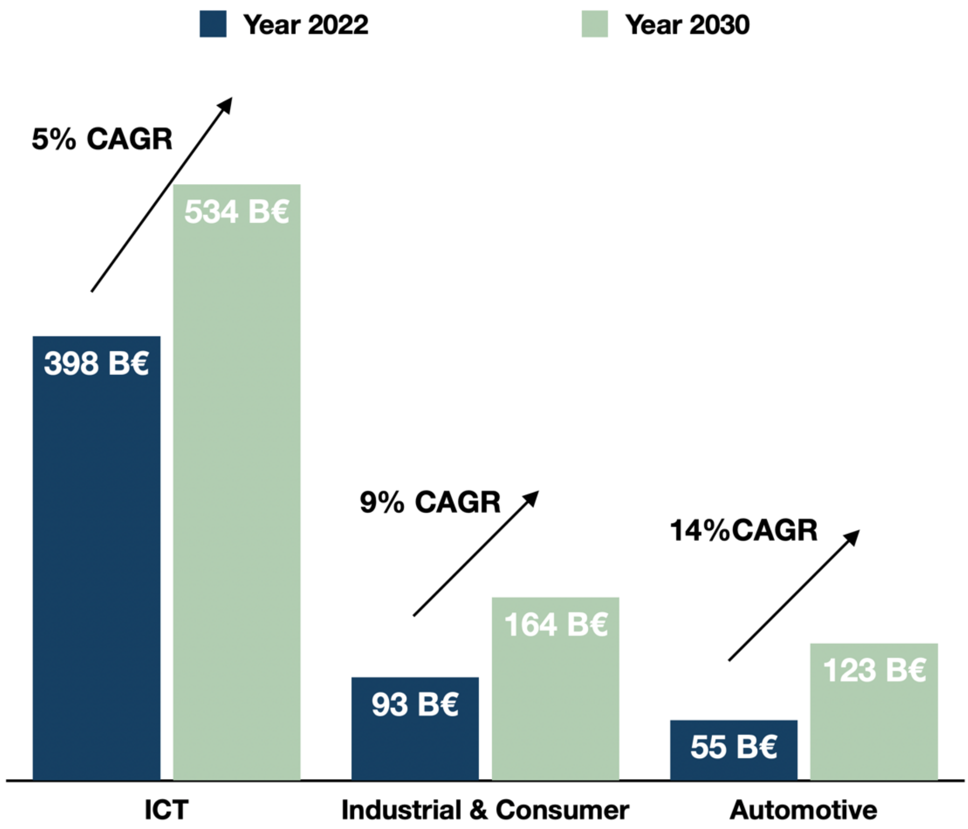
ii. Key end-markets of semiconductors for the coming decade

Historically, Information & Communication Technologies (ICT) has been the largest end-market in value for the semiconductor industry. This trend will likely continue, and ICT still represents the highest growth prospects in absolute terms with a growth of annual sales of +136B€ from 2022 to 2030, driven by the exploding computing and storage demand due to generative AI, 5G/6G and edge computing developments.

The greatest growth is however expected in the automotive sector, where the semiconductor market is forecasted to reach €123 billion in 2030 (with a CAGR of 14.0% from 2022). The key drivers of automotive semiconductors through the end of the decade are electric vehicles (EVs), driver-assistance systems, autonomous-driving, and infotainment systems.

[7] With respectively Infineon, NXP and STMicroelectronics for secure chips, and IMEC, CEA Leti and Fraunhofer for advanced research.

Figure 1: Evolution of key end-markets by 2030



Source: DECISION Etudes & Conseil, WSTS

iii. Main challenges on the road

Towards an exploding compute requirement…

The exponential growth in global data generation is expected to drive a surge in computing requirements. The emergence of 5G/6G networks, the growing demand for electric vehicles, the advancement of generative AI, along with new computing paradigms like neuromorphic computing and quantum technologies, are all fueling the demand for enhanced computing power and increased storage capacity.

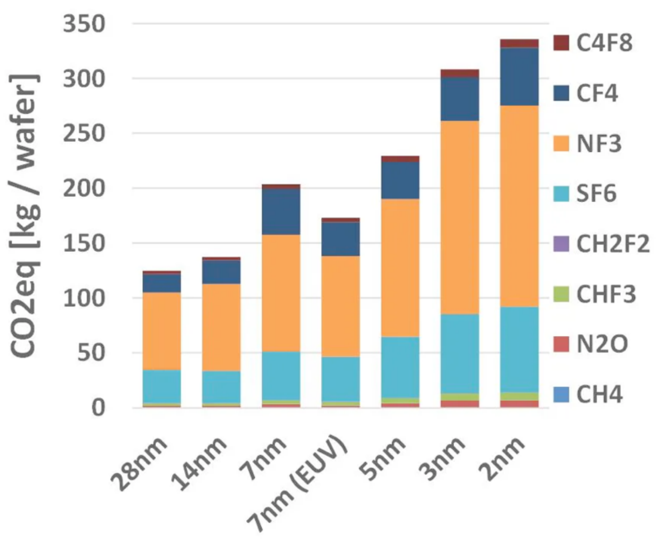
As a result, overcoming the "power wall" and "memory wall" represents a challenge for the semiconductor industry. This will necessitate a more ambitious semiconductor and computing roadmap, one that prioritizes peak performance alongside power efficiency.

…worsening the global energy shortage and rising the emissions…

At the same time, the world is entering a period of energy scarcity, with global oil, gas, and coal production set to decline, not only to cope with climate change, but also for the simple reason of the lack of energy reserves. This phenomenon has already started in Europe and will hardly be compensated for by nuclear and renewable energies.

In this context, the semiconductor industry aims at cutting the world's overall carbon footprint by enabling electrification and making devices more energy efficient. However, the CO2 emissions from manufacturing semiconductors are rising sharply as production shifts to finer processes. Process gases and electricity use account for 80% of these CO2 emissions. As a result, sustainability is becoming crucial in sourcing decisions, putting pressure on the semiconductor industry to lower its emissions. According to TSMC, energy efficiency has become a top priority of the main semiconductors manufacturers in 2023.

Figure 2: Estimated equivalent CO2 emissions from greenhouse gases used in process flows across different nodes



Source: IMEC 2020

The trend in the graph above shows that as the process node size decreases (from 28nm down to 2nm), the CO2 equivalent per wafer generally increases. This implies that manufacturing more advanced and smaller components is associated with a higher carbon footprint, due to the increased node density and to the complexity and energy use during the manufacturing processes. However, the advanced 7nm process, which utilizes extreme ultraviolet (EUV) lithography, shows a lower carbon footprint than the classic 7 nm process, suggesting that this cutting-edge technology is less carbon-intensive.

The graph indicates that the industry's drive towards miniaturization and increased performance, while beneficial for electronic devices' power and efficiency, comes with environmental trade-offs in terms of increased emissions of potent greenhouse gases. This highlights the importance of finding ways to mitigate the environmental impact of semiconductor manufacturing as technology continues to advance.

Responsible for about 0.1% of global emissions in 2021, the semiconductor industry's impact could rise to 1.5% by 2030 if measures are not taken, especially as other sectors advance towards the goals of the Paris Agreement, according to IMEC. This projected increase is due to the anticipated 8% annual growth in wafer volume and the greater complexity of future technology generations.

Semiconductor companies aim to become carbon neutral or achieve net-zero emissions between 2030 and 2050, with many already taking steps to manage and reduce their carbon footprint. There is a call for more standardized data collection on sustainability and increased transparency within the industry to meet these environmental goals[8].

However, semiconductors only represent a small share of the total emissions associated with the manufacture of electronics systems that also involve PCB, and electronics boards and modules assembly. For instance, 75% of a mobile device's carbon footprint is attributed to its manufacturing process, and only a small share of these 75% is related to semiconductors.

A paradox to be resolved?

A contradiction therefore clearly appears between the energy needs of new applications enabled by semiconductors (AI, ADAS, large networks of connected objects, etc.) and the looming global energy shortage. The applications that are driving the growth of the semiconductor industry today will therefore certainly have to face significant downturns for this reason by 2050.

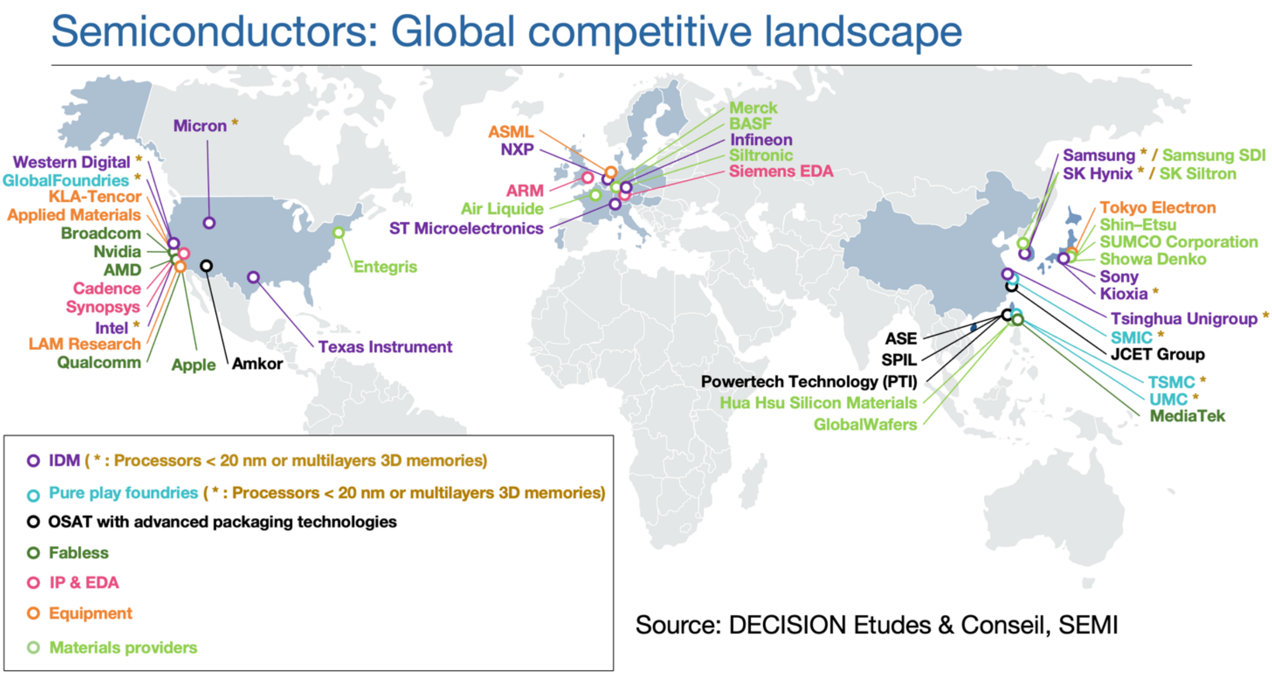
[8] https://www.imec-int.com/en/articles/whats-cooking-imecs-sustainable-semiconductor-program

1.2 Global semiconductor landscape

The map below shows the main players at the different stages of the value chain. This map reflects the current landscape of the semiconductor industry, and one can observe that:

- The US are currently the single country with industry leaders across the entire semiconductor value chain.
- The Asia-Pacific region has the greatest share of chip manufacturing and assembly & test companies.
- The EU is relying on a few relevant IDMs and leading players, especially in materials and equipment.
- China is in the process of building industry leaders all along the value chain, although its three current industry leaders are SMIC, Tsinghua Unigroup and JCET Group[9].

Figure 3: Semiconductors global competitive landscape



Source: DECISION Etudes & Conseil

With countries enacting their respective chip acts and semiconductor policies, the industry landscape is expected to shift by 2030. The main changes should be the emergence of a strong Chinese industry across the value chain, and the reshoring of

[9] SMIC is a manufacturer of chips, TU is semiconductor holding company involved in several steps of the value chain, and JCET is an OSAT.

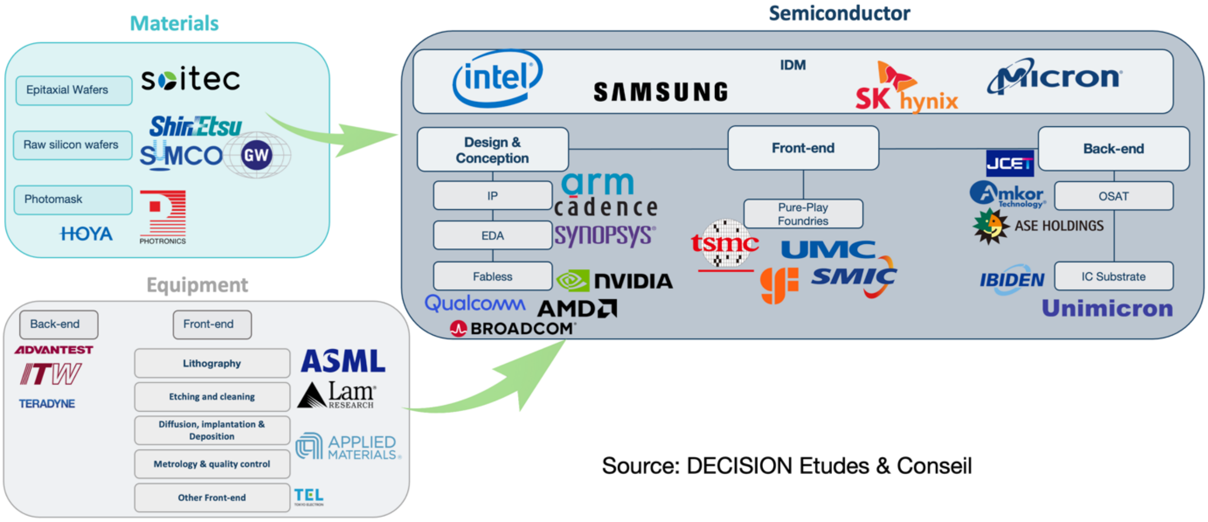
manufacturing facilities back to the US soil. TSMC, Samsung, and Intel are notably ramping up their investments in advanced manufacturing processes in the United States.

Back-end activities, like those handled by OSATs, have not been the primary focus, despite their critical role in the supply chain. Yet, there is a trend from US and EU IDMs to invest more in Southeast Asia, particularly in Malaysia and Vietnam, as they are shifting their operations away from China.

1.3 Worldwide leading players in the value chain

The semiconductor market is driven by increasingly high technological and capital barriers, especially associated with the advancement towards thinner process technologies in chip manufacturing. The investments required for R&D, along with the cutting-edge equipment needed for production on these scales, limit the ability of new entrants to compete, thereby maintaining the market dominance of established players.

Figure 4: Global leading companies across the value chain



Source: DECISION Etudes & Conseil

The semiconductor value chain is therefore turning into increasingly concentrated markets. The top five semiconductor firms account for over 44% of global semiconductor sales in 2022. In terms of production location, a substantial 75% of global front-end manufacturing is localized within four East Asian countries: China, Japan, South Korea, and Taiwan.

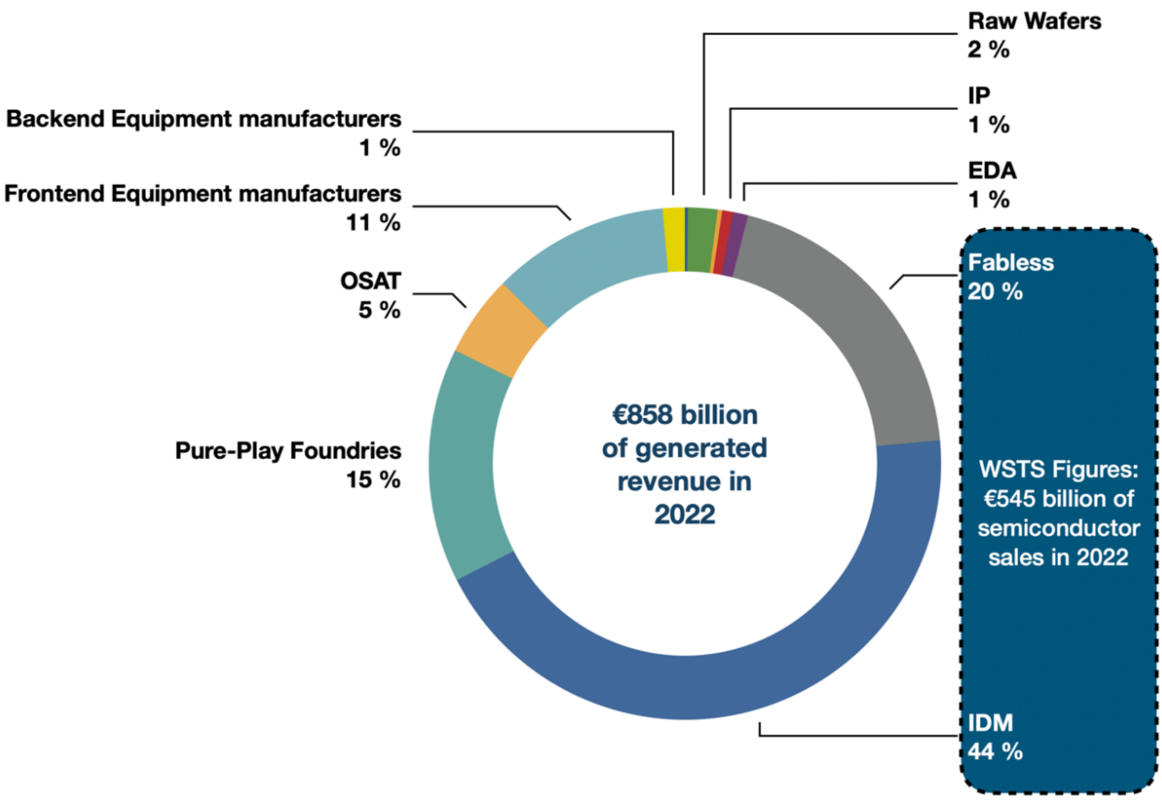
This concentration is even more pronounced within the foundry sector, where South Korea and Taiwan together represented 76% of the pure-play foundries market and 60% of the production in 2022, with Taiwan alone contributing an impressive 60% to the global foundry market.

The semiconductor value chain is getting ever more complex and highly fragmented. The goal for key players is to achieve the scale to become a leader in their domain. The result is a break-up in this value chain with more specializations: the big are getting bigger, and there is less room for contenders. ASML (lithography equipment), Arm (design IP), Nvidia (high-speed processors), TSMC (pure-play foundry) are good illustrations of this trend.

We also observe that the fabless models continue to gain ground, outpacing IDM. For instance, Nvidia is expected to become the largest semiconductor company in 2023, overtaking Intel and Samsung. Indeed, fabless players have established a dominant position in their respective sectors (Nvidia, Qualcomm, AMD…), and there is less interest to be a player across several applications. Looking at the future, we may see new fabless companies entering the game. For instance, Google has the scale to become a leading fabless company for its own applications.

The diagram below shows unique figures calculated by DECISION Etudes & Conseil. It enables us to compare the different semiconductor markets across the value chain. The total revenue for 2022 amounted to €858 billion, encompassing sectors such as Raw Wafers, Equipment, Photomask, IP, EDA, Fabless, IDM, Pure-Play Foundries, and OSATs. As shown on the right of the pie chart, the sum of the sales of Fabless and IDMs corresponds to the global semiconductor market, as described by the WSTS. The other segments correspond to Tier 1 or Tier 2 suppliers.

Figure 5: Weights of the different segment of the value chain



Source: DECISION Etudes & Conseil

The high share of the IDM model, accounting for 44%, is in fact due to two major players, Intel, and Samsung. Following these are Pure-Play Foundries, Front-end Equipment, and OSAT, which account for 15%, 11%, and 5% of the global revenue respectively. While other segments each hold a more limited share of 1% to 2% of the total revenue, they remain essential components of semiconductor production.

1.4 Front-end production capacities

Approximately 3/4 of the global front-end capacities is located in four countries in 2022: China, Taiwan, South Korea, and Japan. However, the EU and the US are on a path to dramatically increase their installed capacities, so that the picture might be more balanced in the coming years despite the continuous investments from Asian countries.

Regarding chip technology, the production of the most advanced chips, the smallest geometries, is currently concentrated in just three countries: South Korea, Taiwan, and the US. In other words, even though China is a leading country in terms of production capacities, the country is still lagging behind in terms of advanced technologies, although since September 2023 China successfully manufactured a 7nm chip. This technological breakthrough, featured in the latest Huawei smartphone Mate 60, was designed by Hisilicon, and produced by SMIC, signaling China's ambitions and capacity in the semiconductor industry.

As regards the EU, its semiconductor production is primarily focused on mature nodes, from 40nm and above. These larger chip sizes are mainly used in the automotive and industrial sectors, corresponding to the industrial strengths of the EU. In the coming years, the current capacity in modern technology will soon be complemented by the factories of Intel in Magdeburg, GF, and ST in Crolles, GF in Dresden and TSMC in Dresden.

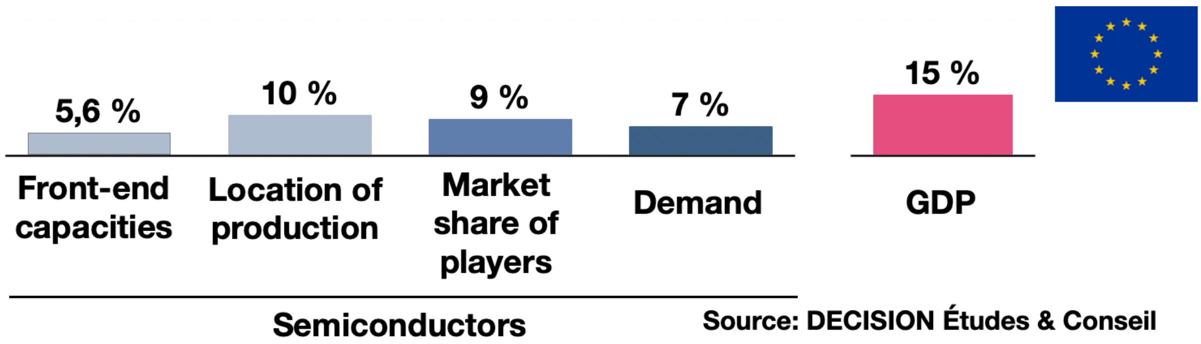
2 The European semiconductor ecosystem

2.1 Overall environment and strategic objectives

The EU semiconductor ecosystem in the global economy

The EU's GDP was valued at €15.8 trillion in 2022, which accounted for **15%** of the global economy[10], whereas its overall semiconductor ecosystem accounted for **9-10%** of the global semiconductor industry depending on the criterion retained[11]. As a matter of comparison, Taiwan's GDP represents 1.3% of the global economy while its overall global semiconductor market share is about 15%.

Figure 6: Position of the EU27 across the semiconductor value chain (in percentage of the World production), in 2022



If the semiconductor ecosystem of the EU is relatively small compared to the size of the EU GDP, it is at a coherent size when compared to the current consumption of semiconductor from the EU industries. Indeed, the EU semiconductor market accounted for 7% of the global semiconductor market in 2022, meaning that the EU end-user industries consumed **7%** of the semiconductor produced in the World in 2022.

Finally, the global demand for semiconductors is booming. The global semiconductor market has doubled its size in 10 years, from €277 billion in 2012 to €545 billion in 2022[12]. It is also expected to double its size from 2022 to 2032, driven by the numerous innovations in semiconductors driving new applications such as artificial intelligence, big data, etc. and many applications specifically linked with the EU end-user industries such as: edge computing, industry 4.0, automotive ADAS[13], infotainment, software defined vehicle, etc. The EU semiconductor consumption should therefore also nearly double by 2030, exceeding €80 billion.

In 2021, the European Union announced a challenging goal to double its share of global production capacity from 10% in 2021 to 20% by 2030. Considering the expansion of

[10] In Purchasing Power Parity.
[11] Whether the production share (10%) or the market share of EU companies (9%). Source: DECISION Études & Conseil
[12] Source: DECISION Études & Conseil, based on WSTS data.
[13] Advanced Driver Assistance Systems

the semiconductor industry worldwide, expected to double its output from 2022 to 2030, this would mean that the EU would have to quadruple its current semiconductor production to reach 20% of global production.

What industrial strategy for the EU?

In this context, the European semiconductor ecosystem must meet two challenges:

1. **Cultivate its strengths to preserve its shares on a booming global market.** The European semiconductor ecosystem represented more than 20% of the global industry in 2000 and this share has declined to 9% in 2022. Preserving the market shares of the European players in the growing semiconductor market will be challenging, especially due to the market shift towards Asia and the rising consumption of processors and memories by the European industries whose main suppliers are Americans. However, European players benefit from unique strengths in specific applications (automotive…) and products (power, analog…) driven by technological advances (FD-SOI, more than Moore…).

2. **Reduce its strategic dependencies.** While the European ecosystem commands a 9% share overall, this figure diminishes to below 2% in certain critical segments. These segments bear significant importance, particularly due to their capacity to disrupt the European semiconductor value chain and impede the supply to strategic end-user markets in Europe with direct implications for the security, safety, and health of Europeans, as well as the success of the green and digital transition. The semiconductor shortage in 2020 and 2021 has highlighted these dependencies. Reducing dependencies can be achieved either through the diversification of the suppliers or the relocation of sovereign production capacities on EU soil.

Identifying EU strengths and strategic dependencies across the value chain

This chapter provides a detailed overview of the EU semiconductor ecosystem, both in terms of demand and supply, products and applications, and considering the most specific segments of the value chain. More than ten value chain sections are studied in detail, estimating both the market shares of the European companies on the global market, and the share of the global production occurring on the EU soil.

In 2022, the European Commission's Joint Research Centre (JRC) released a report titled "The EU's Position in the Semiconductor Value Chain: Insights on Trade, Foreign Acquisitions, and Ownership," covering a scope akin to that of the present report and incorporating supplementary data[14].

[14] Ciani, A., Nardo, M., The position of the EU in the semiconductor value chain: evidence on trade, foreign acquisitions, and ownership, European Commission, Ispra, 2022, JRC129035.

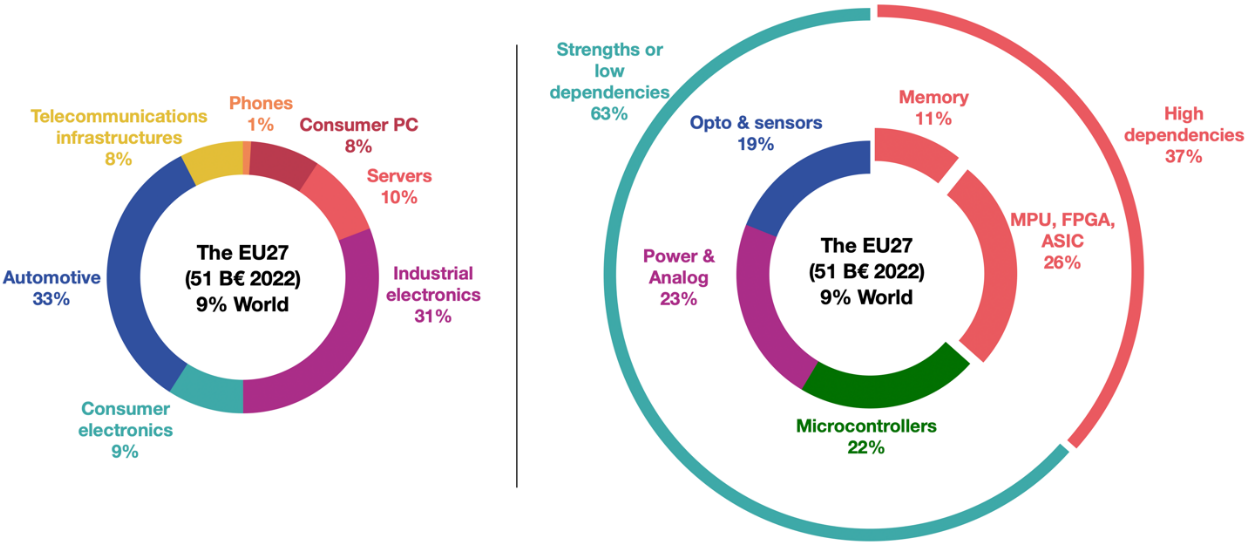
Such findings have also been completed in 2023 by The EC consultation on the semiconductors' value chain, achieved by the JRC[15].

2.2 The semiconductor market of the EU

The EU semiconductor market aligns with the consumption patterns of end-user industries within the EU. In comparison to various countries and regions worldwide, the EU stands out for its distinct disproportion between sizable "embedded electronics industries"[16], and relatively smaller "consumer electronics industries"[17], as illustrated in the figure below.

Embedded electronics industries account for 64% of the EU semiconductor consumption in 2022, while they account for 22% of the global semiconductor consumption.

Figure 7: Spread of EU semiconductor demand by application in 2022



Source: DECISION Études & Conseil

The needs of the EU market in terms of products are aligned with the needs of its embedded electronic production: power & analog, optoelectronics and sensors, and microcontrollers account for 63% of the EU semiconductor consumption in 2022, while they account for 39% of the global semiconductor consumption. The European suppliers

[15] Rosati, N., Bonnet, P., Ciani, A., Duch Brown, N., Miguez, S. and Zaurino, E., *The EC consultation on the semiconductors' value chain*, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/609020, JRC133892.
[16] Namely automotive, industrials (automation, robotics, aerospace-defense, health & care, energies…), and telecommunications infrastructures.
[17] Namely, Phones, consumer PC and consumer electronics (TVs, speakers, headphones, etc.).

of these components are strong and supporting the needs of the EU industries for decades. As a result, the EU has little to no dependencies on these products.

On the opposite, the EU has a very small ecosystem of both design and manufacturing of microprocessors (MPU, FPGA, ASIC) and memories, which are becoming critical products for the embedded industries through technological trends such as AI, cloud computing and edge computing. As these products represent 37% of the EU market, this represents a high dependency that can turn into a risk as these products should represent 50% of the EU consumption by 2030.

If the EU Chips Act considered the needs to raise the production of advanced processors on the EU soil, this turned into investments of two American companies (Intel and GF), towards which the EU will become increasingly dependent in the coming years. In other words, these investments reduce the dependency of the EU in terms of advanced nodes regarding the location of the production as the investments are made in Germany, Ireland, and France. However, these investments do not help reduce the dependency of the EU in terms of advanced nodes regarding the capital ownership, and the EU will become increasingly dependent on the US for its supply of advanced nodes, despite the recent announcement from TSMC in Dresden.

In addition, thanks to its strong R&D ecosystem, the EU benefits from an emerging ecosystem of design of microprocessors which could benefit from the rising needs of the EU industry to scale-up. Currently, this involves NXP (through the former purchase of Freescale), Bosch (new business unit set up in 2022), Elmos semiconductors and a flourishing ecosystem of startups: Kalray, SiPearl, Axelera.ai, Easics, Vsora, Cortus… However, the EU market is currently clearly dominated by US players (Intel – Mobileye, Nvidia, Qualcomm, AMD). If no action is undertaken, the EU should become increasingly dependent on these US players for the design of advanced processors, that should account for more than one third of the EU consumption of semiconductors by 2030.

2.3 The semiconductor industry in the EU

2.3.1 Key EU players across the value chain

On the one hand, the EU is home to several key players in the global semiconductor industry:

- Three major IDMs: STMicroelectronics, Infineon, and NXP[18].

[18] NXP has 93% floating capital, with nine US shareholders accounting for 35% shares. NXP is therefore considered as US-owned in this study. NXP market shares are therefore considered as market shares from an US company.

- The world's leading photolithography company, ASML, although partially owned by US, UK, and Norwegian investors. The EU benefits from an entire ecosystem around ASML: TNO, Trumpf, Carl Zeiss, etc.

- Three prominent Research and Technology Organizations (RTO): IMEC, CEA-Leti, and Fraunhofer.

- One of the world's top epitaxial wafer producers, Soitec, benefiting from a technological leadership on FD-SOI.

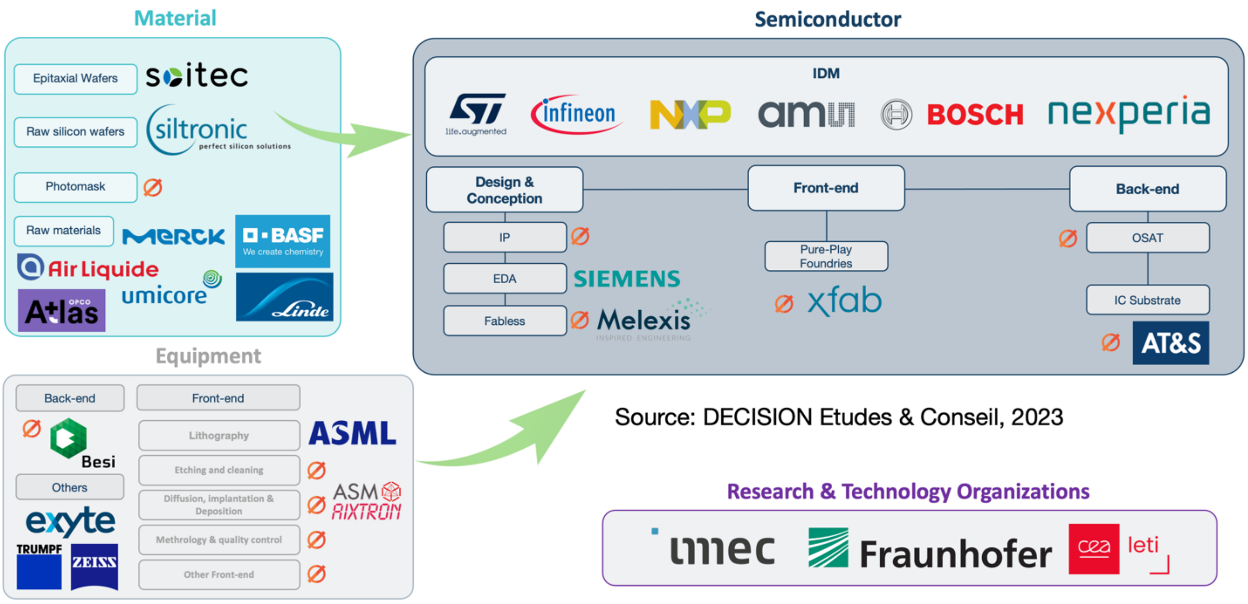
- The German Freiberger Compounds, playing a leading worldwide role in GaAs wafer manufacturing.

On the other hand, the EU has noticeable gaps in multiple segments.

For example, aside from ASML and its state-of-the-art lithography equipment, the EU lacks significant players in other semiconductor front-end manufacturing process equipment and is reliant on US suppliers in etching and cleaning (LAM Research), metrology & quality control (KLA Tencor), and the other segments (Applied Materials). The only alternative supplier worldwide is the Japanese Tokyo Electron (TE), with no equivalent capacities in most sub-segments. China is also building a complete ecosystem at fast pace in front-end equipment. Finally, it is also worth noting that ASML, although a key player in Europe, is partly owned by US investors[19] and has 20% of its workforce located in the US, which means the EU doesn't have complete control over this company, representing a minor dependency towards the United States.

[19] ASML has 98% floating capital. The Vanguard Group as first shareholder with 3.4% shares. Although strong presence of Norway (one shareholder with 2.5%), the UK (one shareholder with 0.85%), Germany (two shareholders with 1% in total), France (two shareholders with 0.8% in total).

Figure 8: The EU key players across the semiconductor value chain



Source: DECISION Etudes & Conseil

In terms of design & conception, the EU is notably lacking Intellectual Property (IP) providers, which are crucial for the design of semiconductor technologies. The EU is dependent on the US, the UK and Japan in this area, with companies like Cadence, Synopsys, or ARM. However, when it comes to Electric Design Automation (EDA) specifically, the EU benefits from Siemens EDA (since the purchase of the US Mentor Graphics)[20]. Finally, it must be noted that semiconductor companies face a very high cost of switching EDA suppliers. Indeed, design engineers in semiconductor companies get to learn how to use specific EDA tools. Switching EDA tools requires reskilling all the designers of a company and implies a significant delay in the design of new products. Consequently, this creates a significant barrier, deterring companies from making the switch. This is why, even though the EU benefits from the presence of Siemens EDA, many EU companies are dependent on Cadence and Synopsys as they have been engaged with these companies for decades.

In manufacturing, the EU does not have any prominent pure-play foundry that focuses on advanced chip geometry. The only companies that manufacture advanced process nodes of 16nm and below in the EU today are or will be foreign companies like Intel, GlobalFoundries, and TSMC.

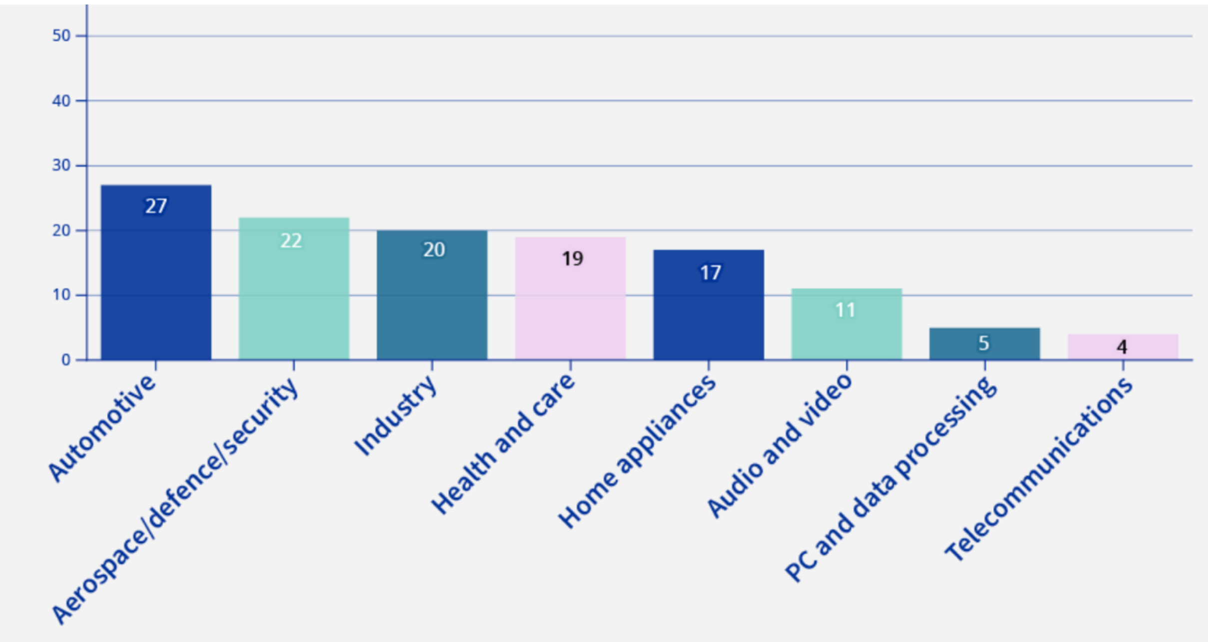
[20] Although the location of the 6000 employees of Mentor Graphics has not significantly changed since the purchase by Siemens in 2017. The vast majority remains on the US soil and the EU is only home of R&D centres in France, Germany, Hungary, Poland, and Romania.

Similarly, the EU has no relevant Outsourced Semiconductor Assembly & Test company (OSAT)[21], after decades of outsourcing of back-end manufacturing towards Asia. Such outsourcing was based on the perception of back-end as a low value-added step. However, as advancing Moore's Law is increasingly difficult today, advanced packaging has become an efficient way to circumvent the innovation costs and energy expenditures to keep improving semiconductors' performance. Therefore, back-end manufacturers are regaining strategic importance, while there are very few manufacturing capacities left on the EU soil and no relevant EU player anymore in this segment.

2.3.2 Key applications served by the EU suppliers

In terms of applications, European suppliers are leading in "embedded systems", namely Automotive, Industrial & robotics, Energies, Health & Care, Aerospace / Defense / Security, and telecommunications infrastructures. This is shown on an infographics on the EU Chips Act provided by the European Council of the EU in 2023[22], as shown below.

Figure 9: Europe's market shares in chip production for different sectors in 2023 (in %)



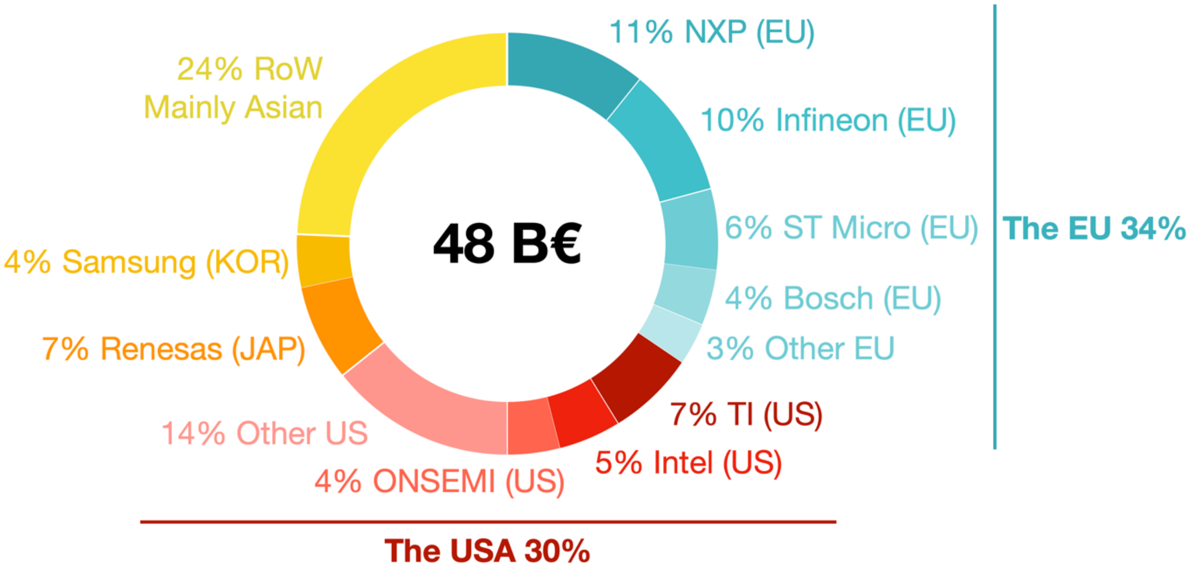
Source: European Council of the EU, 2023

[21] A few manufacturing sites remains in the EU, but no significant EU players. Amkor owns a large factory in Porto, Portugal (former factory from Infineon), Intel plans an advanced back-end factory in Wroclaw, Poland. ST Micro and Infineon both have three back-end factories on EU soil. The EU is also home to 11 small-sized back-end factories. However, in total, these 19 factories on EU soil account for 1-2% of the global production capacity.

[22] https://www.consilium.europa.eu/en/infographics/eu-chips-act/

EU companies owned 34% of the global semiconductor market for automotive in 2021 according to DECISION, as shown on the figure below, although this market share decreases over the years.

Figure 10: Market shares on the global automotive semiconductors market in 2021



Source: DECISION Etudes & Conseil

Indeed, European companies face an increasing competition from foreign players -and especially American players - whether through the trend of "edge computing" driving the growth of newcomers such as Intel / Mobileye, Qualcomm, Nvidia, AMD, Micron, or on more traditional segments such as power (Wolfspeed[23] and Onsemi[24] investing on the EU soil to supply the EU automotive industry…).

In terms of products, European actors are leading in most segments associated with the "More than Moore" trend. STMicroelectronics, Infineon, NXP, and Bosch are among the top 5 companies worldwide in four key markets related to More than Moore:

1. Power components[25]. Used in the production, transmission, storage, and utilization of electrical energy. This category includes integrated circuits for power management, voltage monitoring, battery management, etc., and discrete components such as thyristors, diodes, MOSFETs, IGBTs. Infineon and STMicroelectronics are the European leaders on this segment, facing strong competition from American players such as Texas Instrument, ON SEMI, Analog Devices, Wolfspeed…

[23] Link to the Wolfspeed press release on its partnership with the car equipment manufacturer ZF Group on a Silicon Carbide device fab
[24] Link to the Onsemi press release for more details on its investment in Silicon Carbide manufacturing capacity
[25] Source: DECISION, based on IC Insights data.

2. Microcontrollers[21]. Mainly used in embedded applications, including automotive, industrial, aerospace-defense-security, and healthcare. NXP, Infineon and STMicroelectronics are in the TOP 5, facing competition from the Japanese Renesas and the American Microchip.

3. MEMS (Micro-Electro-Mechanical Systems)[26]. Primarily used in sensors. EU companies account for approximately 30% of the global MEMS sales, behind American companies (~40%) and ahead of Japan (~20%) and China (~8%). Bosch is the global leader, followed in the EU by STMicroelectronics, NXP, Infineon, Amphenol, Melexis, Silex Microsystems, Lynred… Other global leaders include Broadcom (US), Qualcomm (US), Qorvo (US), TI (US), TDK (Japan), Goertek (China)…

4. Security integrated circuits[27]. Used for payment applications, SIM cards, and identity documents. Infineon, NXP and STMicroelectronics own ~60% of the global market shares. Their main competitors are Samsung (~20%), and the Chinese CEC Huada (~10%).

[26] Source: DECISION, based on Yole Development data.
[27] Source: DECISION, based on IC Insights and Eurosmart data.

2.3.3 European players' market shares and production across the value chain

In this report, particularly in this chapter and across each country fact sheets, the discussed market shares and production shares are defined and computed based on the following definitions:

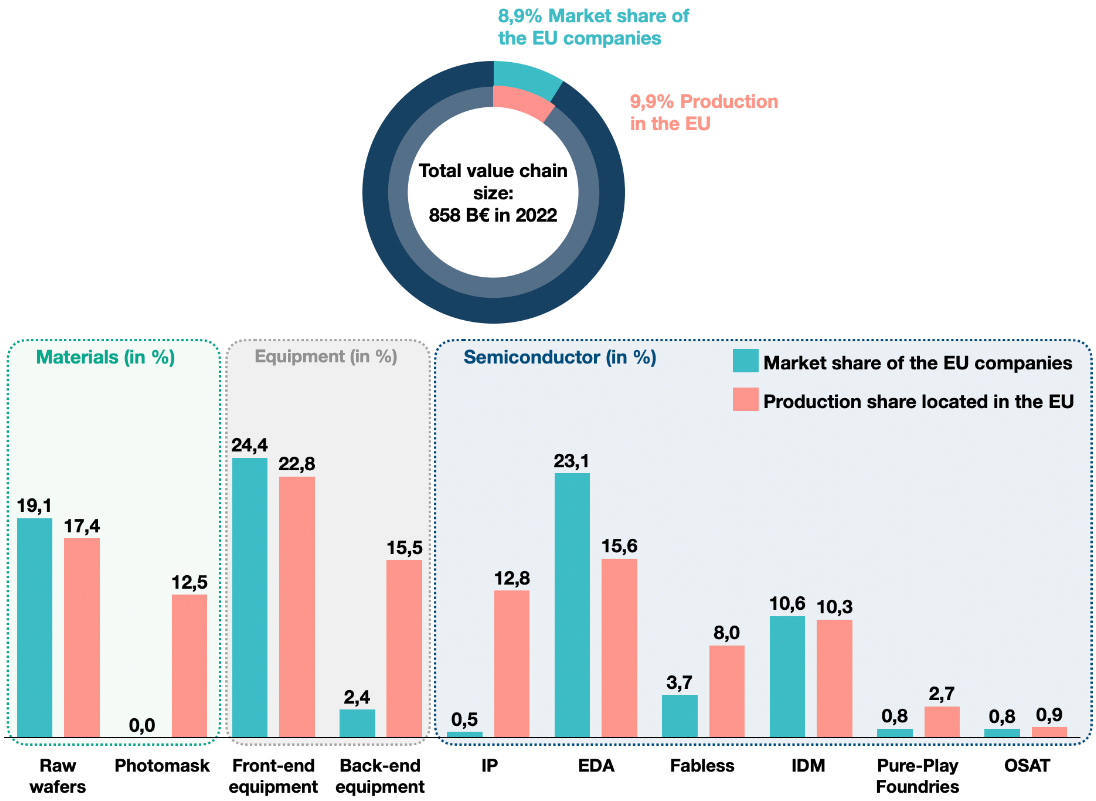
- Market Share: This refers to the proportion of the industry's total revenue that is attributable to companies from a specific country. This includes companies that have a majority of shareholders from that country, across all segments of the value chain. For example, the figure below states that the EU holds a 8.9% market share. This means EU-based companies, or companies with a majority of EU shareholders, contributed approximately €85.8 billion to the total €858 billion generated revenue in the industry in 2022 across all segments.
- Production Share: This metric indicates the percentage of the industry's global production that takes place within a specific region. It's calculated based on either the distribution of employees or the capacities installed within the region, encompassing both local and foreign companies operating there. For instance, the figure below notes that 9.9% of global semiconductor production, across all segments of the value chain, is based in the EU. This includes production from both EU companies and foreign companies with operations in the EU.

Overall, the semiconductor players are getting more specialized and aiming for leading positions in their respective fields. A typical example is ASML, which over the past decades built a quasi-monopolistic position in EUV lithography equipment, with 88% market share in 2022.

As we can observe on the graph below, the EU has a relatively strong global position in three parts of the value chain, respectively SOI wafers (SOITEC), front-end equipment (ASML)[28], and EDA (Siemens EDA).

[28] Although considered as an EU-owned company, ASML has 98% floating capital, The Vanguard Group as first shareholder with 3.4% shares. Although strong presence of Norway (one shareholder with 2.5%), the UK (one shareholder with 0.85%), Germany (two shareholders with 1% in total), France (two shareholders with 0.8% in total).

Figure 11: Market share and production share of the EU across the value chain in 2022



Global market size	16 B€	2.5 B€	96 B€	12 B€	6 B€	8 B€	168 B€	377 B€	127 B€	44 B€

In comparison, the EU account for 17% of the global GDP in 2022[29].

Source: DECISION Etudes & Conseil

On the other hand, in the back-end equipment segment, the EU is in a vulnerable position. There are smaller European companies that manufacture the needed equipment, accounting for 2.4% of the global market in 2022. But there are no leaders that could fulfill the EU demand for these types of equipment. In addition, the major shareholders from BESI, a company headquartered in the EU, are US funds. BESI is therefore considered as an US-owned company. This leads to dependencies on US and Japanese players, which are monopolizing the market: Advantest, Teradyne…

Moreover, this graph is highlighting the weaknesses of the EU in manufacturing, especially advanced front-end manufacturing, and advanced packaging. These are major dependencies for the EU, especially considering the increasing needs from the EU end-user industries for applications requiring advanced nodes and advanced packaging.

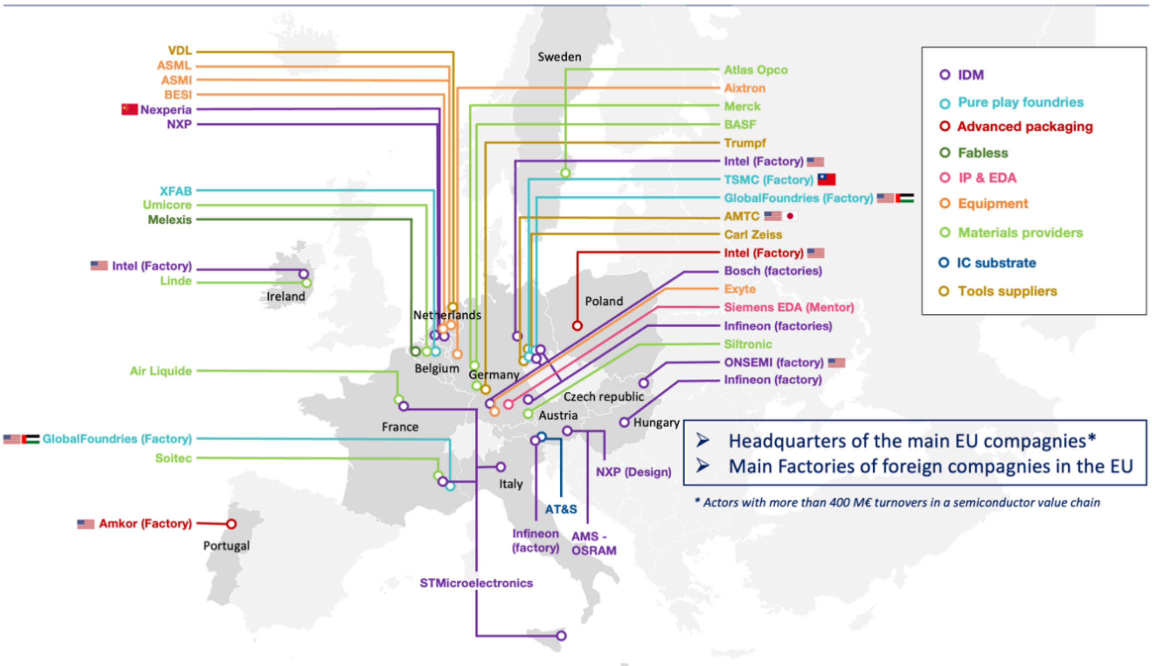
Even though the EU has no leading Photomask, IP, or Fabless players, it remains home to production that has been preserved in the EU soil. For instance, Qualcomm and Nvidia are well established fabless companies in the EU, partaking in the 8% production share

[29] Source: IMF, World Economic Outlook, October 2023.

of the EU, with major design centers with a considerable number of employees located in the EU.

Finally, the map below provides an overview of the EU semiconductor ecosystem, with the key players involved at the different value chain steps.

Figure 12: Main semiconductor clusters in the EU



Source: DECISION Etudes & Conseil

2.3.4 Front-end capacities: The EU is focused on larger nodes, dedicated to embedded systems

Almost all of the front-end capacities located in the EU are 40 nm and above nodes, which are nodes that are mostly made for automotive and industrial applications.

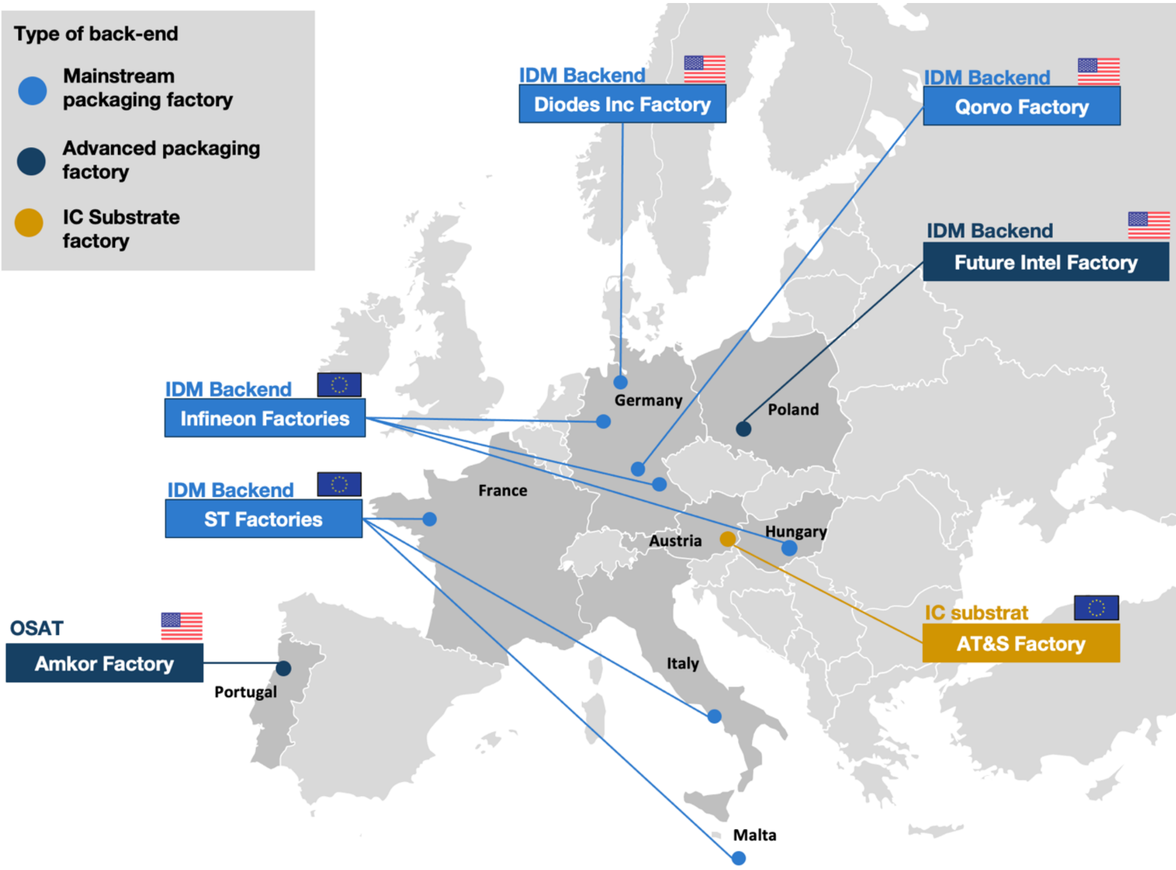
The only facility in the EU that currently manufactures advanced geometry semiconductors, 10nm and below, is Intel's fab located in Leixlip, Ireland, which employs over 5,000 people. Part of the back end of this fab is operated by Amkor's fab of Porto. Intel and Amkor are US companies. In the coming years, three new factories will be built on EU soil: GF (US) in Crolles, Intel (US) in Magdeburg, and TSMC (Taiwan) in Dresden.

This issue of lack of advanced manufacturing capacities becomes critical when considering current automotive trends. Modern vehicles are increasingly equipped with advanced computing systems, such as Advanced Driver Assistance Systems (ADAS), which rely on artificial intelligence and computer vision, which necessitate advanced node semiconductors. The demand for these advanced semiconductors in the automotive sector is expected to rise significantly in the coming years. There is a similar trend in industry 4.0, health & care, and defense among other sectors.

2.3.5 Back-end, advanced packaging, and IC substrate: A strategic dependency towards the US and Asia

The map below provides an overview of the relevant players in advanced packaging in the EU. Only nine significant semiconductor back-end factories are left on EU soil, after decades of offshoring of production towards Asia: three factories from STMicroelectronics, three from Infineon, and three from US firms (Amkor, Diodes, and Qorvo). In addition, the EU also benefits from nine small factories from SMEs located in France (3), Germany (3), the Netherlands (2), and Finland (1)[30].

Figure 13: European ecosystem of Back-end, advanced packaging, and IC substrate in 2023



Source: DECISION Etudes & Conseil

The main European end-user market for advanced packaging is automotive, driven by trends such as ADAS, infotainment and E/E architectures (Central Car Units). While wire-bonding continues to be the dominant interconnect for automotive packages, ADAS modules are increasingly using advanced interconnect technologies such as flip chip BGA, wafer level fan-out, and flip-chip CSP.

The only two projects of advanced packaging factories in the EU are handled by US firms: Amkor in Porto (Portugal), and Intel in Wroclaw (Poland). In early 2023, Amkor

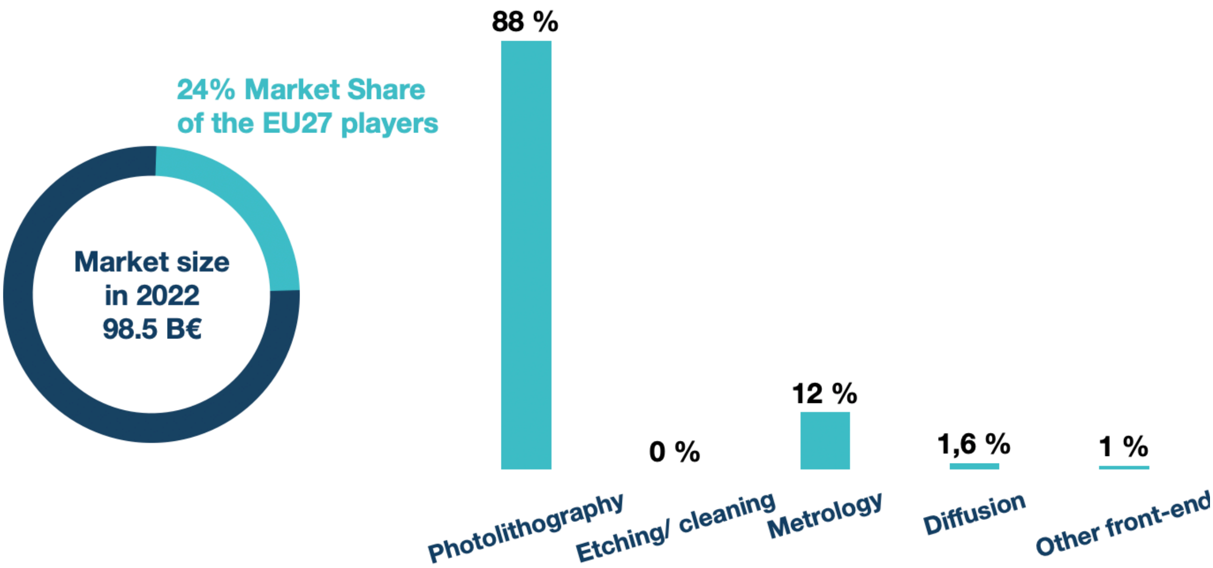
[30] These small factories have not been shown on the map above.

formed a strategic partnership with GlobalFoundries to establish the largest back-end facility in Portugal, to serve in particular the automotive market.

2.3.6 Front-end Equipment: The EU leads in lithography, but faces dependencies in the other segments

At first glance the EU seems well-positioned in the front-end equipment segment. However, when looking into the details, the EU is only leading in photolithography.

Figure 14: Spread of the market share of the EU players by type of front-end process equipment, 2022



Global market size	~23 B€	~23 B€	~9 B€	~18.5 B€	~25 B€

Source: DECISION Etudes & Conseil, based on companies financials[31]

Several EU companies are involved in manufacturing equipment for the semiconductor industry. The EU particularly excels in the photolithography segment, and especially in EUV lithography, with ASML standing out[32]. ASML is also an important supplier of metrology & inspection equipment, with a 12% share on the global market, dominated by the American KLA Tencor. Additionally, the EU has expertise, though more limited, in other segments, such as the diffusion process, with notable contributions from companies like ASM International (Netherlands) and Aixtron (Germany[33]). Other

[31] These figures have been crossed-checked for consistency with several source: Yole Development, and custom studies from Credit Suisse, and Exane BNP Paribas.
[32] Although considered has an EU-owned company, ASML has 98% floating capital, The Vanguard Group as first shareholder with 3.4% shares. Although strong presence of Norway (one shareholder with 2.5%), the UK (one shareholder with 0.85%), Germany (two shareholders with 1% in total), France (two shareholders with 0.8% in total).
[33] Aixtron has 98% floating capital, and four US shareholders with 11% shares. Strong presence of Norway (one shareholder with 4.2%), the UK (one shareholder with 2.9%) and Germany (two shareholders with 4.4%). Aixtron is therefore considered as US-owned.

segments of front-end equipment manufacturing are covered to a lesser extent, as they are mostly addressed by innovative SMEs, whose impact remains relatively limited on a global scale.

The EU is in a situation of strategic dependency towards the USA for etching & cleaning (LAM Research), but also Metrology (KLA Tencor), and most of the other segments (Applied Materials), without which the current and future fabs in construction could not go into production. The only alternative supplier for some products is Tokyo Electron (Japan).

In 2023, the JRC published a report "Semiconductors in the EU - *State of play future trends and vulnerabilities of the semiconductor supply chain*" [34], providing a complementary overview of key global players for manufacturing equipment by country and technology in 2021. The results are reported in the table below.

[34] Cerutti, I. and Nardo, M., *Semiconductors in the EU*, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/038299, JRC133850.

Figure 15: Overview of key global players for manufacturing equipment by country and technology

Equipment	Market share, 2021							Total sales	
	North America	**Taiwan**	**South Korea**	**Japan**	**EU**	**China**	**RoW**	2021, $bn	CAGR 2017-21
Total equipment	**41.6%**	**0.4%**	**4.0%**	**29.4%**	**19.2%**	**1.9%**	**3.6%**	**104.1**	**15%**
Wafer Fabrication Equipment	44.9%	0.1%	3.2%	27.8%	21.4%	1.6%	1.2%	89.0	16%
Microlithography and Mask Making Eqpt	*0.6%*	*-*	*0.4%*	*25.1%*	*73.4%*	*0.4%*	*0.1%*	*21.6*	*20.0%*
Resist Processing Eqpt	*0.3%*	*-*	*2.3%*	*94.4%*	*1.9%*	*1.0%*	*-*	*3.6*	*17.0%*
Optical Exposure Eqpt	*0.4%*	*-*	*0.0%*	*7.8%*	*91.4%*	*0.3%*	*-*	*17.2*	*20.8%*
Direct Write Systems	*-*	*-*	*-*	*67.3%*	*32.7%*	*-*	*-*	*0.04*	*5.0%*
Mask Exposure Eqpt	*5.9%*	*-*	*-*	*83.3%*	*10.8%*	*-*	*-*	*0.8*	*18.2%*
CMP Equipment (*)	*68.7%*	*-*	*1.3%*	*28.5%*	*-*	*1.5%*	*-*	*2.8*	*12.0%*
Ion Implanters	*93.2%*	*1.0%*		*5.2%*	*-*	*0.6%*	*-*	*2.0*	*11.4%*
Deposition & Related Tools	*59.7%*	*-*	*5.2%*	*24.1%*	*7.6%*	*2.1%*	*1.3%*	*23.5*	*14.6%*
Etching & Cleaning Tools	*54.3%*	*-*	*4.7%*	*37.4%*	*0.6%*	*2.4%*	*0.5%*	*25.7*	*14.6%*
Process Diagnostic Equipment	*71.4%*	*-*	*0.7%*	*13.1%*	*8.0%*	*1.2%*	*5.6%*	*11.0*	*18.2%*
Other Equipment (**)	*8.6%*	*-*	*7.4%*	*70.1%*	*11.9%*	*-*	*2.0%*	*2.3*	*4.6%*
Test and Related Systems	35.4%	2.6%	10.8%	43.3%	0.9%	4.2%	2.8%	8.6	13%
Assembly Equipment	5.1%	0.8%	6.1%	34.0%	13.6%	2.9%	37.5%	6.5	9%

(*) Chemical-Mechanical Planarization.
(**) Wafer Manufacturing Eqpt, Automated Handling Systems, Reticle Repair Systems, Wafer Marking Systems.
Note: the market share for assembly corresponding to the ROW is almost entirely attributable to Singapore.
Source: JRC elaboration on TechInsights (data, accessed 08/02/2023). CAGR stands for compound annual growth rate.

Source: JRC, 2023

According to the JRC, nearly 80% of input suppliers and 63% of customers to the companies in the EU supply chain were located outside the EU in 2021.

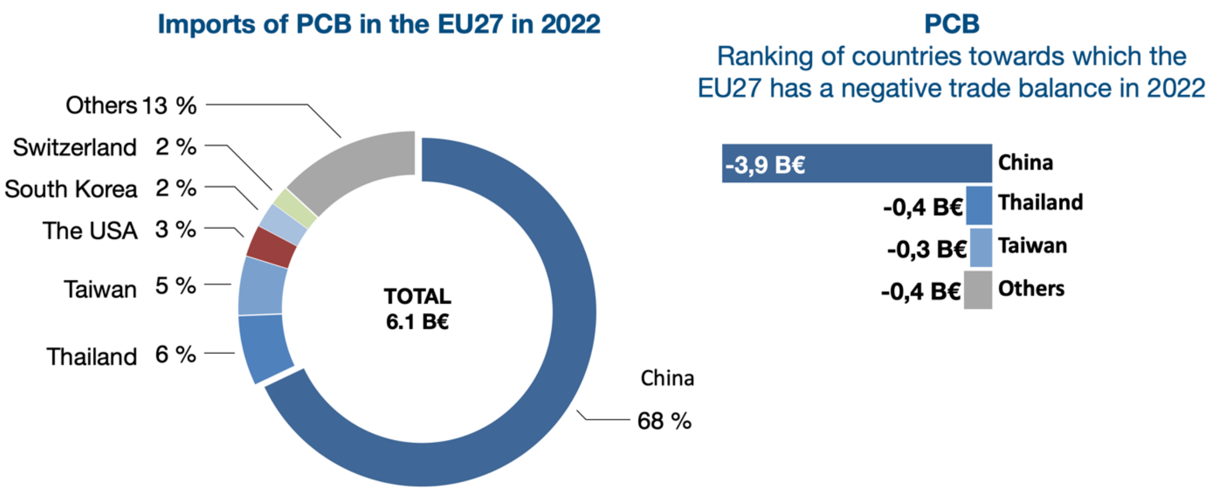
2.3.7 Printed Circuit Boards – A strategic dependency towards China

Printed Circuit Boards (PCB) are the bare boards used to mechanically support and electrically connect electronic components using conductive tracks, pads and other features etched from one or more sheet layers of copper laminated onto and/or between sheet layers of a non-conductive substrate. They are necessary equipment for all electronic devices and products and are responsible for the transmission of digital and analog signals, power supply (automotive, energy industries…), and sending and receiving radio frequency and microwave signals for electronic devices (digital, 5G/6G, edge IoT). PCB are not semiconductors but are compulsory to build an electronics system.

Printed Circuit Boards (PCBs) correspond to the typical situation of strategic dependency of the EU towards a third country:

- An absence of minimum capacities for internal production to substitute imports. In 2022, the production of PCB on EU soil accounted for 2.9B€, corresponding to 3,5% of the global production. For already a decade, the factories located in the EU only serve the aerospace-defense market and a few health & care applications. The only large company in the EU is the Austrian AT&S.
- The reliance on a limited number of countries. In 2022, the electronics industry located in the EU consumed nearly 7B€ PCB and an amount of 6.1 billion euro (cf. figure below) was imported in the EU. In value, 68% was coming from mainland China which turns out to be the largest supplier with whom the EU had negative trade balance of 3.9B euro in 2022.
- A strategic importance. PCB are required to manufacture any type of electronics systems, including for automotive, telecommunications infrastructures, servers & data centers, renewable energies (solar panels, wind turbines, etc.), etc. Currently, the EU is dependent on China for the manufacture of all these electronics systems through PCB.

Figure 16: A strategic dependency from the EU towards China for PCB



Source: DECISION Études & Conseil, from Eurostat figures. Code 7722: Printed Circuits, and parts thereof, nes.

PCB manufacturers are also required in the manufacture of IC substrates. The dependency of the EU in PCB is linked with its dependency in IC substrates. The only significant company in the EU manufacturing IC substrates is also the Austrian AT&S.

2.3.8 Raw materials – The EU faces numerous strategic dependencies despite benefiting from a strong industrial ecosystem.

The EU benefits from a strong ecosystem of industrial suppliers of raw materials & tools for semiconductors

- Pure gases (nitrogen, oxygen, argon, hydrogen, helium, CO_2). The EU benefits from three global leaders: Merck (Germany), Air Liquide (France) and Linde (Ireland).
- Materials & chemicals used in up to 250 semiconductor manufacturing steps. The EU benefits from five global leaders: Merck (Germany), Air Liquide (France), BASF (Germany), Umicore (Belgium), Linde (Ireland).
- Tools. Atlas Copco (Sweden), including its subsidiary Edwards Vacuum, provides vacuums and industry 4.0 solutions and certified tools for cleanrooms. Atlas Copco's global semiconductor sales in 2022 are estimated at ~1.5 B€ by DECISION. Regarding EUV lithography, ASML is supported by Trumpf (Germany), providing lasers; Carl Zeiss (Germany), providing optical systems; VDL (Netherlands), providing vessels; Süss MicroTec (Germany), providing photomasks amongst other tools...
- Factories & cleanrooms. Exyte (Germany) is a global leader in the building of semiconductor factories, including cleanroom, acting as an integrator and construction site manager. With global sales in semiconductors of ~4.5 B€ in 2022, Exyte is the fifth largest semiconductor company in the EU, after ASML, STMicroelectronics, Infineon and NXP, but before Bosch, AMS OSRAM, etc.

These players account for ~15-20% global market shares on average in their respective segments and collaborate with the leading semiconductor companies both in the US and in Asia.

In spite of this strong ecosystem, the EU faces several strategic dependencies, especially regarding raw materials.

The table below, from the report Applying the SCAN methodology to the Semiconductor Supply Chain (JRC Working Papers in Economic and Finance, 2023/8), reports the scoreboard of products under medium or high risk according to structural indicators (columns 1 to 6), as well as the subset of products that are in high distress due to reductions in import quantity accompanied by increases in import prices observed over the last available quarter (columns 9 to 11).

Figure 17: Scoreboard of SCAN indicators for products in the semiconductor value chain

		Structural Indicator (S)								High-frequency Indicators (H)		S+H
		Concentration indexes (2021)			Substitutability indexes (2021)			% change (2021 -2019)				
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Product	Segment	1st source	Share 1st source (%)	HHI index	Imp/Exp	Exposure Index (%)	Ex-ante risk	Conc.	Subst.	% change import p	% change import q	Level of distress
Germanium oxides and zirconium dioxide	R	China	50.9	0.30	1.6	64.5	*	7.8	7.2	26.0	12.6	
Azides, silicides, whether or not chemically defined	R	India	53.2	0.37	1.2	78.3	*	-1.2	-6.4	55.1	-58.3	High distress
Borides whether or not chemically defined	R	United Kingdom	48.3	0.40	2.4	87.5	*	-2.8	-1.8	-28.9	115.6	
Photographic plates and film in the flat for monochrome photography	IW	Japan	82.5	0.70	0.9	60.7	*	24.0	8.2	48.7	-20.5	High distress
Articles of niobium "columbium" or rhenium, n.e.s.	IW	United States	71.4	0.58	2.3	68.7	**	7.4	21.8	9.2	36.6	
Sheets and plates of polarising material	I	Japan	51.3	0.32	1.9	81.5	*	-4.3	-3.5	10.4	-8.0	High distress
Fans of a kind used solely or principally for cooling microprocessors	E	China	57.3	0.35	0.8	83.5	*	-3.6	28.6	152.5	-49.7	High distress
Diodes (excl. photosensitive or light emitting diodes "LED")	F	China	56.8	0.35	0.5	65.7	*	15.9	8.5	44.1	-0.8	High distress
Photosensitive semiconductor devices, incl. PV cells	F	China	88.6	0.79	1.3	88.3	**	34.2	1.1	22.6	148.4	
Electronic integrated circuits as dynamic random-access memories "D-RAMs", with a storage capacity of <= 512 Mbit	F	Taiwan	59.1	0.39	0.6	98.7	*	35.7	-19.0	51.5	-46.2	High distress

Source: Report "Applying the SCAN methodology to the Semiconductor Supply Chain", JRC, 2023/8[35].

[35] *JRC B.1 elaboration on COMEXT (trade statistics) and PRODCOM (production statistics) data (year 2021) for structural indicators (last extraction date: 21/03/2023), and on monthly trade data (COMEXT) for the period 2019-2023 for high-frequency indicators (last extraction date: 29/03/2023). Data on the quality of governance from the Worldwide Governance Indicators project are used for the heat-map in column 1. R: Raw materials, IW: Inputs for wafers, I: Foundry inputs, E: Equipment, F: Final products.*
NOTE: How to read this scoreboard: for values of structural indicators above the thresholds; chosen thresholds for concentration indexes are 50% for the share of 1st source in extra-EU imports (column 2) and 0.4 for the HHI index (column 3). For substitutability indexes, the thresholds are equal to 1 for the ratio of extra-EU imports and total EU exports (column 4), and to 60% for the exposure index (column 5). The exposure indicator is computed as the share of extra-EU imports in EU total supply (sum of domestic production from PRODCOM and extra-EU imports).
Column 1 reports the country name that is the 1st source in supplying a given product to the EU market. Orange-coloured cells indicates countries with an average WGI between the first and the second quartile (i.e., low-medium score ranking); yellow-coloured cells indicates countries with an average WGI between the second and the third quartile (i.e., medium-high score ranking); green-coloured cells indicates countries with an average WGI (World Governance Indicators) above the third quartile (i.e., high score ranking).
Column 7 reports the average of the percentage changes in the two concentration indexes over the period 2021 – 2019. Column 8 reports the average of the percentage changes in the two substitutability indexes over the period 2021 – 2019.
High-frequency indicators, i.e. changes in import prices (column 9) and changes in import quantities (column 10), are constructed by comparing the average for the quarter Nov. 2022 – Jan. 2023 with the average of the same period for 2021, 2020, and 2019.
Products under medium risk (in column 6) have at least one concentration index and one substitutability indicator above the relative thresholds, while high risk products (**) have values above the thresholds in all four structural indicators. Products in high distress (column 11) are those in ex ante medium or high risk of disruptions while also reporting increases in import prices and falls in quantities.*

Looking at the structural indicators displayed in this table above, one can observe that eight products belonging to this supply chain can be considered in medium risk of import disruption due to high import concentration and low substitutability in year 2021[36]. This group of products in medium risk includes raw materials, inputs to produce wafers, equipment for the manufacture of semiconductors, and semiconductor devices, which are the final products of this supply chain. The name of the country accounting for the largest share of EU imports is displayed in column 1. Most of these products are sourced from Asia, and China is the main first source country of EU imports for these products.

Ideally, the strategic role of the first source country for imports of products in this supply chain shall be pondered by taking into consideration the possible risks associated to import dependence on this country. Given this, the JRC augmented the information provided in column (1) by employing data on the geopolitical risk of the country accounting for the largest share of EU27 imports, relying on information from the World Governance Indicators (WGI)[37].These indicators, developed by the World Bank, inform on the traditions and institutions by which political power is exercised in each country. These include the procedures by which governments are monitored while in charge, how their powers are balanced, how they can be replaced, the respect of citizens and state for the institutions governing economic and social interactions. The WGI focus on six broad dimensions of governance[38]:

i. Voice and accountability
ii. Political stability and absence of violence/terrorism
iii. Governance effectiveness
iv. Regulatory quality
v. Rule of law
vi. Control of corruption.

Trade partners like China and India, which report an average of WGI for year 2021 between the first and the second quartile of the WGI distribution at the global level, are

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[36] If one of the two concentration indexes and one of the two substitutability indexes are above the respective thresholds, a product is considered as being in medium risk.

[37] The Worldwide Governance Indicators (WGI) project reports aggregate and individual governance indicators for over 200 countries and territories over the period 1996–2021 (see https://info.worldbank.org/governance/wgi/).

[38] The Worldwide Governance Indicators (WGI) are assembled by summarizing the views on the quality of governance provided by a large number of enterprise, citizen, and expert survey respondents in industrial and developing countries. These data are gathered from a number of survey institutes, think tanks, non-governmental organizations, international organizations, and private sector firms.

indicated in orange, while countries with a higher average WGI are indicated in green in column (1).

In addition, we find two products that can be considered under high risk of import disruption as all their structural indicators are above the respective thresholds. In column 6, these high-risk products are highlighted with a double asterisk to distinguish them from medium risk products (single asterisk). Indeed, around 70% of EU27 imports for the product *"articles of niobium columbium or rhenium"* originate from the United States, while extra-EU imports more than double total EU exports. For *"photosensitive semiconductor devices"*, imports from China make up almost the entire extra-EU supply with a market share around 90%.

Structural indicators provide a picture on medium-term dependencies of the EU, while observing their evolution over time provides insights on how dependencies varied over the last years. It is therefore important to stress that the EU reported sizeable increases in import concentration and/or reductions in substitutability (which are determined by either an increase in the import/export ratio or/and in the exposure index) for seven products out of ten in medium or high risk during the period 2019-2021 (columns 7 and 8). This evidence further confirms the need to closely monitor this strategic supply chain.

Results obtained from high-frequency data sheds light on changes in EU27 import prices and quantities over the last quarter (Nov. 2022 to Jan. 2023). A total of six products in medium or high risk of disruption according to structural indicators, are also in high distress due to observed reductions in import quantities accompanied by increases in import prices (columns 9 to 11) over the last observed quarter. Products traded along the semiconductor supply chain whose imports are in high distress are:

i. Azidies, Silicides.

ii. Photographic plates and film in the flat for monochrome photography.

iii. Sheets and plates of polarising material.

iv. Fans of a kind used principally for cooling microprocessors.

v. Diodes.

vi. Electronic integrated circuits as dynamic random-access memories.

Most of these products are currently subject to EU import restrictions from specific geographical areas. A subset of them is also subject to EU export authorizations due to their potential dual use (e.g. *Photographic plates and film in the flat for monochrome photography, Diodes, Electronic integrated circuits as dynamic random-access memories)*[39].

[39] The interested reader can refer to: https://www.tariffnumber.com

According to the Study on the EU's list of Critical Raw Materials (2020), 48% of the Indium production is located in mainland China, while it is required in the manufacturing of semiconductors & LEDs.

Finally, the JRC 2023 report "Semiconductors in the EU - *State of play future trends and vulnerabilities of the semiconductor supply chain*" [40], provides a complementary overview of the EU dependency on non-EU imports for raw materials and intermediate products used by EU companies. The results are reported on the table below.

Figure 18: EU dependency on non-EU imports for selected products used in the semiconductors value chain, 2021.

			2021		
Segment	HS code	Product	EU dependency on foreign imports (%)	top importer in the EU	Share of top importer in tot EU imports (%)
Raw Materials					
	28256000	Germanium oxides and zirconium dioxide	63	CN	32
	28500060	Azides, silicides, whether or not chemically defined	76	IN	40
	28500090	Borides, whether or not chemically defined	86	UK	41
Intermediate goods used in equipment production					
	84145915	Fans of a kind used solely or principally for cooling microprocessor	84	CN	48
	84863000	Machines and apparatus for the manufacture of flat panel displays	100	KR	40
Intermediate goods used as input for wafer production					
	37013000	Photographic plates	61	JP	50
	81129930	Articles of niobium "columbium" or rhenium	89	US	64

[40] Cerutti, I. and Nardo, M., *Semiconductors in the EU*, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/038299, JRC133850.

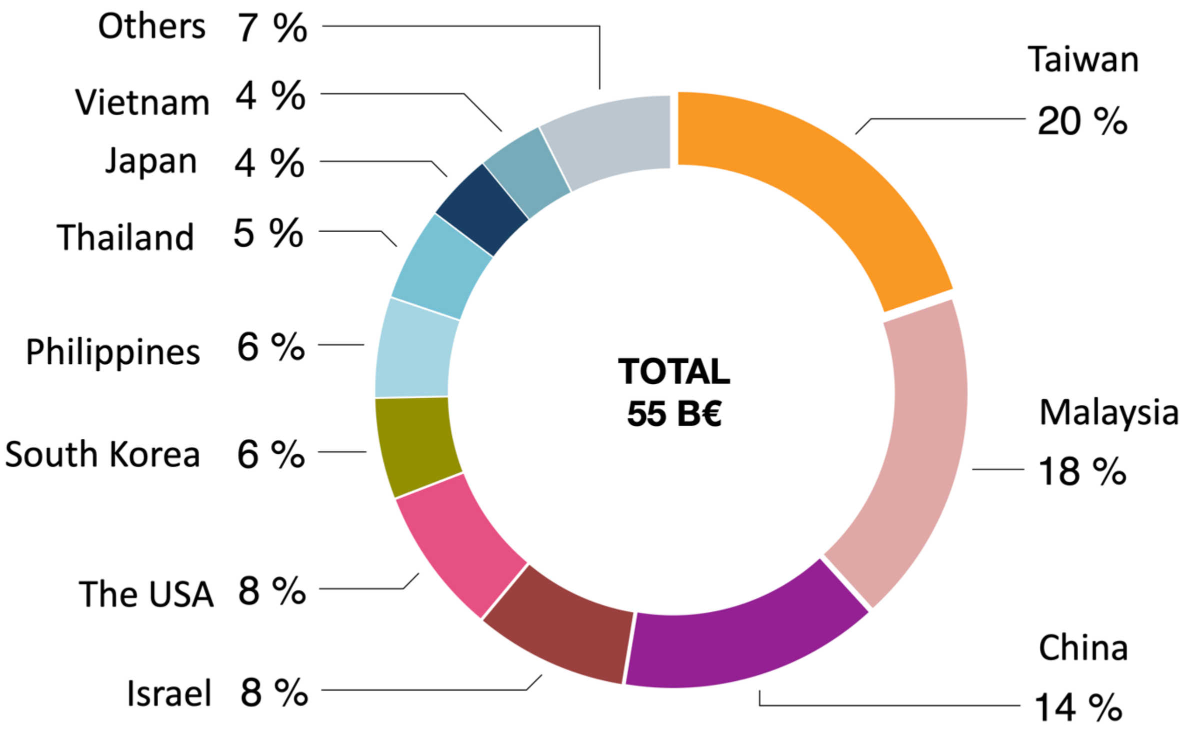
Silicon&chemicals used for wafers					
	38180010	Silicon doped for use in electronics, in the form of discs, wafers	55	JP	34
	38180090	Chemical elements and compounds doped in the form of discs, wafers	57	JP	21
Intermediate goods used as input for foundries					
	90012000	Sheets and plates of polarising material	81	JP	42
	90314100	Optical instruments and appliances for inspecting semiconductor wafers	75	SG	29
	90019000	Lenses, prisms, mirrors and other optical elements	70	CN	20
Chips					
	85235910	Semiconductor media, unrecorded, for the recording of sound	98	TH	20
	85235110	flash memory cards or flash electronic storage cards, unrecorded	96	KR	31
	85235190	flash memory cards or flash electronic storage cards, recorded	93	TW	18
	85235990	Semiconductor media, recorded	98	JP	40
	85414010	Light-emitting diodes, incl. laser diodes	83	CN	34
	85414090	Photosensitive semiconductor devices, incl. photovoltaic cells	88	CN	78
	85423190	Electronic integrated circuits as processors and controllers	83	MY	22
	85423231	D-RAMs", with a storage capacity of <= 512 Mbit	99	TW	58
	85423239	D-RAMs, with a storage capacity of > 512 Mbit	99	TW	46
	85423245	static RAMs, incl. cache random-access memories	100	TW	30
	85423261	flash E2PROMs, with a storage capacity of <= 512 Mbit	87	TW	36
	85423269	flash E2PROMs, with a storage capacity of > 512 Mbit	87	JP	18
	85423275	E2PROMs (excl. flash E2PROMs)	73	CN	18
	85423290	Other stack D-RAMs	83	TW	23
	85423310	MCOs (amplifiers)	83	MY	25

Source: JRC elaboration on a basket of 74 products associated to the semiconductors value chain according to OECD, 2019. Raw data come from Comext and Prodcom 2021. Product labelling has been abbreviated for space reasons.

2.4 EU trade balance in semiconductors

Overall, three countries, Taiwan, Malaysia, and China are accounting for 52% of the total EU semiconductor imports.

Figure 19: Imports of semiconductors (excluding optoelectronics) in the EU27 in 2022[41]



Note : The Eurostat data nurturing this graph combine trades of semiconductors as end-products with semiconductors as work-in-process (after the front-end steps, but before the back-end step).

Source: DECISION Etudes & Conseil, Eurostat

Some European IDMs have a significant proportion of their manufacturing production relocated to the South-East Asian countries. For example, AMS and Infineon have 63% and 27% respectively of their front-end capacity located in Malaysia. Similarly, on the back-end, AMS, Infineon, NXP and STMicroelectronics respectively have 1, 4, 1 and 3 factories respectively in this region. The imports from these countries are mainly

[41] Data from Eurostat EU trade since 1999 by SITC [DS-018995__custom_6558893]. The HS codes considered are 7764 Electronics Integrated Circuits, 77689 Parts of the articles of subgroup 776.4: Electronic components, parts nes, 77632 Transistors (excluding photosensitive transistors) with a dissipation rate of < one watt, 77633 Transistors (excluding photosensitive transistors) with a dissipation rate of one watt/more, 77639 Other semiconductor devices and 7763X Trade of sub-group 7763, not elsewhere specified. It excludes optoelectronics, associated with the HS codes 77631 Diodes, other than photosensitive/light-emitting diodes and 77637 Photosensitive semiconductor devices: light-emitting diodes. In 2022, the EU of a negative trade balance towards China of -19B€ regarding optoelectronics components. 89% of the EU's imports of optoelectronics come from China.

corresponding to intermediate steps of production from European factories abroad. This is partially controlled relocation, so it is a minor dependency.

For the other countries in the graph, the imports can be considered as major dependencies as it can be imports of previous relocation of manufacturing services or imports of end products. By decreasing order: Taiwan (20%), China (14%), Israel (8%), the USA (8%), South Korea (6%), and Japan (4%).

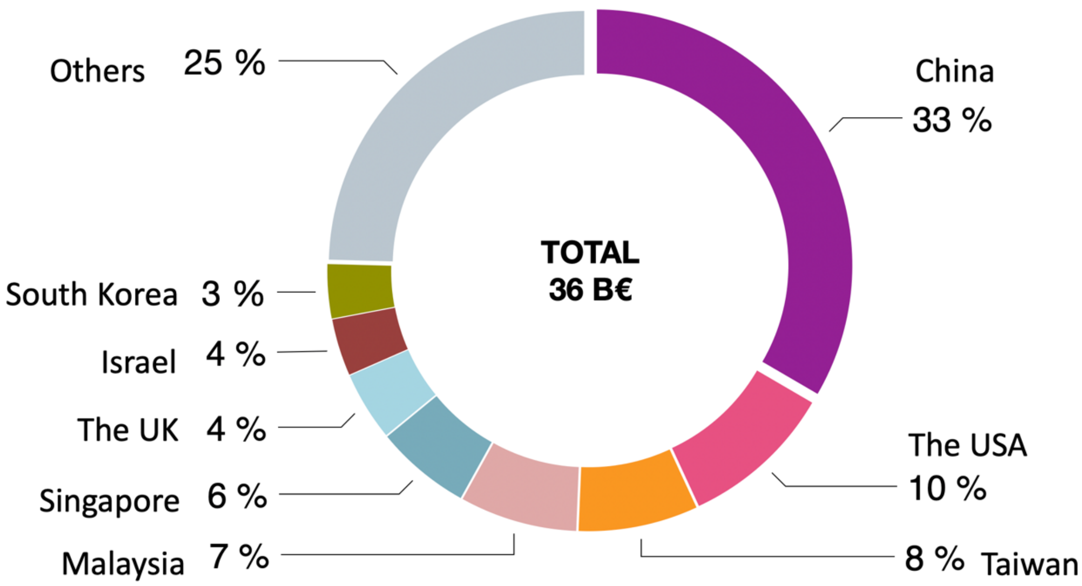
In terms of trade balance (Exports minus imports), the EU is mainly dependent towards:

- Taiwan (-8.1B€ in 2022)
- Israel (-3.3B€ in 2022)
- South Korea (-1.8B€ in 2022)
- Japan (-1.5 B€ in 2022)
- The USA (-1 B€ in 2022)

These dependencies in terms of imports have contributed to the widening of the trade balance gap in semiconductors of the EU towards non-EU countries over the past few decades.

The table below shows the exports of semiconductors from the EU to the rest of the World.

Figure 20: Exports of semiconductors (excluding optoelectronics) from the EU27 in 2022[43]



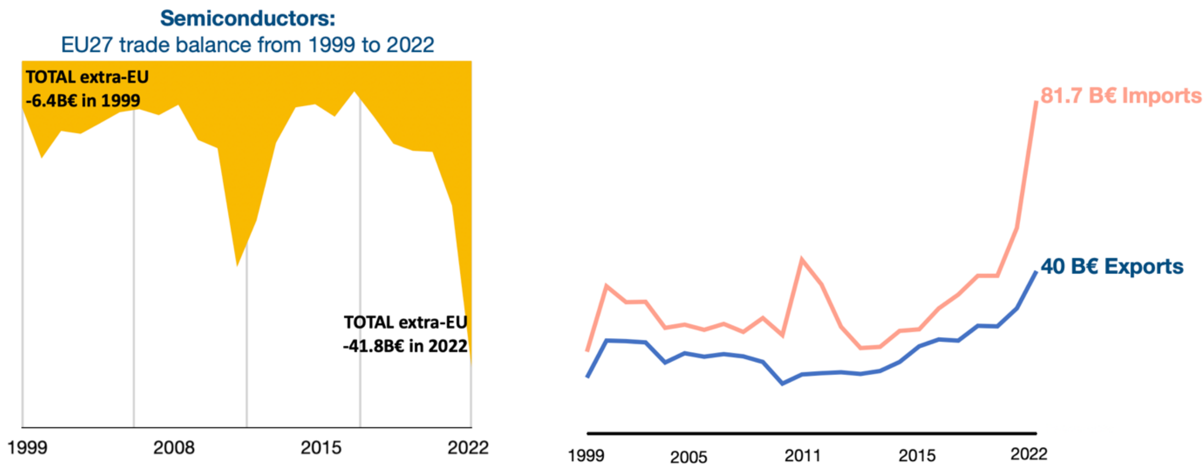
Note: The Eurostat data nurturing this graph combine trades of semiconductors as end-products with semiconductors as work-in-process (after the front-end steps, but before the back-end step).

Source: DECISION Études & Conseil, Eurostat

China appears by far as the first end-market of the EU production of semiconductors, representing 12 B€ exports in 2022. The USA comes in second with only 3.6 B€ exports in 2022.

Finally, the diagram below provides an overview of the EU trade balance with the rest of the World from 1999 to 2022.

Figure 21: The EU trade balance with the rest of the World from 1999 to 2022[42]



Source: DECISION Études & Conseil, from Eurostat

The semiconductor trade deficit of the European Union stood at €42 billion in 2022, a significant increase from the €6.4 billion deficit observed in the late 1990s. This indicates that the EU manufacturing production did not ramp up over the last decades. In fact, the situation appears to have deteriorated over recent years.

However, the strong deterioration of the EU trade balance in 2021 and 2022 is mainly due to a rise of the prices of the semiconductor imported in the EU due to the global semiconductor shortage. These figures enable to estimate that the raising of semiconductor prices imported in the EU due to the semiconductor shortage has costed 22B€ to the EU member states over the 2020-2022 period[43]. This corresponds to the price of the strategic dependencies and the lack of anticipation from the EU end-user industries.

However, looking at 2023 and the next years, the semiconductor market is now entering into a phase of reversal of its economic cycle leading to an excess of supply and a

[42] Data from Eurostat EU trade since 1999 by SITC [DS-018995__custom_6558893]. The HS codes considered are 7764 Electronics Integrated Circuits, 77689 Parts of the articles of subgroup 776.4: Electronic components, parts nes, 77632 Transistors (excluding photosensitive transistors) with a dissipation rate of < one watt, 77633 Transistors (excluding photosensitive transistors) with a dissipation rate of one watt/more, 77639 Other semiconductor devices and 7763X Trade of sub-group 7763, not elsewhere specified. In this figure, optoelectronics components are included. They are associated with the HS codes 77631 Diodes, other than photosensitive/light-emitting diodes and 77637 Photosensitive semiconductor devices: light-emitting diodes. In 2022, the EU of a negative trade balance towards China of -19B€ regarding optoelectronics components. 89% of the EU's imports of optoelectronics come from China. This explains the gap between the value of imports and exports between figure 24 and figures 22 and 23.

[43] DECISION has compared over the 2020-2022 period the growth of the prices of the semiconductors exported from the EU to the rest of the World on the one hand, with the growth of the prices of the semiconductors imported into the EU own the other hand. Prices of semiconductors imported into the EU have grown at a way higher pace. DECISION model the scenario in which the growth of prices would have followed the same pace over the 2020-2022 period, whether imported into the EU or exported to the rest of the World. In such scenario, the EU trade balance would have improved for +22B€.

decrease of prices. Several orders sent from EU companies for semiconductor at high prices will be cancelled, lowering the impact of the semiconductor shortage on prices for 2023 and the next years.

The JRC published a report "Semiconductors in the EU - *State of play future trends and vulnerabilites of the semiconductor supply chain*"[44], in 2023, which provides insights on the interdependencies between countries and regions through international trades. The results are reported on the two tables below, for integrated circuits.

Figure 22: Heat map of the global flows of import (in billion EUR) in 2021 relative to electronic integrated circuits and their parts

From→ To (Reporter)↓	ASEAN	China	EU27	Japan	South Korea	Taiwan	USA	TOTAL
ASEAN		34	4	7	19	27	7	97
China	122		11	24	95	175	17	445
EU27	13	5		1	1	3	3	26
Japan	3	2	1		2	12	2	21
South Korea	5	18	1	3		12	3	42
Taiwan	12	17	2	9	14		4	58
USA	21	2	2	1	2	5		32
TOTAL	176	78	21	43	133	234	37	721

Source: Data taken from UN Comtrade for HS code 8542 in 2021. Data refers to import from the importer.

China (including Hong Kong) had the highest trade flows in 2021, in particular from Taiwan and ASEAN (Association of Southeast Asian Nations) countries.

The EU27 not only has a strong trade with China but also a CAGR of import with the same country of around 19.5% in over the 2017-2021 period.

[44] Cerutti, I. and Nardo, M., *Semiconductors in the EU*, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/038299, JRC133850.

Figure 23: Heat map of the CAGR (in percentage) for the import in the period 2017-2021 relative to electronic integrated circuits and their parts

From→ To (Reporter)↓	ASEAN	China	EU27	Japan	South Korea	Taiwan	USA	AVG on import
ASEAN		23.2	4.7	9.6	5.4	7.1	-5.7	9.7
China	10.8		16.2	7.8	5.8	15.7	10.5	11.2
EU27	16.4	19.5		-8.9	12.0	7.6	21.1	15.1
Japan	1.9	8.1	-0.3		2.5	8.2	1.1	5.7
South Korea	3.1	17.1	14.9	1.5		8.6	-5.3	9.3
Taiwan	14.6	19.3	6.3	12.0	21.4		3.8	15.5
USA	7.3	-4.9	-5.6	-8.0	4.4	7.1		4.5
AVG on export	10.5	18.8	8.6	7.6	6.9	13.4	4.4	

Source: Data taken from UN Comtrade for HS code 8542 in 2017 and 2021. Data refers to import from the importer.

2.5 Strengths, weaknesses and dependencies

Strengths of the EU Semiconductor Industry

- Integrated Device Manufacturers (IDMs): The EU has important IDMs that produce semiconductors for automotive and industrial applications, reflecting a rather strong market position in these sectors.
- Product specificity: There is a pronounced expertise in designing and manufacturing analog chips, radio frequency (RF) components, sensors & MEMS, power semiconductors, microcontrollers, and silicon photonics.
- Materials and Equipment: The EU holds a competitive edge in the supply of materials (gases and chemicals)[45], and lithography equipment necessary for advanced semiconductor manufacturing processes.
- Research and Development: The region is home to leading R&D centers that contribute to innovation in the semiconductor industry at the world level.

Weaknesses

- Collaboration in the Value Chain: There is a need to foster stronger cooperation between large companies and innovative SMEs, which currently struggle to gain attention. This is especially true in the design of advanced processors for embedded systems, where the EU is homed to a flourishing ecosystem of startups (supply) and has one of the strongest end-user industries (automotive, industrial, health & care...).
- Digital Logic Design: The EU is not as strong in designing digital logic components, which are becoming increasingly crucial due to the rise of data, AI, and connectivity.
- Industrial Translation of R&D: Despite robust investment in R&D, European players face challenges in translating these advancements into industrial benefits, partly due to the absence of advanced manufacturing processes locally, that could be bolstered with the implementation of pilot lines.

[45] The EU benefits from a strong industrial ecosystem, with leading players such as Merck, Air Liquide, BASF, Umicore, Atlas Copco (including Edwards Vacuum), and Linde. The cumulated sales of the EU players on the global semiconductors materials market accounted for 12B€ in 2021 according to DECISION (based on company financials). According to SEMI and Techcet, the global market of semiconductors materials accounted for 49B€ in 2021. This implies 24% market shares for the EU players, although many of them have a strong presence of non-EU funds and companies in their capital: Air Liquide, BASF (mainly US owned), Umicore, and Linde (mainly US owned). ICOS do not have specific inputs on the location of the manufacturing sites, this would require a specific study.

Dependencies

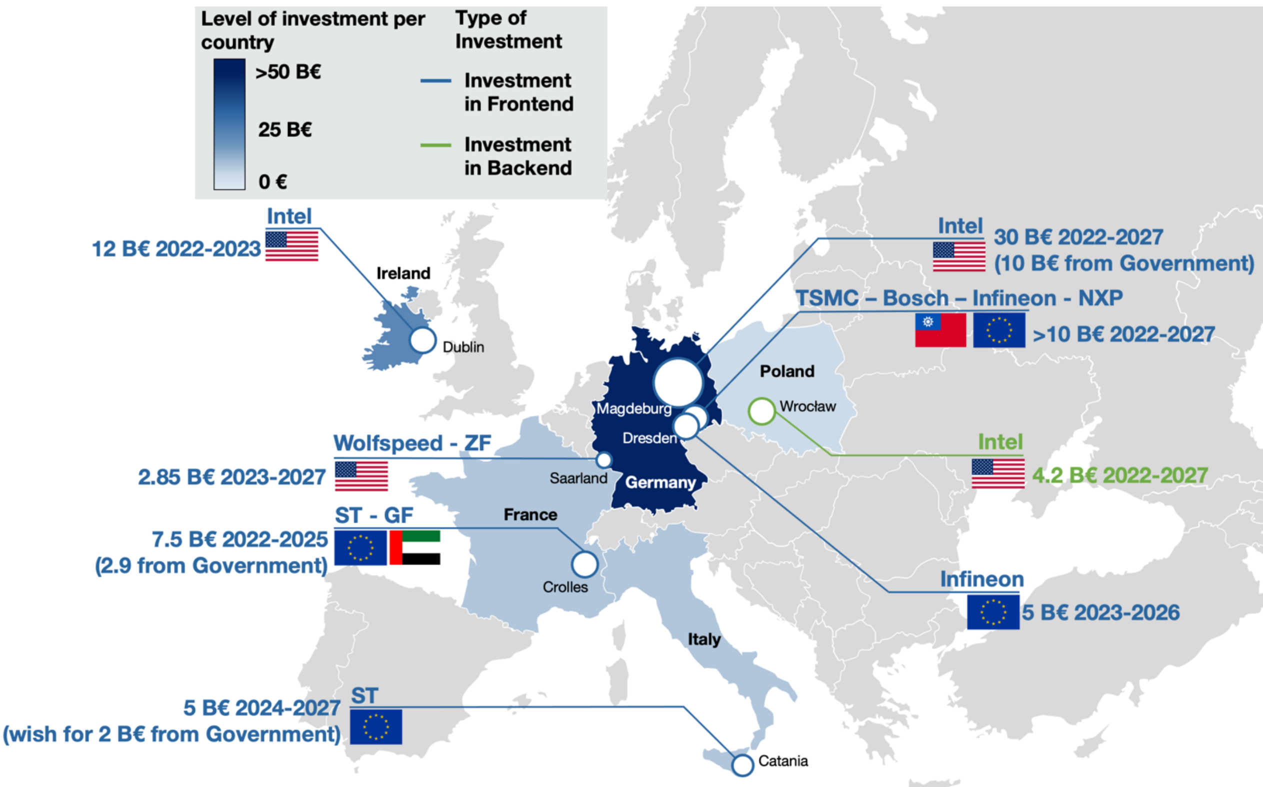
- Critical Dependencies:
    - Advanced Logic Capabilities: There is a significant gap in advanced logic design and manufacturing, such as microprocessors and memory, which are vital for digital advancements in areas like AI, Edge Computing, ADAS, Infotainment, Smart Industry and 5G/6G. The EU market for advanced logic semiconductors is expected to grow from €3 billion in 2021 to €25 billion in 2027, according to DECISION. This market is currently mostly dominated by US players (Intel – Mobileye, Nvidia, Qualcomm and AMD).
- Major Dependencies:
    - Printed Circuit Boards (PCBs): Main suppliers are predominantly in China and Taiwan, from which 50% of the EU consumption comes from.
    - Rare Earth Materials: Over 40% of raw materials for semiconductor like silicon and gallium are sourced from China.
    - Advanced Packaging: The EU is highly dependent on major OSATs for these services, which are located in Asia. The few advanced capacities that are located in the EU are or will be owned by US manufacturers: Intel and Amkor.
    - Etching & Cleaning Equipment: There is a significant reliance on the United States for this machinery (LAM Research), as the EU has no equipment manufacturer for these processes.
- Minor Dependencies:
    - IC Substrate: This is another area where the EU shows considerable reliance on external sources, with a single relevant supplier (AT&S), and less than 1% of the manufacturing capacities located on EU soil. Japanese manufacturers, and to a lesser extent Taiwanese and South Korean manufacturers are leading this market.
    - Photomasks: Although 13% of the global manufacturing capacities are located on EU soil, the EU has no supplier in this field, indicating a heavy reliance on imports for these essential components. The main suppliers are Japanese (>60% of global production), except the American Photronics and a few Chinese manufacturers. Some IDMs also produce their own photomasks.

2.6 Ongoing investments in the EU

The map below is providing an overview of all the main investment in semiconductors announced within the EU for the 2022-2027 period. Only the investments exceeding 1 B€ are reported on the map. The most important investments are:

- Intel foundry in Magdeburg (Germany). The planned investment is €17 billion, 40% of which would be funded by the German government. Intel targets the angstrom geometry in Magdeburg.
- Intel foundry in Leixlip (Ireland), with a new investment of 12 B€ to produce in 7 nm.
- TSMC is partnering with Bosch, NXP and Infineon to create a joint venture for chip manufacturing (300mm, heading towards 12 nm). They are expecting 40% subsidies out of a total of more than 10 B€ investment.
- STMicroelectronics' co-investment in Crolles with GF (US) for 7.5 B€, with 2.9 B€ subsidies from the French government, to produce 22 nm FD-SOI at first, then 18 nm FD-SOI.

Figure 24: Ongoing investment plans in semiconductor in the EU, November 2023



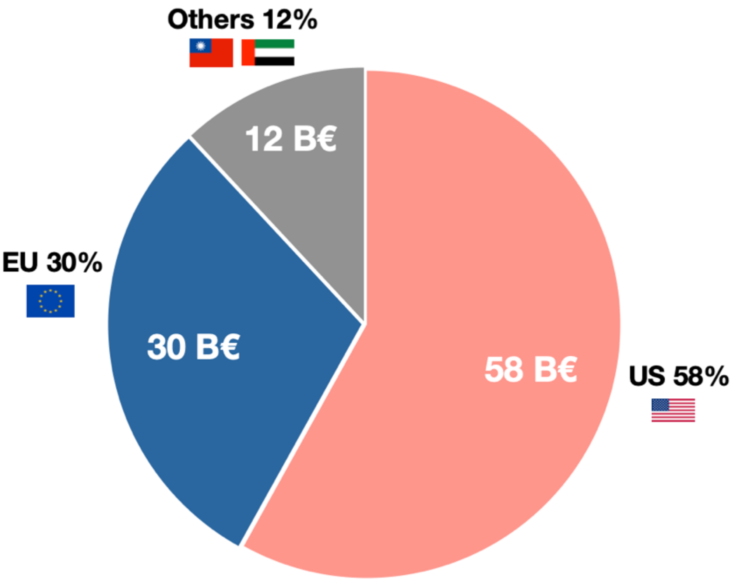
Source: DECISION Etudes & Conseil

- Infineon has begun the construction of a €5 billion chip plant in Germany, for 12 nm Power SiC and analog mix signal semiconductors (automotive and industrial manufacturing). The company was granted €1 billion, 20% of the total investment, in subsidies.

- STMicroelectronics plans to open a new megafab in Catania, Italy, with a €5 billion investment dedicated to silicon carbide chip production. The company is seeking up to 40% of the total cost in public subsidies under the European Chips Act. Moreover, a €730 million SiC substrate manufacturing facility is under construction in Catania, Italy.

Bosch also plans to invest €3 billion through 2026 to expand semiconductor production, aligning with the EU's IPCEI funding program. This investment addresses the growing demand for semiconductors in the automotive industry, propelled by electrification and autonomous vehicle technology. Bosch will build two new development centers in Reutlingen and Dresden, costing over €170 million, and add clean room space at its Dresden wafer production site. The Reutlingen site will also see an expansion worth about €400 million.

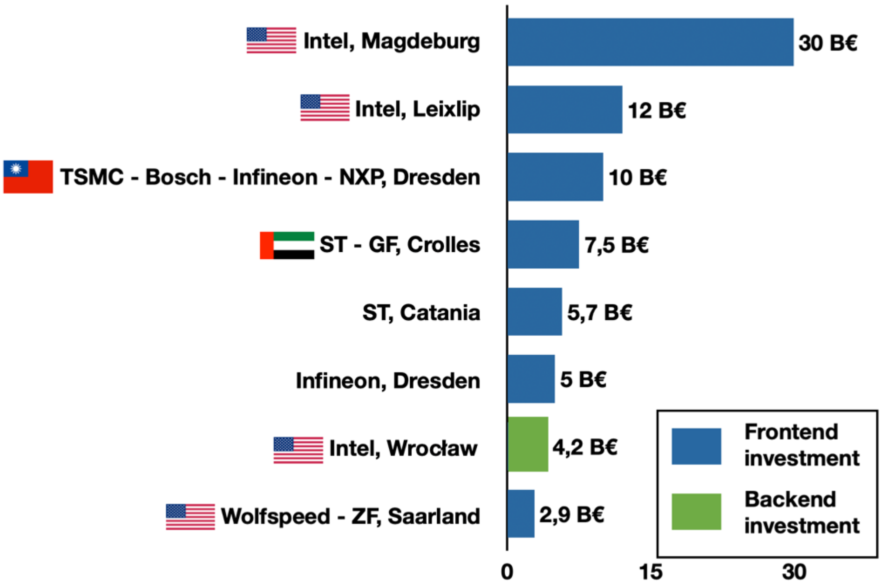
Figure 25: Investment in semiconductors in the EU from 2022 to 2027, breakdown by nationality of beneficiaries



Source: DECISION Etudes & Conseil

The pie chart above illustrates the distribution of capital expenditures of investment projects announced from 2022 and projected through to the beginning of production of the last project in 2027. In total, semiconductors investments in the EU currently account for 100B€, as announced by Commissioner Thierry Breton. This data is subject to change, as additional investments could modify the timeline and the total investment from each region. Within this period, the US companies lead in terms of investment amounts on EU soil, with a total of approximately €58 billion. This is followed by players from the EU, contributing a total investment of €30 billion, and then by other regions, Taiwan (TSMC), and the Emirates (GF), with combined projects amounting to €12 billion. This distribution highlights the significant investing power of the US in the EU. The EU is in a unique situation, where more than half of the investments on its soil benefits to companies owned by a single foreign country.

Figure 26: Ranking of the major semiconductor investments in the EU from 2022 to 2027



Source: DECISION Études & Conseil, November 2023

Out of the top 10 investments over the 2022-2027 period, US companies play a major role, participating in seven investments. Intel stands out, funding the two largest investments in the EU, as well as one of the two single large-scale back-end investment in Europe. Even if these investments could result in an increase in manufacturing capacities in the next few years, it represents a rising dependency of the EU towards the US in the coming years.

Another aspect to consider is the imbalance in terms of investment across the value chain as there is only one investment in back-end for ten investments in front-end manufacturing.

Finally, there are still no EU companies investing in advanced nodes whereas foreign companies invest in the EU, especially in the nodes made for the automotive industry, to bolster the EU automotive industry.

2.7 Cooperation & alliances

2.7.1 Existing cooperation framework

The European Union (EU) has been actively engaging in Trade and Technology Councils (TTC) and Digital Partnerships. This engagement is primarily focused on research and development cooperation, crisis management, and increased transparency regarding subsidies. These initiatives are in line with the objectives set forth in the EU Chips Act, which aims to strengthen the region's semiconductor industry.

Digital partnerships

In 2022, the European Union announced the establishment of Digital Partnerships with Japan, South Korea, and Singapore. These partnerships were formally launched in 2023, signifying a new phase of international technological collaboration. EU Commissioner Thierry Breton emphasized the significance of these partnerships, noting their expected impact on the EU Chips Act, which underscores their potential to influence and shape the EU's semiconductor policy and industry framework.

Under the Digital Partnership framework, the European Union and Japan have fortified their collaborative efforts in the semiconductor sector by signing a Memorandum of Cooperation. This agreement sets the stage for **enhanced research and development collaboration**, **the establishment of an early warning system for disruptions in the semiconductor supply chain**, and **joint efforts to develop advanced skills** within the industry. While Japan currently prioritizes deeper cooperation with the United States, it remains open to exploring collaborative opportunities with the EU. The EU and Japanese co-chairs of the Japan-EU Digital Partnership Council plan to meet again in 2024 in Brussels. This meeting aims at assessing the progress made and discuss additional measures to strengthen their collaborative relationship.

The Digital Partnership between the European Union and South Korea is set to enhance collaborative efforts across various domains, including the semiconductor industry.

In contrast, the Digital Partnership formed between the EU and Singapore does not specifically address the semiconductor sector, indicating a broader focus in their collaborative agenda.

Trade and Technology Councils (TTC)

The USA-EU Trade and Technology Council (TTC), initiated in September 2021, focuses on several cooperation areas, including strengthening the resilience of semiconductor supply chains.

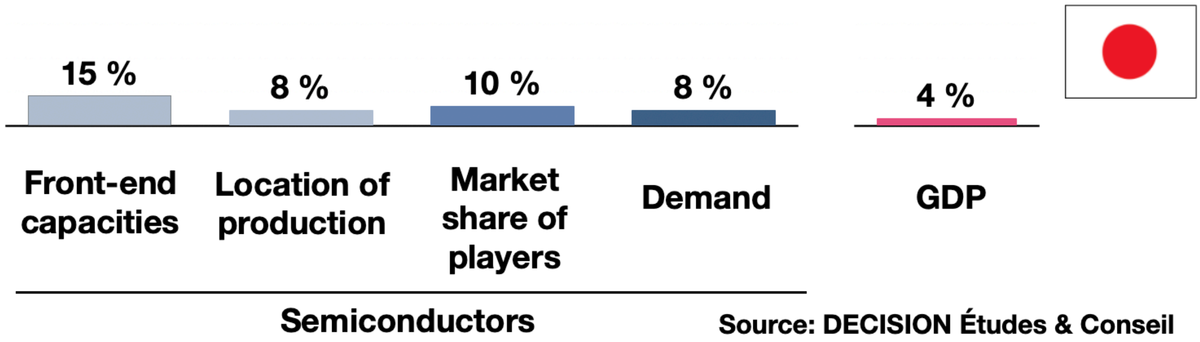
Similarly, the India-EU TTC, established in June 2021, also emphasizes agreements to bolster semiconductor supply chain resilience among other topics.

3 The Japanese semiconductor ecosystem

3.1 Overall environment and strategic objectives

The semiconductor industry is critical for the Japanese economy. At the end of the 1980s, the industry accounted for over 50% of world production; however, this figure had fallen to 9% by 2022. Today, the Japanese industry lags behind in terms of technology. Japan is adopting major new industrial policies with the objective of restoring the international competitiveness of its semiconductor industry.

Figure 27: Position of Japan across the semiconductor value chain (in percentage of the World production), in 2022



In June 2021, Japan's Ministry of Economy, Trade, and Industry (METI) announced a core strategy for the nation's semiconductor and digital industries. The priority was to establish partnerships with the US, with whom Japan has a long-standing historical relationship.

- A partnership with the US aims to design and manufacture next-generation chips. This goal is being pursued through the creation of Rapidus, a consortium of Japanese firms, IBM, and European labs like IMEC.
- The development of an R&D center, LSTC[46], with support from IBM.
- Subsidies for domestic chip manufacturing, covering 1/3 of the capital costs, are conditioned on a minimum of 10 years of domestic production and prioritization of domestic supply in case of a shortage.

Japan's effort to reinforce its chipmaking capabilities will also include the "back-end" of the production process—assembly, testing, and, in particular, packaging, which is seen as playing a crucial role in the development of advanced chips. "More than Moore," which refers to innovation beyond Moore's Law, is seen as the greatest opportunity for the Japanese semiconductor industry to regain its leadership.

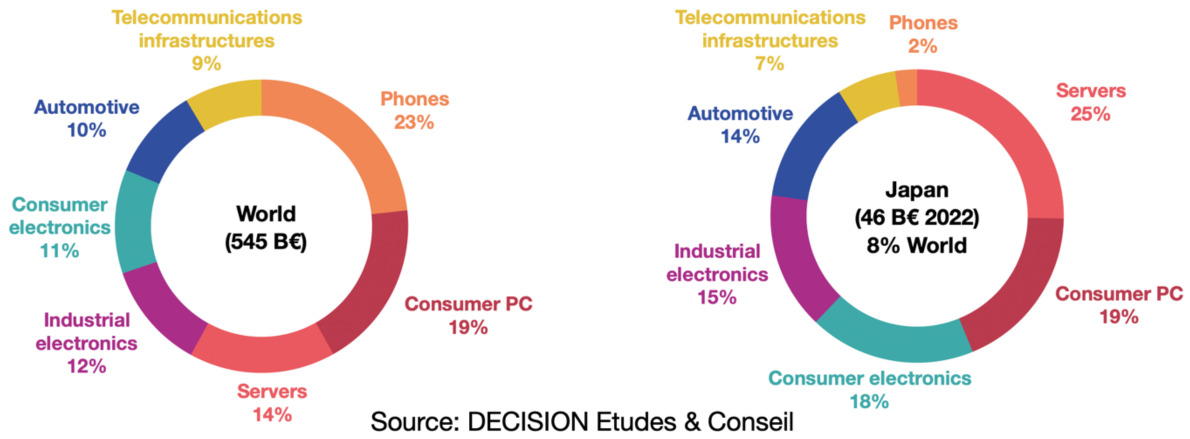
[46] Leading-edge Semiconductor Technology Center

3.2 The semiconductor market in Japan

For many decades, Japan's electronics industry was the most prosperous and innovative sector in the global electronics market. However, there is now evidence that Japanese companies have lost their traditional advantage over their rivals. Despite this decline, Japan remains home to some of the largest electronics manufacturers in the world, who have earned a global reputation for producing high-quality and reliable products.

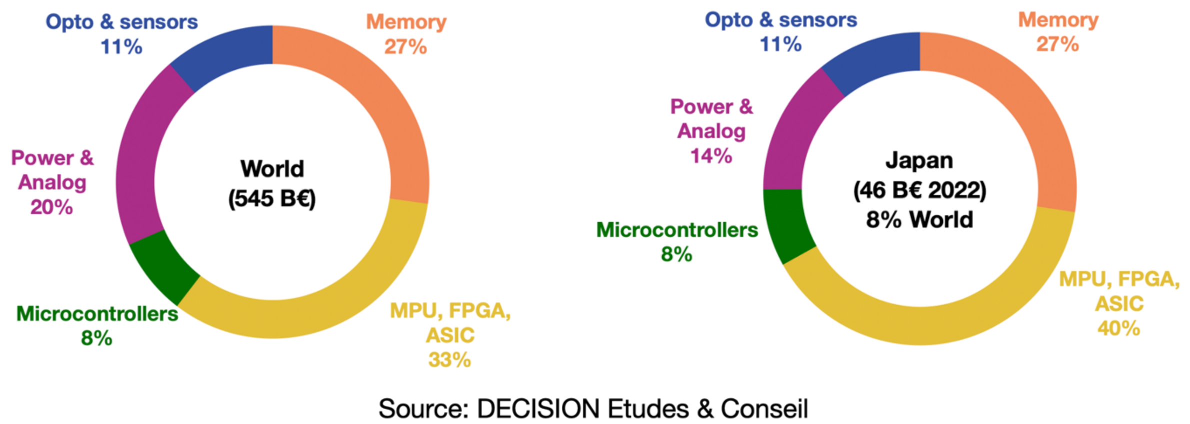
Overall, the Japanese semiconductor demand represents 8% of the global demand.

Figure 28: Spread of the Japanese semiconductor demand by application



Japan has higher shares in automotive, industrial electronics, consumer electronics and servers which depicts its strong industries. However, there is a contrast with the demand for semiconductors for phones where Japan only consumes a share of 2%.

Figure 29: Spread of the Japanese semiconductor demand by product



When looking at the product breakdown, the higher share of the consumption stems from MPUs, FPGAs, and ASICs at 40%, and Memory components at 27%. This aligns with demand for semiconductors in the server and consumer PC market, as these components are crucial for computing tasks.

Microcontrollers, optoelectronic components, and sensors, essential for a wide range of electronic devices, represent 8% and 11% of Japan's semiconductor demand, matching the global figure. These components are necessary to both industrial electronics and consumer products, supporting Japan's alignment with global semiconductor application spread in these areas.

3.3 The semiconductor industry in Japan

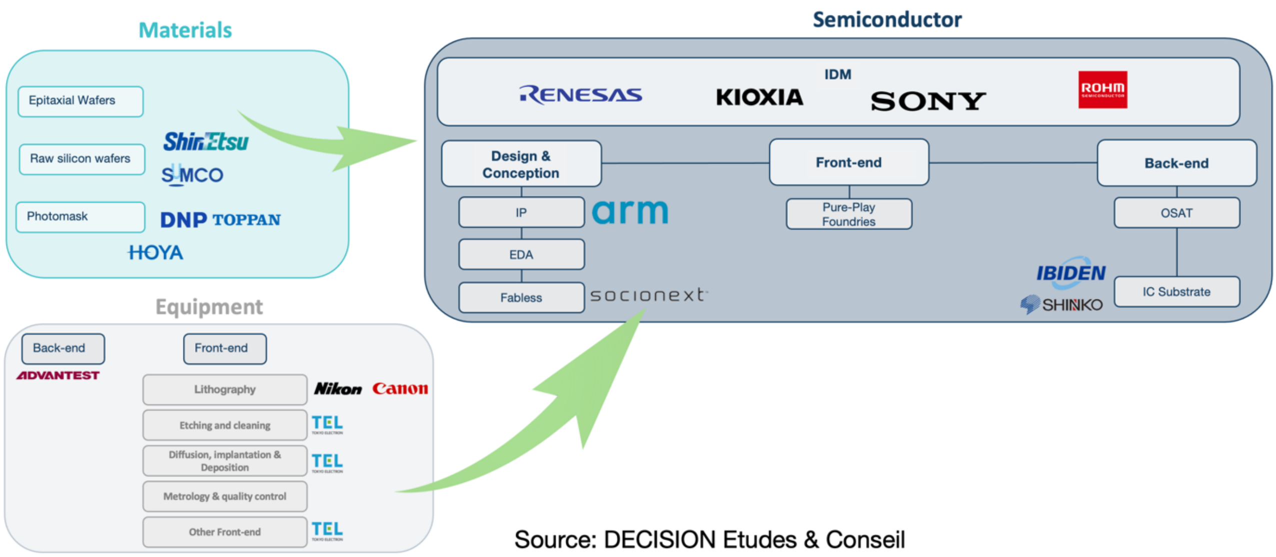
3.3.1 Key Japanese players in the value chain

The Japanese semiconductor industry shares some similarities with the European one, yet there are distinct differences as well. Japan does not have pure-play foundries or relevant OSAT companies, and only a few mid-tier fabless companies, it has maintained its historical Integrated Device Manufacturer (IDM) structure with a few specific IDMs leading the way.

Renesas is a leader among IDM players in Japan. The company has seen a significant shift in strategy, moving away from its historical focus on mergers with other Japanese companies, such as Mitsubishi and NEC. Embracing a more global outlook, Renesas has executed 9 acquisitions in various sectors, including Analog and Mixed-Signal ICs, Internet of Things infrastructure, and Enterprise Technology in Europe, spending over €21.4 billion on these acquisitions.

Kioxia is a leading IDM in memory semiconductors, especially in Flash memory where the company has always been in the Top 3 providers. Sony and Rohm are also important players in Japan.

Figure 30: Key Japanese players across the value chain



Yet, Japan is also definitely a dominant player in the field of materials and equipment. In materials, Japan has leading companies such as Shinetsu and Sumco which are providers of raw silicon wafers, and DNP, Hoya and Toppan which are suppliers of photomasks.

In the field of equipment, Japan has relevant front-end and back-end equipment manufacturers. In front-end equipment, Nikon and Canon are providers of photolithography equipment and are two competitors for ASML. Tokyo Electron Limited (TEL) is an equipment manufacturer in front-end processes such as Etching, Cleaning, Deposition, and other processes. TEL is particularly relevant as the EU has no competing companies and has dependencies towards these equipments.

In the field of back-end equipment, Advantest is a relevant player and has the scale to play a global role in the value chain.

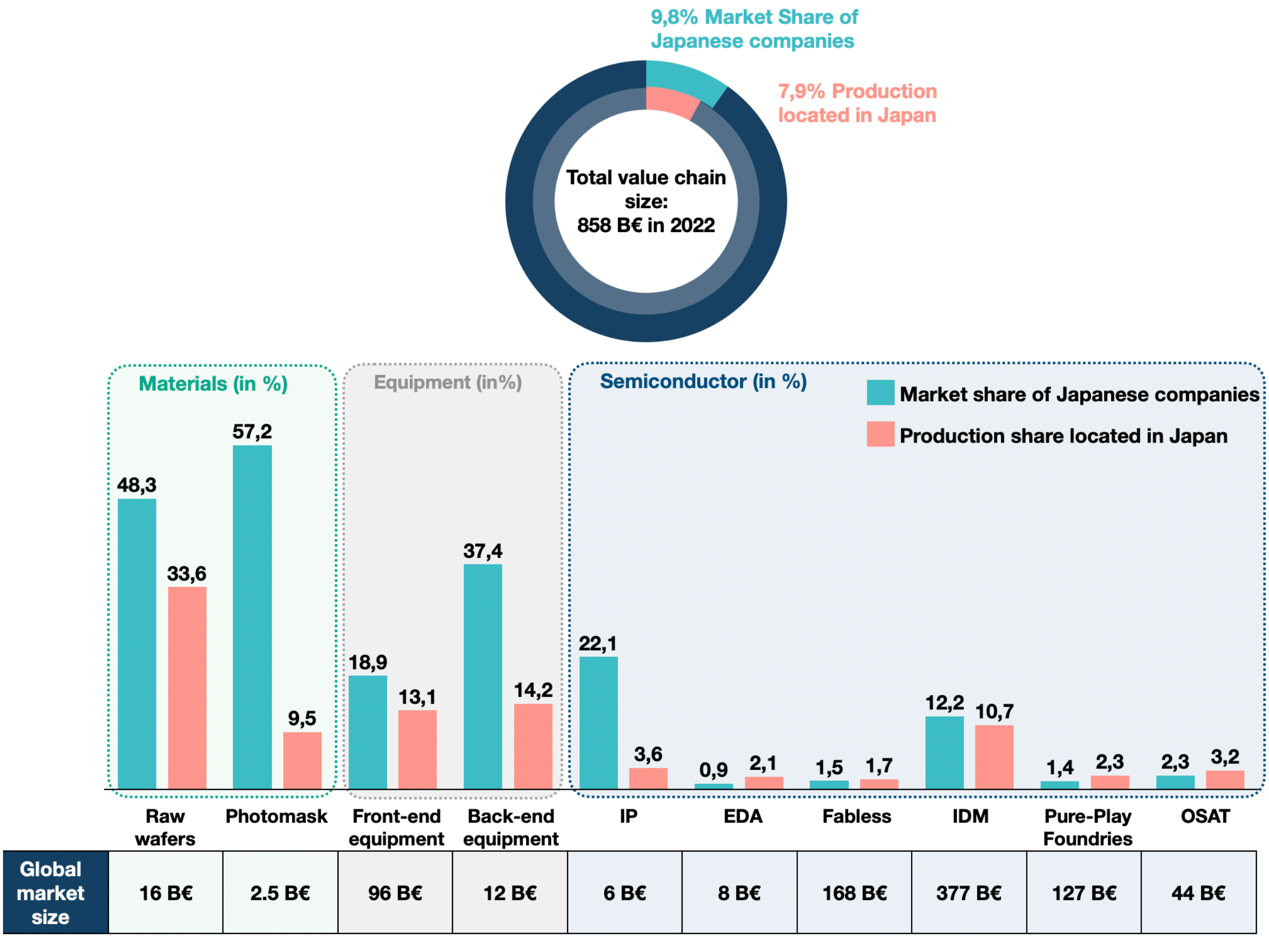
Last but not least, Softbank, a leading telecom operator in Japan, acquired Arm in 2016. Arm is a dominant player for microcontroller IP.

3.3.3 Japanese players market share and production across the value chain

In 2022, Japanese semiconductor companies generated approximately 83 billion euro in revenue, capturing a 9.8% market share all over the global value chain, valued at 858 billion euro.

Japan has a strong presence in the semiconductor materials market, leading with a 48.3% market share in raw silicon wafers and a 57.2% market share in photomask supply. However, a significant portion of this production is outsourced, which can be seen as a vulnerability.

Figure 31: Market share and production share of Japan across the value chain in 2022



Source: DECISION Etudes & Conseil

In manufacturing equipment, Japanese companies are also key players. They hold a 18.9% market share in front-end equipment, offering solutions across all stages of front-end manufacturing and competing with major US firms. In the back-end equipment segment, Japan's 37.4% market share, which reduces reliance on US companies by providing comprehensive back-end manufacturing solutions.

Japan is also historically strong in IDM, accounting for 12.2% of global revenues. Leading IDMs like Kioxia and Renesas contribute significantly to this success, alongside other relevant players such as Sony and Rohm.

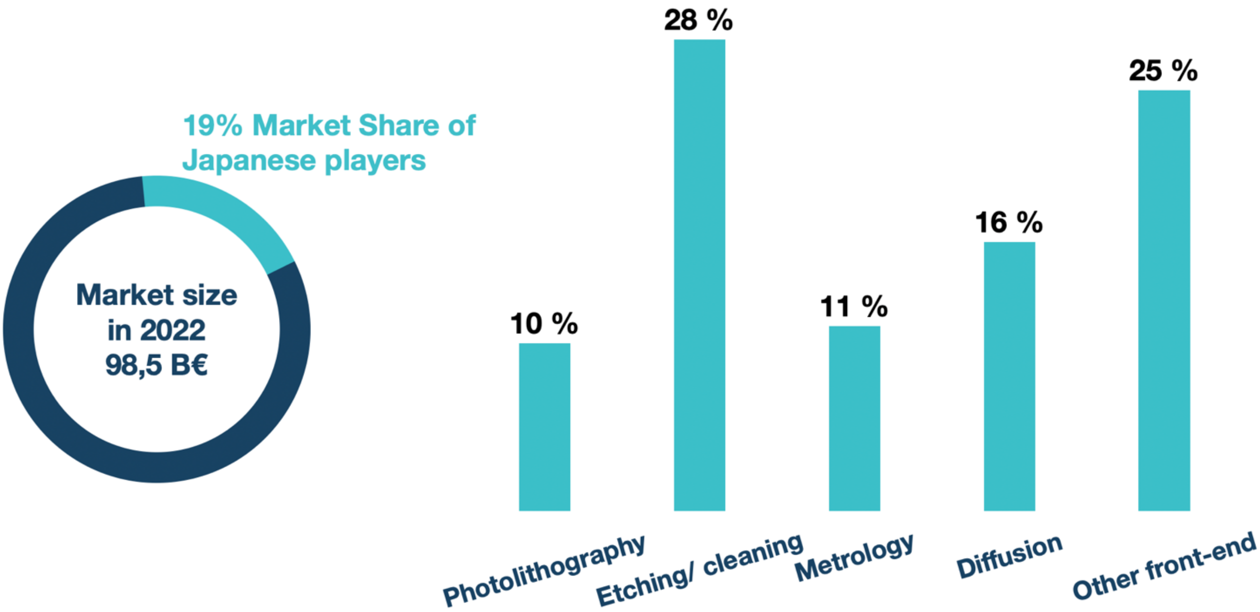
The acquisition in 2016 of Arm, a leader in microelectronics intellectual property, marked a strategic shift for Japan, increasing to 22.1% the market share of the country on this segment. However, as Arm is originally a UK-based company, much of its activity remains in the UK and Europe, with only 3.6% of the production share located in Japan.

Japan's main dependencies in the semiconductor sector lie in EDA tools, design companies, pure-play foundries, and assembly and packaging companies. These segments also exhibit lower proportions of production relocated to Japan, underscoring a dependence on external resources.

3.3.4 Focus on front-end equipment

Japan is one of the few if not the only competitor to American equipment manufacturers, with a market share of 19% in front-end equipment, equivalent to approximately €19 billion in 2022.

Figure 32: Spread of the Japanese market share by front-end process equipment



Global market size	~23 B€	~23 B€	~9 B€	~18,5 B€	~25 B€

Source: DECISION Etudes & Conseil

In the segments of the front-end process, Japanese manufacturers are present at every stage, notably in etching and cleaning with a 28% market share.

This represents a valuable alternative to the near monopoly of American companies. Japan's role is particularly critical as it provides a diversified source of equipment essential for semiconductor manufacturing, reducing global dependence on a single country.

3.3.5 Front-end capacities

Japan ranks among the top countries in semiconductor production capacity, behind China, South Korea, and Taiwan.

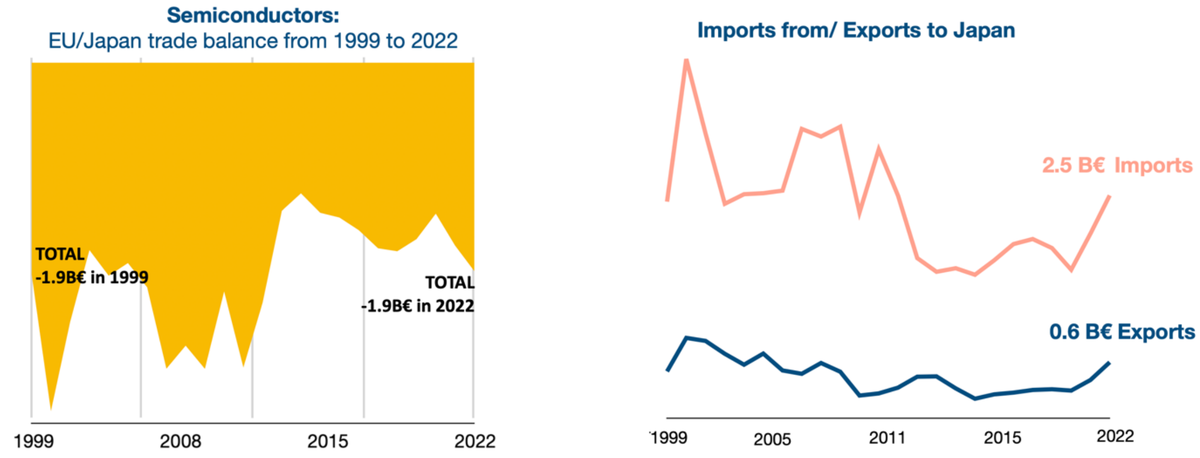
In terms of technology nodes, most of the Japan's capacity is dedicated to producing semiconductors with nodes of 20nm and above. This is in line with Japan's consumption trends, as automotive, industrial electronics, and consumer electronics – sectors that typically use these larger geometry chips – constitute a significant share of its market.

Moreover, the lower nodes of Japan's production are produced by two key players: Micron, and a joint venture between Kioxia and Western Digital (previously Toshiba and SanDisk, focusing on flash memory components).

Japan is comparatively lagging behind in the manufacturing of more advanced nodes, with no current capacity for producing chips at 10nm or smaller. However, considering the current investments in Japan, these weaknesses in advanced nodes will decrease as TSMC is building fabs that could manufacture up to 6nm nodes in Kumamoto and Rapidus' ultimate goal is to produce 2nm nodes semiconductors.

3.4 Trade Balance with the EU

Figure 33: The EU trade balance with Japan from 1999 to 2022



Source: DECISION Études & Conseil, from Eurostat

From 2000 to 2020, the EU's semiconductor imports from Japan have generally been declining, with occasional upticks. A notable drop in the trade balance occurred in the 2010s, reflecting the decline in Japan's semiconductor production, the aftermath of the Fukushima accident and the concurrent rise of Taiwan and South Korea, who expanded their production capacities and surpassed Japan.

In the last two years, however, there has been a resurgence in imports from Japan to the EU, as a result of the supply chain disruption, reaching nearly €2.5 billion in 2022. This recent increase has brought the trade deficit back to levels seen in 1999, at approximately -1.9 billion euro for the EU.

3.5 Ongoing investments in Japan

As Japan seeks to regain its former glory in the semiconductor industry, several major players have announced considerable investments in the country. There are multiple leading companies involved.

Firstly, the Japanese company Kioxia aims to maintain its position as one of the leaders in Flash memory components. Kioxia Corporation, in partnership with Western Digital, is investing in expanding its semiconductor production capabilities in Japan. They have jointly invested in the Fab7 facility at Kioxia's Yokkaichi Plant, which will start producing advanced 3D flash memory, including 112- and 162-layer and future nodes. Additionally, Kioxia has announced the construction of a new facility, Fab2, at its Kitakami Plant. This facility, expected to be completed in 2025, will deploy AI in manufacturing to increase capacity and enhance product quality. The aim of these investments is to strengthen Kioxia's production capability and market competitiveness in response to the growing demand for flash memory driven by emerging technologies.

Rapidus is another project that aims to bolster the Japanese semiconductor industry. Rapidus was established in August 2022 with the support of eight major Japanese companies namely: Denso, Kioxia, MUFG Bank, NEC, NTT, SoftBank, Sony, and Toyota, with an initial investment of approximately €53 million. The goal of Rapidus is to increase advanced semiconductor manufacturing capacity with a 2nm process by 2027. The new company is planning to build its first plant in Hokkaido, for which it has already received about €2.3 billion from the government.

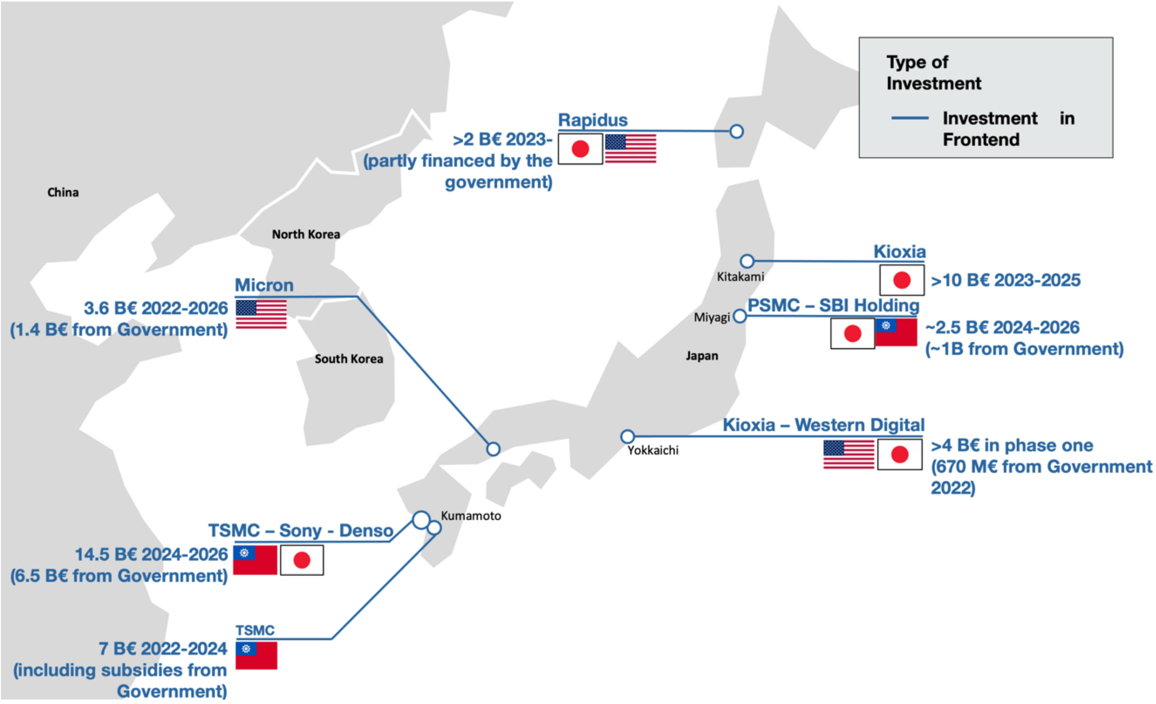
As Japan encourages investments from foreign companies, a few players have begun to get involved in the country.

Micron Technology announced in May 2023 its plans to invest up to €3.3 billion in extreme ultraviolet technology (EUV) over the next few years, with support from the Japanese government. It will be the first chipmaker to bring EUV technology to Japan for production.

Furthermore, TSMC is making significant investments in semiconductor production to enhance Japan's technological edge, with two plants in the country. The first TSMC plant, supported by a substantial subsidy from METI, is set to start operations by December 2024. The second TSMC facility, funded by an allocation of 770 billion yen, is expected to begin construction in April 2024 and produce 12nm to 6nm chips by 2026. But TSMC is also considering creation of a third fab for 3nm chips, which construction and equipping is estimated at more than €20 billion. These investments aim to strengthen Japan's semiconductor manufacturing capabilities and address supply chain and geopolitical challenges, while also focusing on the development of generative

AI technology. As Sony and Denso will benefit from the chips produced by the TSMC plants, they have participated, to a lesser extent, in the investments.

Figure 34: Ongoing major investments in Japan



Source: DECISION Etudes & Conseil

Besides these major investments, there are a few other significant investments to bolster Japan’s semiconductor industry:

- Samsung is considering setting up its first chip packaging test line in Japan near its existing research and development center in Yokohama.
- ASML plans to establish a base in Japan's northern island of Hokkaido to support production at a chip plant for Japanese startup Rapidus (as of September 2023).
- Bosch has planned to develop a new research and development facility in Yokohama, aiming to complete construction in September 2024. The investment is around 250 million euro.

3.6 Strengths and dependencies

Main Strengths

1. EUV Lithography: Tokyo Electron (TEL) dominates the global market for in-line coaters and developers used in EUV lithography, holding nearly 100% of market share. These processes involve applying and developing photoresist on wafers before and after photolithography.
2. Chip Stacking: TEL collaborates closely with IBM on pioneering chip stacking operations on 300mm wafers.
3. Photomasks: Japan corners about 57% of the global market for lithography mask-making and over 80% for EUV lithography masks.
4. High-End Photoresist: Four Japanese companies—Shin-Etsu Chemical, Tokyo Ohka Kogyo, JSR, and Fujifilm Electronic Materials—collectively produce 75% of the high-end photoresist for advanced chipmaking and nearly monopolize the photoresist market for EUV lithography device fabrication.
5. Silicon Wafers: SUMCO and Shin-Etsu Chemical, two Japanese firms, jointly hold a 45% share of the global market for silicon wafers.

Main Dependencies

1. Back-End Operations: Most Japanese packaging and other back-end operations are located outside Japan.
2. Advanced Node Technology and Packaging: Despite strengths in certain areas, Japan has notable weaknesses in advanced node technologies and advanced packaging. This should be somewhat offset by TSMC's current investments in Japan for 12nm to 6nm nodes, and proximity to countries with expertise in advanced packaging. However, this production remains largely outside Japan's control.
3. EDA Tools: While Japan has a strong presence in IP, it lacks sufficient Electronic Design Automation (EDA) tools that complement this intellectual property.

3.7 Cooperation & alliances

3.7.1 Existing Cooperation framework

Today, collaborations with foreign partners are viewed as crucial by the Japanese government, making Japan one of the most proactive and open regions in establishing global cooperation and alliances. Among the 15 global cooperation agreements in the semiconductor sector, Japan is involved in 5, including agreements with the US, Taiwan, the Netherlands, Europe, and South Korea.

Cooperations with the US: Seeking to reduce its dependence to China, the US sees Japan as a potential manufacturing hub for high-tech industries. Both countries are addressing their semiconductor vulnerabilities as a priority, recognizing that neither can be self-sufficient in this sector.

Measures in Japan and the US include:

- Enactment of major semiconductor-related industrial promotion legislation.
- Collaborations in chip manufacturing and research.
- Restrictions on exporting advanced chip technology to China.

Cooperation with Taiwan: Japan's new 2nm chipmaking alliance with IBM and IMEC is bolstered by a partnership with TSMC. This collaboration focuses on producing legacy chips for the Japanese industry and developing advanced assembly, test, and packaging technology.

Cooperations with the Netherlands: A trilateral agreement between the US, Netherlands, and Japan aims to further restrict the sale of chipmaking machines to China, though specifics of the impacted equipment remain unclear.

Cooperation with the EU: The EU and Japan have signed a Memorandum of Cooperation (MoC) on semiconductors, fostering in-depth collaboration in three areas:

- Research and development
- Early warning mechanisms for critical disruptions.
- Cooperation on advanced skills. The Japan-EU Digital Partnership Council co-chairs plan to reconvene in Brussels in 2024 to review progress and deepen the partnership. Furthermore, Rapidus, IMEC have formed a strategic partnership, with Rapidus joining IMEC's advanced nanoelectronics program, supported financially by METI, the Government of Flanders, and the European Commission.

On the private side:

- IMEC is participating in the Rapidus project with the US and Japan.
- ASML is setting up a structure in Japan to support the Rapidus project.

Cooperation with the US & South Korea: As per a joint statement from August 2023, Japan, the US, and South Korea will strengthen cooperation in sectors including semiconductors, batteries, technology security and standards, artificial intelligence, and quantum computing.

Position with regards to China: In March 2023, Japan announced it would restrict exports of 23 types of chipmaking technologies, aligning with US trade controls. Major Japanese chip equipment makers like Nikon and Tokyo Electron are required to seek export permission for all regions, without explicitly naming China as the target.

3.7.2 Existing alliances

Fab 4: Strengthening the Chip Supply Chain: Japan plays a pivotal role in the US-East Asia Semiconductor Supply Chain Resilience Working Group, also known as the "Fab 4." This US-led semiconductor alliance, which also includes Taiwan and South Korea, is dedicated to bolstering the semiconductor supply chain resilience.

Rapidus and IBM Joint Venture: Rapidus, in a joint venture with IBM, is set to develop and produce 2-nanometer chips, aiming for a prototype line by 2025. This ambitious project marks a significant advancement in chip miniaturization and manufacturing technology.

The Launch of LSTC: The Leading-edge Semiconductor Technology Center (LSTC) serves as Japan's counterpart to America's National Semiconductor Technical Center (NSTC). This open platform for research and development not only involves top Japanese researchers and technicians from institutions like the National Institute of Advanced Industrial Sciences and Technology, Riken, and the University of Tokyo but also maintains affiliations with the NSTC, IBM's research and development facilities in Albany, New York, the CEA-Leti in France and the Interuniversity Microelectronics Center in Belgium.

4 The US semiconductor ecosystem

4.1 Overall environment and strategic objectives

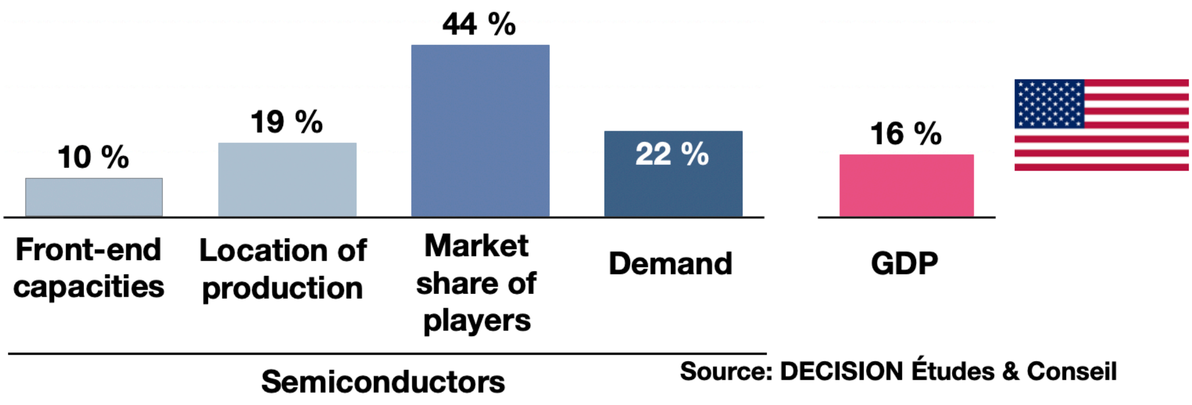
Overall environment

Over the past thirty years, the US have seen a consistent decline in their semiconductor manufacturing capabilities with production capacity increasingly moving overseas. Countries in Asia, especially China and Taiwan, have heavily invested in chip manufacturing, significantly altering the global semiconductor landscape.

As a consequence, the US share of global semiconductor manufacturing capacity has diminished from 37% in 1990 to just 12% in 2020 according to the Semiconductor Industry Association (SIA). Today, the front-end manufacturing capacity in the US is estimated at approximately 10% of the world capacity.

In contrast, the combined semiconductor manufacturing capacity of Taiwan, China, and South Korea has seen remarkable growth during this period. Starting from virtually zero, these countries now account for about 60% of the world's semiconductor production capacity. This significant increase is largely attributed to the manufacturing incentives provided by Asian governments, which have placed the US and Europe at a competitive disadvantage.

Figure 35: Position of the USA across the semiconductor value chain (in percentage of the World production), in 2022



Source: DECISION Etudes & Conseil

Objectives

The US government is responding to the significant decline in its semiconductor manufacturing sector by setting ambitious goals:

- Reducing Dependency on Asian Manufacturing: The US aims to lessen its reliance on Asian regions for semiconductor production by supporting various national plant development projects.
- Maintaining Leadership in Chip Design: According to the Semiconductor Industry Association (SIA), China's share in chip design is projected to increase from 9% in 2020 to over 20% by 2030, posing a considerable challenge to US dominance in this field.

Additionally, a key strategic objective of the US is to tightly regulate the export of critical technologies to China. Which is why, the US government enacted a series of new export control regulations in October 2022. These regulations specifically target China's artificial intelligence (AI) and semiconductor industries.

This policy shift marks the start of a new chapter in US-China relations and signals a significant change in the geopolitical dynamics of the semiconductor industry.

Strategy: The US Chip Act

The Chips Act is set to direct a substantial $277 billion in spending over the coming decade, allocated as follows:

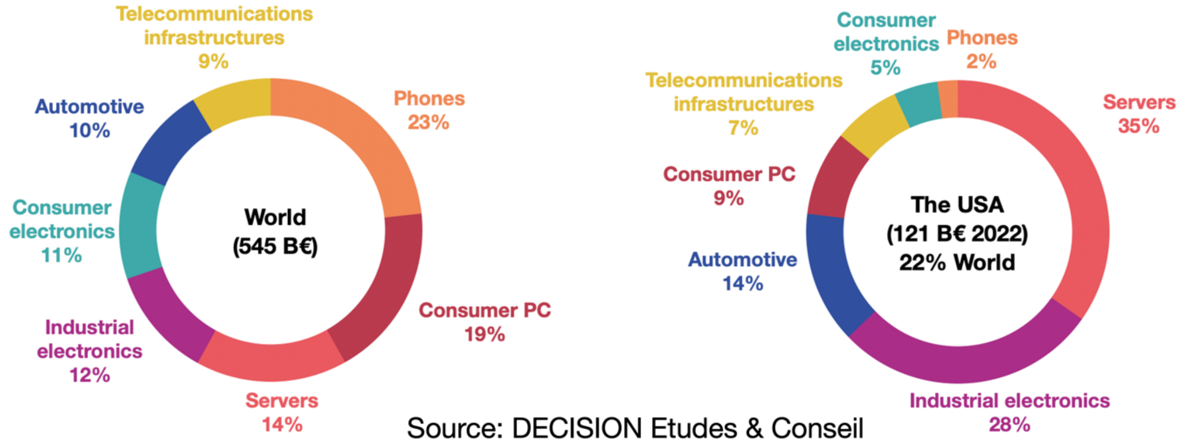
- $200 billion dedicated to scientific research and development (R&D) and the commercialization of new technologies.
- $53 billion earmarked for semiconductor manufacturing, further R&D in this sector, and workforce development initiatives.
- $24 billion allocated as tax credits to incentivize chip production.

4.2 The semiconductor market in the US

Historically, the US have maintained global leadership in digital applications, particularly in Information Communication Technologies (ICT). The country is home to some of the world's leading digital companies, including the GAFA (Google, Apple, Facebook, Amazon), which command the largest global market share.

This dominant position in digital applications significantly influences both applications and product mix in the semiconductor industry. In 2022, server applications accounted for more than one-third of US semiconductor sales, with leading companies like Nvidia, AMD, Intel providing the semiconductor components required for this market.

Figure 36: Spread of US semiconductor demand by application

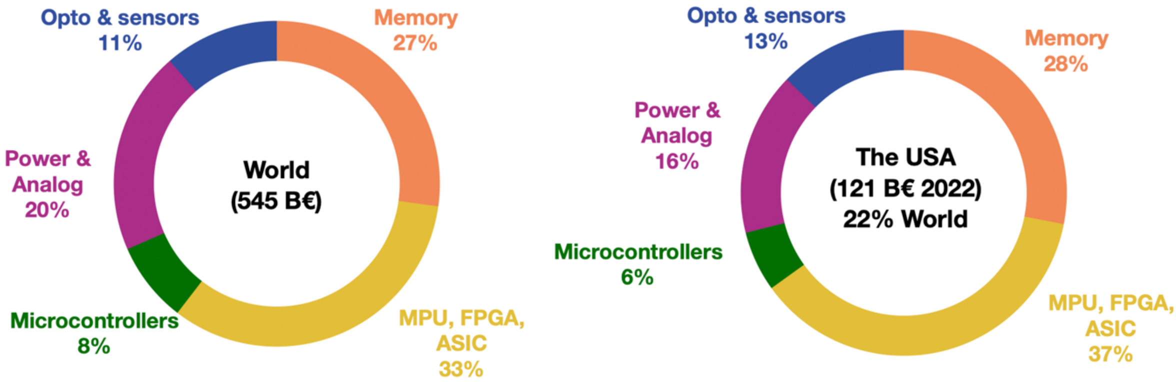


The automotive industry and industrial electronics also represent two prominent markets in the US. On the contrary, these markets need different types of semiconductors that the ICT segment uses.

Apart from these markets, the consumer PC, telecommunications, consumer electronics and phones represent a lower share of semiconductor consumption, as these are not the prominent market in the US.

Regarding product mix, microprocessors and memory chips together represented almost two-thirds of total semiconductor sales, which is line with the applications described previously.

Figure 37: Spread of US semiconductor demand by product



Source: DECISION Etudes & Conseil

However, the MCU, Power & Analog, Opto & Sensors, represent a lower share in the product mix compared to the share of industrial electronics and automotive in the application mix. In the following years, this share will tend to decrease as the US are investing in more advanced process nodes.

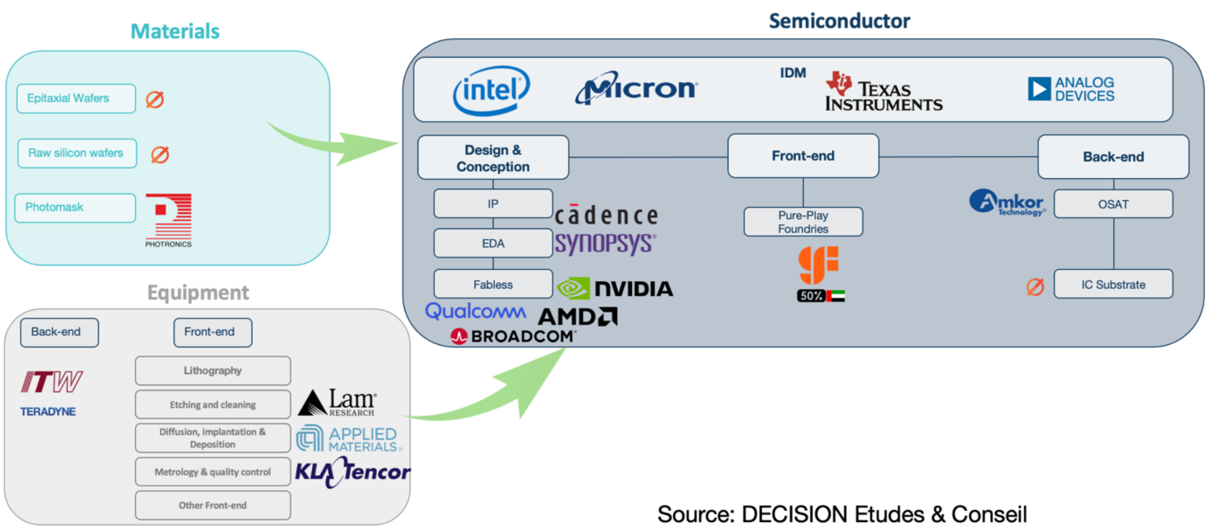
4.3 The semiconductor industry in the US

4.3.1 Key US players in the value chain

In the semiconductor value chain, the US stands out for their leadership in almost every segment, with the exception being the production of raw silicon wafers. The country is home to industry giants such as Intel and AMD, which lead in innovative Microprocessor Units (MPUs), and Nvidia, which excels in Graphics Processing Units (GPUs). Additionally, Micron is well-known for its Memory components, while Qualcomm and Broadcom are key players in the Radio Frequency (RF) components sector. These companies have considerable investment capacities, underscored by significant manufacturing projects involving Intel and Micron.

In the pure manufacturing domain, the US hosts relevant players in the pure-play foundries and OSAT sectors. While GlobalFoundries is primarily owned by Abu Dhabi's Mubadala Investment Company, it still retains a portion of US investment and has deep relations with the US, including operating two plants that supply components to the US military. Amkor, a significant company in back-end manufacturing, especially in advanced packaging, has important capacities to develop alternatives to Moore's Law limitations. However, it is important to note that most of GlobalFoundries' fabs and all of Amkor's fabs are situated outside the US, representing a minor dependency for the US.

Figure 38: The US key players across the value chain



Source: DECISION Etudes & Conseil

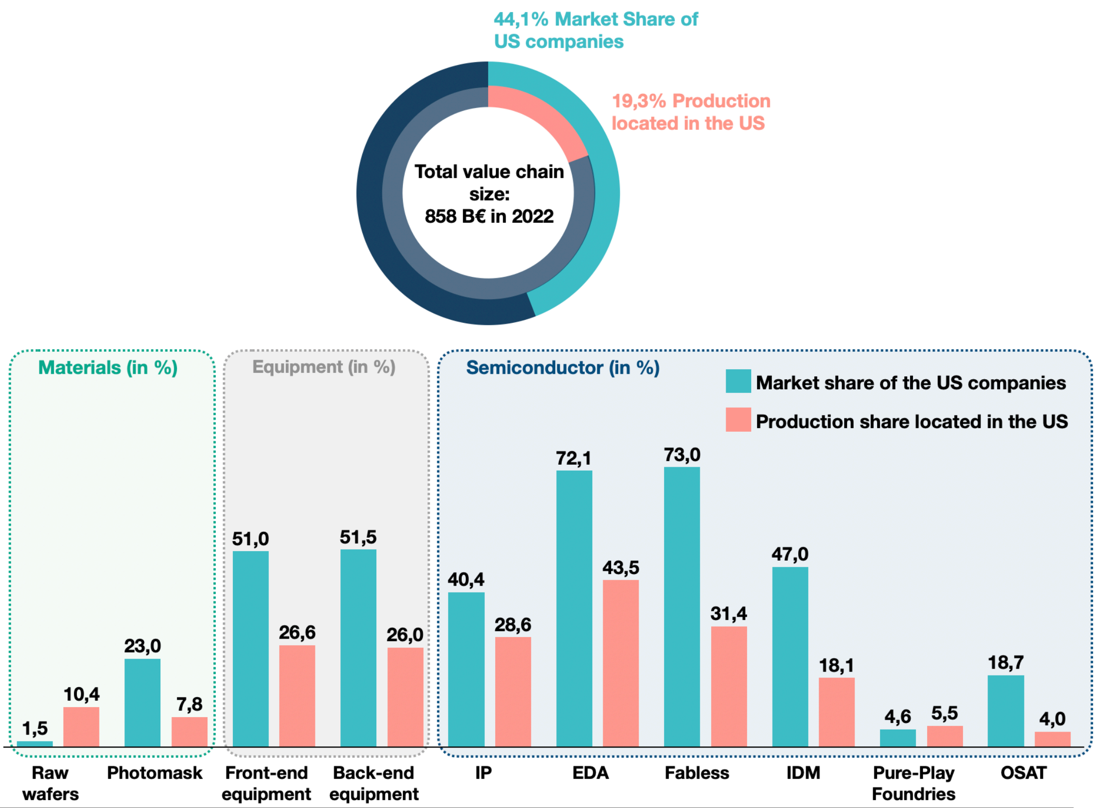
The US also leads in the fields of Intellectual Property (IP) and Electronic Design Automation (EDA), with companies like Cadence and Synopsys having considerable market shares. Photronics, a prominent merchant supplier of photomasks, also consolidates the US's position in semiconductor materials.

In terms of equipment manufacturing for semiconductors, US companies nearly monopolize the market across all front-end manufacturing processes. This dominance is evident even in photolithography, where ASML, though not an American company, is partly owned by US investors. Industry leaders such as Applied Materials, LAM Research, and KLA Tencor produce equipment for every stage of front-end manufacturing. A similar near-monopoly situation exists in back-end equipment manufacturing, with leading companies like Illinois Tool Works (ITW) and Teradyne which are US-based.

4.3.2 The US players market share and production across the value chain

The graph below illustrates the US market shares and production shares in various segments of the semiconductor value chain. Overall, the US accounts for 44.1% of the global revenue and 19.3% of global production in this industry. The graph also reveals that while the US hold strong positions in many aspects of the value chain, the US have weaker presence in raw silicon wafer and manufacturing, notably in the Pure-play foundries and OSAT sectors.

Figure 39: Market share and production share of the US across the value chain



	Raw wafers	Photomask	Front-end equipment	Back-end equipment	IP	EDA	Fabless	IDM	Pure-Play Foundries	OSAT
Global market size	16 B€	2.5 B€	96 B€	12 B€	6 B€	8 B€	168 B€	377 B€	127 B€	44 B€

Source: DECISION Etudes & Conseil

An initial observation is that the US generally have a lower share of domestic production compared to its market share. This indicates a significant relocation of production capacity to international locations, highlighting the US strategy of maintaining a global presence.

The fabless company model, which originated in the US, has positioned the country as a leader with a 73% market share, with leading companies like Nvidia, AMD, Qualcomm, and Broadcom. However, many of these companies have offices and operation plants and offices outside the US, particularly in the EU.

Still in the design segment, the US dominate both in IP and EDA with market shares of 40.4% and 72.1%, respectively. Cadence and Synopsys are leading US companies in these areas, with a total market share of more than 30% and 70% in each segment. Like the fabless companies, these firms also have a significant presence outside the US, once again mainly in the EU.

For the Integrated Device Manufacturing (IDM), the US hold 47% market share, with over ten companies each generating revenue of more than €1 billion. These companies, too, are relocating part of their production, especially to Asian countries.

For pure-play manufacturing, the US have a notable presence even if it is limited in number of players. At the pure-play foundry level, GlobalFoundries, partially US-owned, covers 5% of the market. In the OSAT sector, Amkor, second in revenue in 2022, has all of its facilities located outside the US, primarily in Asia, with one notable facility in Portugal. This geographical distribution of facilities benefits IDMs in proximity but could pose a vulnerability for the US due to the offshore location of these capacities.

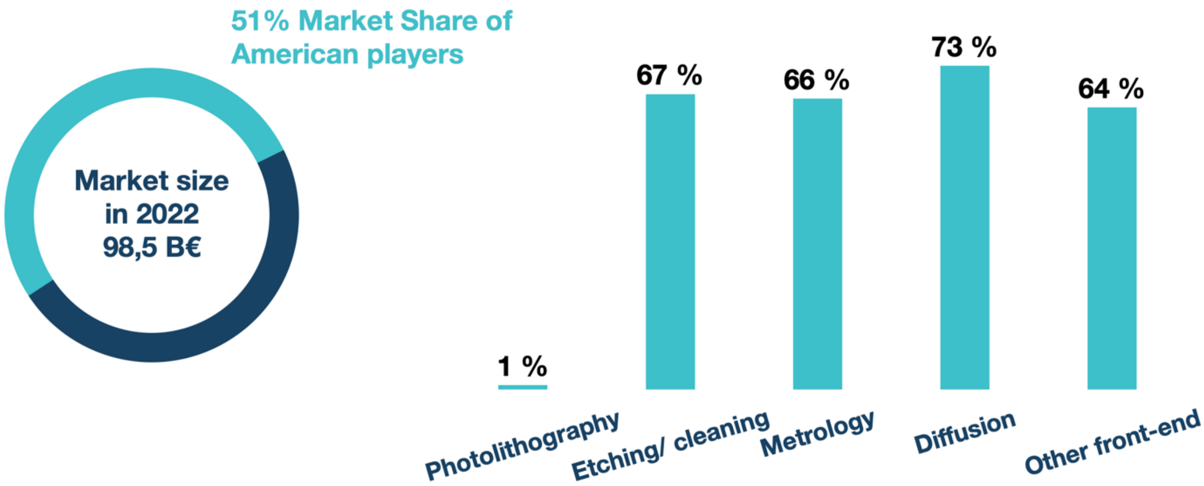
In equipment manufacturing, the US nearly monopolize the market, holding 51% market shares in both front-end and back-end equipment, respectively. Companies like Applied Materials, LAM Research, KLA Tencor, ITW, and Teradyne together hold significant portions of these markets.

Lastly, the US demonstrate dependencies in the materials segment, particularly in raw silicon wafers where they have little to no market share, and in photomask supply where they have a single but leading company.

4.3.3 Front-end process equipment

The analysis of market share distribution across various semiconductor processes clearly establishes the US as a dominant player in equipment manufacturing. In the studied segments, the US commands over 60% of the market share in each category, spanning from etching and cleaning to wafer probe. Additionally, the US also have significant involvement in testing and packaging equipment manufacturing.

Figure 40: Spread of the US market share by front-end process equipment



Global market size	~23 B€	~23 B€	~9 B€	~18,5 B€	~25 B€

Source: DECISION Etudes & Conseil

The US's partial ownership of ASML, a key player in photolithography equipment, further solidifies its comprehensive coverage in the semiconductor equipment sector. This ownership effectively ensures US self-reliance in semiconductor equipment.

Such a dominant position places other regions in a state of dependence towards US suppliers for building semiconductor fabrication plants. Japan emerges as the only country with the capacity to compete with the US in the equipment manufacturing domain to mitigate this major dependency situation.

4.3.4 Front-end and back-end capacities

A key challenge facing the US: a mismatch between its strengths in digital applications and a relatively low production share in advanced manufacturing processes on the US soil. This misalignment particularly affects the digital industry, which is heavily reliant on Taiwan for advanced semiconductor needs.

Notably, the US are one of the only countries with the capability to produce a wide range of node technologies, from larger geometries to the thinnest advanced ones.

The US are among the few countries, alongside Taiwan and South Korea, capable of producing state-of-the-art advanced node technologies (6nm and below). These advanced semiconductors are crucial for the applications and product distribution detailed previously. However, given the high demand for servers, the current US capacity in advanced nodes is insufficient to meet domestic needs fully.

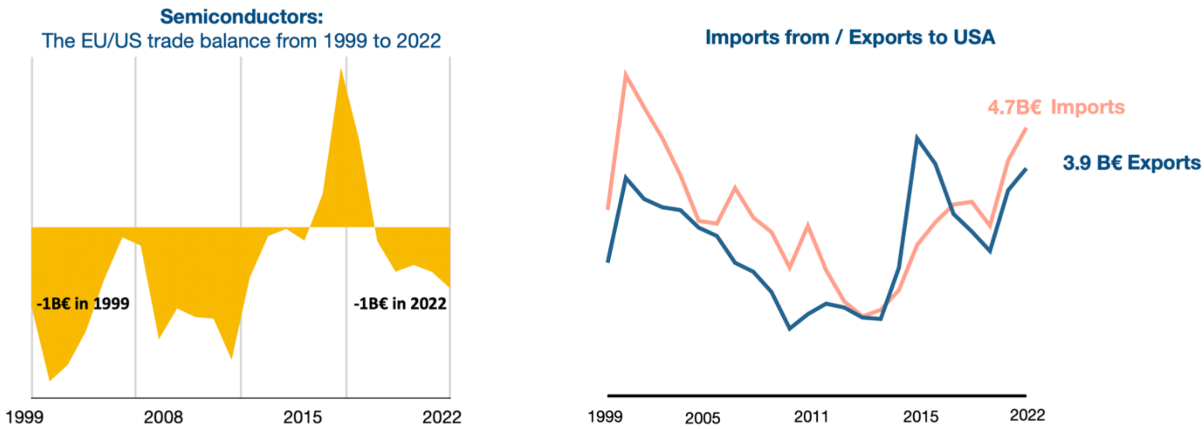
The US currently also have a limited number of advanced packaging facilities within its borders. The most notable one is Intel's factory in Rio Rancho, New Mexico, which stands as the only relevant domestic factory.

While Amkor, a major US company in advanced packaging, is headquartered in the US, all its current manufacturing facilities are located overseas. This geographical distribution leads to a minor dependency issue. Nonetheless, these Amkor factories are strategically positioned near the overseas fabs of US IDMs which helps in maintaining a direct supply chain, albeit not directly within the US. Furthermore, Amkor announced in December 2023 that it will invest in Arizona for a total amount of €1.9 billion euro for a packaging and test facility, which marks an important step in strengthening the US manufacturing resilience.

4.4 Trade balance between the EU and the US

The trade balance chart below between the US and the EU for semiconductors from 1999 to 2022 shows that the EU has consistently imported more semiconductors than it has exported, with a trade deficit of €1 billion in both 1999 and 2022. The trend line for imports and exports is somewhat symmetrical over time, indicating that while the trade deficit has persisted, the gap has not significantly widened. The few spikes, including the spike of exports in 2016, are attributed to demand cycles. In 2022, the EU imported semiconductors worth approximately €4.7 billion and exported about €3.9 billion, suggesting a close balance in trade volume in recent years.

Figure 41: The EU trade balance with the US from 1999 to 2022



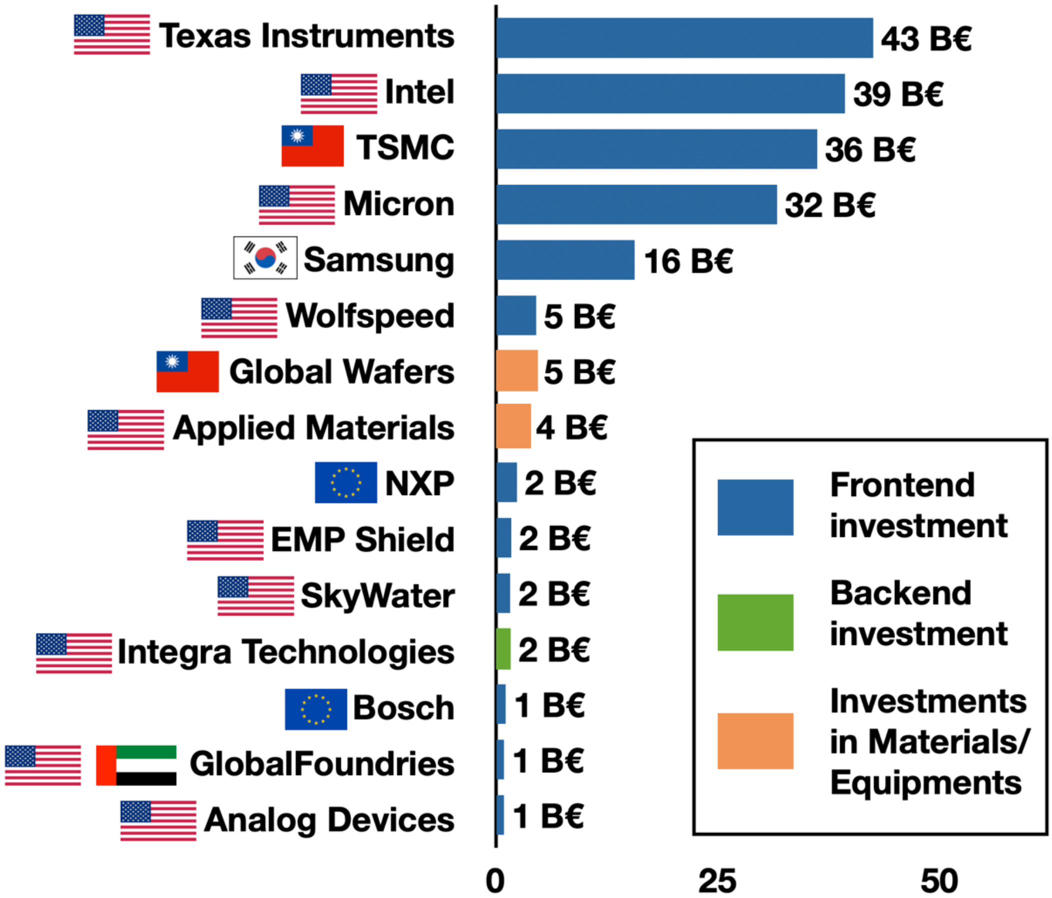
Source: DECISION Études & Conseil, from Eurostat

This close gap between imports and exports over the past 20 years can be explained by the fact that none of the 2 countries have enough manufacturing and OSAT capabilities, which are the main drivers of semiconductor imports and exports.

4.5 Ongoing investments in the US

In comparison to other regions, the US demonstrate the broadest range of investments in the semiconductor industry, both in terms of the diversity of companies and the segments of the value chain targeted. There are over sixty investment projects in the US. The map below focuses on the major ones, those exceeding €1 billion.

Figure 42: Ranking of the ongoing major investment in the US



Source: DECISION Etudes & Conseil

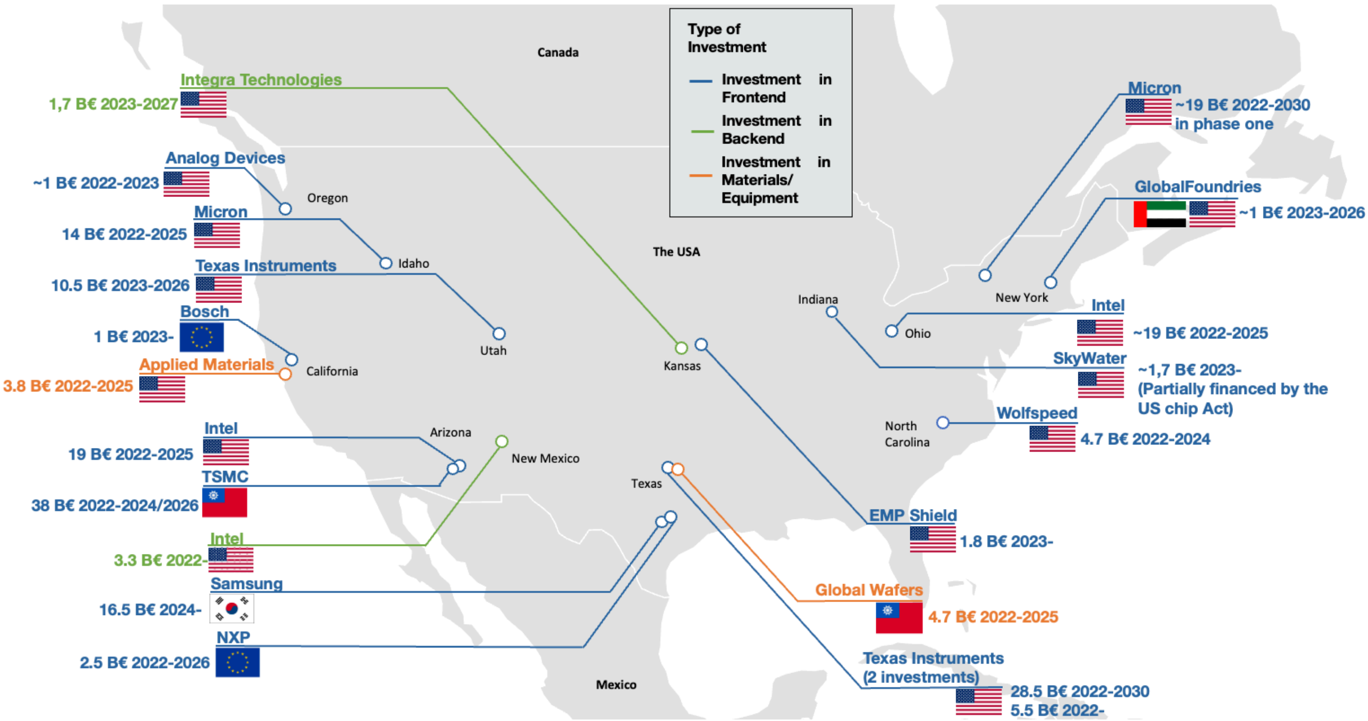
Out of the twenty largest investments, fifteen are led by American companies, indicating their commitment to revitalize local capacity and operations. Among the eight largest projects valued at over €10 billion each, six are driven by American companies, like Intel, Micron, and Texas Instruments, each involved in multiple investments within the US. Notable examples include:

- Micron Technology's announcement of the largest semiconductor fabrication facility in US history in Clay, New York, with a projected investment of up to €95 billion over 20 years. This megafab is central to Micron's plan to increase its American-made DRAM production to 40% of its global output, supported by €5.2

billion in incentives from New York State and anticipated federal grants and tax credits from the Chips and Science Act.

- Texas Instruments' decision to develop its next 300-mm fabs in Sherman, Texas, with an investment of €28.5 billion, is aimed at boosting chip supply, with the first facility's production starting by 2025.
- Intel's investment of over €19 billion for two new chip factories in Ohio, reinforcing its IDM 2.0 strategy and further investing €95 million in regional education and research partnerships.

Figure 43: Ongoing major investments in the US



Source: DECISION Etudes & Conseil

These investments reflect a concerted effort by US firms to strengthen domestic semiconductor production, enhancing supply chain resilience and national competitiveness.

However, foreign investments also play a significant role in the US:

- Samsung is investing €16.5 billion in a new semiconductor facility in Taylor, Texas, representing the state's largest foreign direct investment. This facility will focus on advanced logic chips for applications like mobile, 5G, HPC, and AI starting production in late 2024.
- TSMC is investing €38 billion for two fabs in Arizona, marking the state's largest foreign direct investment. These fabs will produce cutting-edge N4 and 3nm process technologies, with an annual output of over 600,000 wafers.

In addition to front-end capacity, there are notable investments in other segments such as equipment and raw silicon wafers from companies like Applied Materials and GlobalWafers. These investments are critical for enhancing supply chain resilience, with the example of GlobalWafers' investment reducing dependency on Asian imports.

These various investments reinforce the US's semiconductor supply chain resiliency.

4.6 Strengths and dependencies

Strengths:

- Design for Digital Applications: The US has a near monopoly in Electronic Design Automation (EDA) and Intellectual Property (IP), primarily driven by US companies.
- Front-End and Back-End Equipment: US companies almost monopolize the market. The partial US ownership of ASML further indicates US control over every manufacturing process equipment, from deposition to final testing.
- Fabless Players: This model, originating in the US, has US companies at the forefront. For example, Nvidia, a US company, was the top semiconductor company in 2023.
- Advanced Node Semiconductor: With Intel the US are among the leading countries in producing semiconductors with advanced node technology, behind South Korea and Taiwan.
- Design of Logic Components: US companies like Intel, Nvidia, and AMD are renowned for their Microprocessor Units (MPUs) and Graphics Processing Units (GPUs).
- Artificial Intelligence and Semiconductors: US firms, particularly Nvidia, have been instrumental in developing semiconductors optimized for AI model training, with recent GPU updates enhancing AI model processing speeds.

Dependencies:

- Materials: The US are somewhat dependent on the import of silicon wafers, as they lack domestic companies in this sector. Additionally, the US rely on imports of raw materials like silicon, gallium, and germanium, essential for wafer-making.
- Pure-Play Foundries: These are predominantly located abroad, highlighting a dependency in this segment, especially on foundries that could manufacture advanced nodes technology semiconductor.
- OSAT: All major US OSAT facilities are located overseas, particularly in Asia, indicating a geographical dependence for these services.
- IC Substrate for Advanced Packaging: The US depends on external sources for IC substrates, a key component in advanced packaging technology.

4.7 Cooperation & alliances

4.7.1 Existing cooperation framework

For the US, the main motivation for international cooperation on the semiconductor industry is to reduce its dependencies on China and more generally on Asian regions.

Recent Ventures and Investments:

The US has initiated several significant ventures to bolster domestic semiconductor production:

- Micron announced a €100 billion investment plan to establish memory manufacturing facilities.
- GlobalFoundries and Qualcomm have expanded their partnership to enhance domestic semiconductor production.
- Intel, Texas Instruments, and Samsung Foundry are planning to expand their production capabilities within the US.
- TSMC has announced a €36 billion manufacturing facility in Phoenix, Arizona, marking a major foreign direct investment in US semiconductor capacity.

Existing Cooperation and Alliances:

The US government has been proactive in forming international collaborations in the semiconductor sector:

- The US are partaking in the Chips 4 Alliance, a multilateral coalition for semiconductor production including Japan, South Korea, and Taiwan.
- Through IBM, the US are collaborating with Japan on the "Rapidus" initiative, a consortium of Japanese firms, and IMEC, focusing on advanced semiconductor technologies.
- The US-EU Trade and Technology Council (TTC), established in 2021, aims to foster joint development in technology and innovation, promoting democratic and market-oriented approaches.
- In January 2023, the US Semiconductor Industry Association (SIA) and the India Electronics and Semiconductor Association (IESA) announced a private-sector task force to strengthen US-India collaboration in the global semiconductor ecosystem.

5 The Chinese semiconductor ecosystem

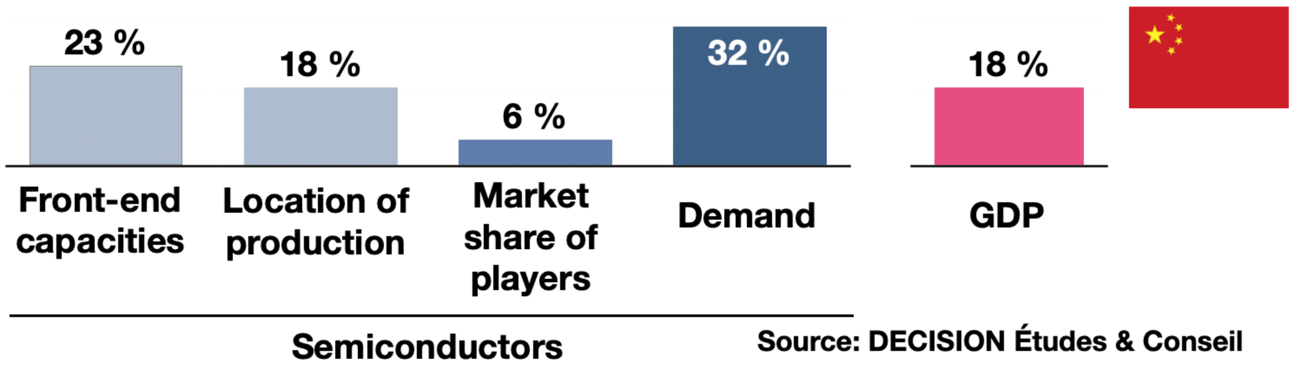
5.1 Overall environment and strategic objectives

Overall environment

China is the largest consumer of semiconductors globally, accounting for 32% of global chip purchases. Despite the presence of thousands of semiconductor companies within the country, most of China's production is concentrated on lower-end chips. This results in a dependency on foreign suppliers for high-end semiconductor products. China is particularly reliant on foreign-owned technologies for the advanced nodes crucial for applications in mobile phones and artificial intelligence.

A pivotal moment for China's semiconductor strategy occurred in October 2022 when the US imposed strict export controls on semiconductor technologies to China and persuaded other countries to adopt similar policies. These actions have led China to increasingly view its semiconductor industry through the lens of national security, rather than purely economic considerations. This shift marks a significant change in how China approaches its semiconductor strategy as it aims for self-sufficiency and technological independence in every segment of the value chain, from raw materials to packaging.

Figure 44: Position of China across the semiconductor value chain (in percentage of the World production), in 2022



Objectives

China is currently focusing on three major objectives:

- Reducing Dependence on Foreign Markets: A primary goal is to limit China's vulnerability to foreign economic pressures. This involves reducing reliance on international supply chains and technologies.
- Leveraging AI for Economic and Security Advantages: China aims to harness the economic and security potentials of Artificial Intelligence (AI), which requires advanced semiconductor technologies.
- Restructuring the Semiconductor Industry: A significant reshaping of its semiconductor industry is underway, aimed at enhancing capabilities and capacities.

Specifically, in the realm of semiconductors, China's ambitions are:

- To generate €142 billion in revenue from this sector over the next decade.
- To achieve complete self-sufficiency across the semiconductor value chain, encompassing everything from raw materials to advanced chip manufacturing.

To achieve these goals, particularly on self-sufficiency, China appears as open to international cooperation in the semiconductor sector with countries (except the USA), and particularly the EU.

Strategy

In October 2023, China announced the launch of a substantial new state-backed investment fund, aiming to raise approximately €38 billion to bolster its semiconductor industry. This fund, likely to be the largest among the three launched by the China Integrated Circuit Industry Investment Fund, also known as the Big Fund, which marks a significant move forward in China's semiconductor strategy.

The Chinese government is contributing to 20% of the total amount, with the remaining 80% expected to be raised from private investors.

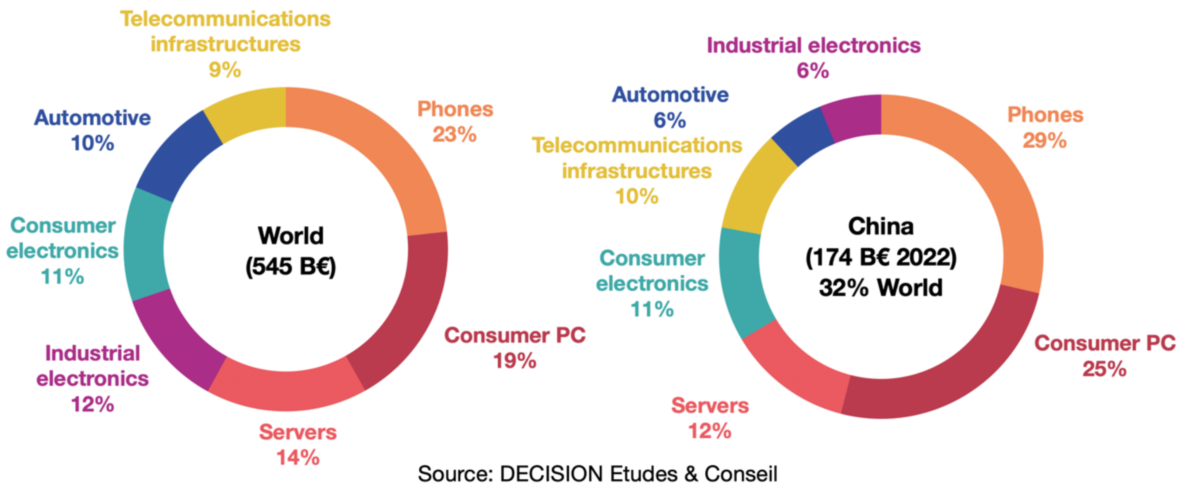
Key beneficiaries of this fund will include major players like Semiconductor Manufacturing International Corporation (SMIC), Hua Hong Semiconductor, and Huawei. Equipment suppliers such as NAURA and Advanced Micro-Fabrication Equipment Inc China are also slated to receive support.

5.2 The semiconductor market in China

When analyzing the breakdown of the Chinese semiconductor market, there is a strong tendency towards consumer markets, which are phones, consumer PC and Consumer electronics which account for 65% of the Chinese semiconductor consumption.

There is also a considerable 12% consumption of semiconductor in servers which can be attributed to Chinese objectives in advanced computing and AI.

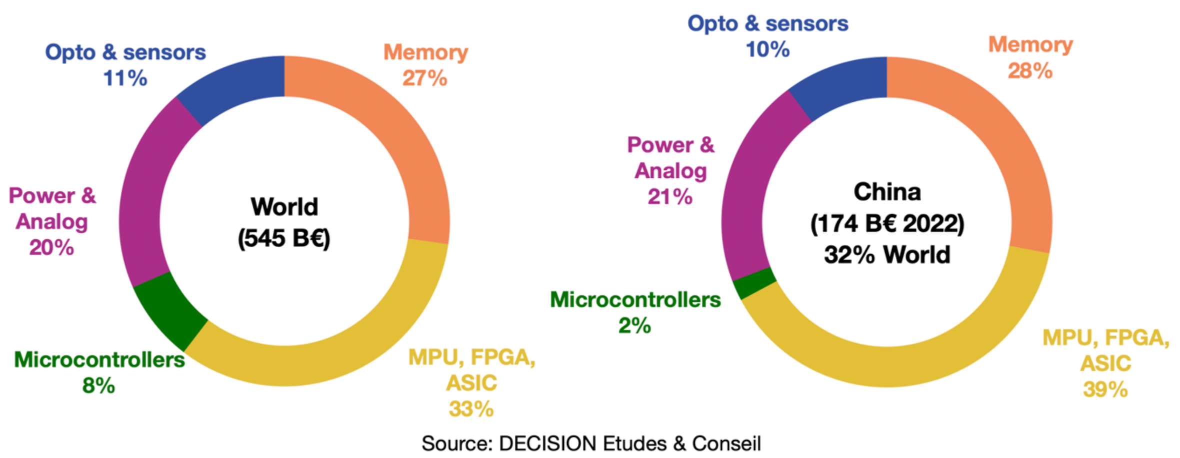
Figure 45: Spread of the Chinese semiconductor demand by application



On the opposite, there is a lower share of semiconductor dedicated to telecommunication infrastructures, automotive and industrial electronics. However, as the Chinese consumption represents 32% of the world's semiconductor consumption, which equals €174 billion, the low percentages still represent considerable amounts.

When looking at the split per product, there is a strong share for memory components, MPU/ASIC/FPGA and Power/Analog, which are semiconductor products that are in accordance with the breakdown per market.

Figure 46: Spread of the Chinese semiconductor demand by product



5.3 The semiconductor industry in China

5.3.1 Key Chinese players in the value chain

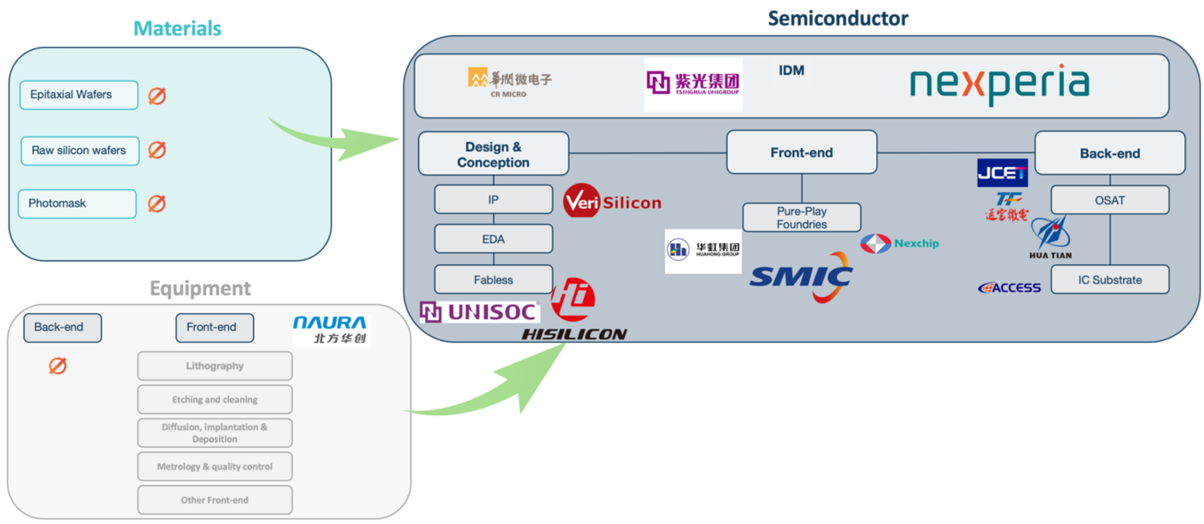
China's semiconductor industry is characterized by its significant presence across various segments of the manufacturing process, from design to back-end manufacturing. China is particularly strong in both front-end and back-end manufacturing segments.

On one hand, the pure-play foundry market in China is dominated by SMIC, a state-owned and the largest contract chip maker in mainland China, with other key players including Hua Hong Semiconductors and Nexchip. These companies primarily focus on producing semiconductors with nodes in the 12nm range and above.

On the other hand, China's presence in the OSAT market is also significant, with JCET ranking among the top three global leaders, followed by Tongfu Microelectronics and Tianshui Huatian. Advanced packaging techniques are a notable strength of Chinese OSAT companies.

In the design aspect, China has players in Open IP, and fabless companies. The only lacking aspect is in EDA, with no relevant player currently. In the Open IP market, China is home to Verisilicon. And in the fabless market there are Unisoc and HiSilicon, the latter being a subsidiary design house of Huawei. HiSilicon has designed 12 nm and 14 nm chipsets and filed a patent for advanced lithography. Thanks to this patent, Hisilicon could sell to foundries in China like SMIC to start manufacturing competitive advanced chips. Moreover, testifying China's will to master the design aspect, Will Semiconductor has acquired the American firm Omnivision in 2019, a company that won the Guinness World Record for the World's Smallest Image Sensor that same year.

Figure 47: Key Chinese players across the value chain



Source: DECISION Etudes & Conseil

The country also has key IDMs in every type of semiconductor products. In memory components, China strategically invested to reduce dependency on foreign suppliers. For instance, Yangtze Memory Technologies Co. (YMTC), has heavily invested in research and development, positioning China as a potential major player in the global memory market. But overall, CR Micro is China's largest IDM with businesses ranging from chip design and manufacturing to packaging and testing. The company has the capacity to produce 230,000 6-inch wafers and 140,000 8-inch wafers monthly.

In the equipment segment, despite the US export sanction, China is making progress as well with an emerging key player. As China's largest semiconductor equipment manufacturer, NAURA's portfolio includes plasma etching, PVD, CVD, oxidation/diffusion, cleaning systems, and annealing equipment, playing a crucial role in supporting the semiconductor industry. This company has the scale to supply the Chinese facilities with equipment, alleviating the country's dependency towards US equipment.

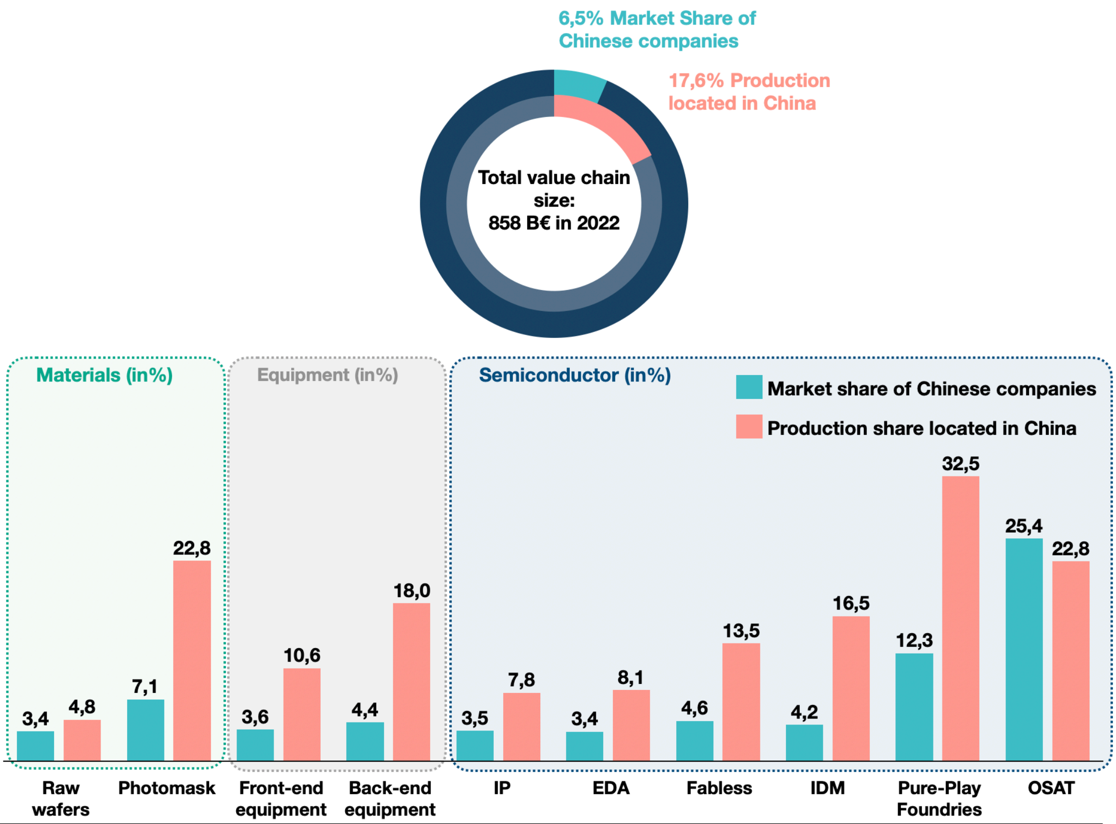
However, despite progresses in various sectors, China lacks significant players in raw silicon wafer manufacturing and photomask production. Nonetheless, it compensates by being a leading provider of essential raw materials like silicon, gallium, and germanium, crucial for semiconductor manufacturing.

5.3.2 Chinese players market share and production across the value chain

The graph below reveals that China's production share in the semiconductor industry consistently exceeds its market share across all segments, highlighting its role as a primary destination for relocation. China holds 6.5% of world market share but 17.6% of production share across the entire semiconductor value chain. This disparity is particularly significant considering recent export control measures and China's status as a critical manufacturing location and market for major global players like TSMC, Samsung, and SK Hynix.

At the IDM level, China's production share is nearly four times its market share. This is largely due to foreign IDMs relocating some of their facilities in China. For instance, companies such as Diodes, Texas Instruments, and Wolfspeed have established front-end fabs in the country. Moreover, China is also a favored destination for back-end relocation from IDMs companies, as for instance Texas Instruments and Infineon both have three back-end facilities in the country.

Figure 48: Market share and production share of China across the value chain in 2022



Global market size	16 B€	2.5 B€	96 B€	12 B€	6 B€	8 B€	168 B€	377 B€	127 B€	44 B€

Source: DECISION Etudes & Conseil

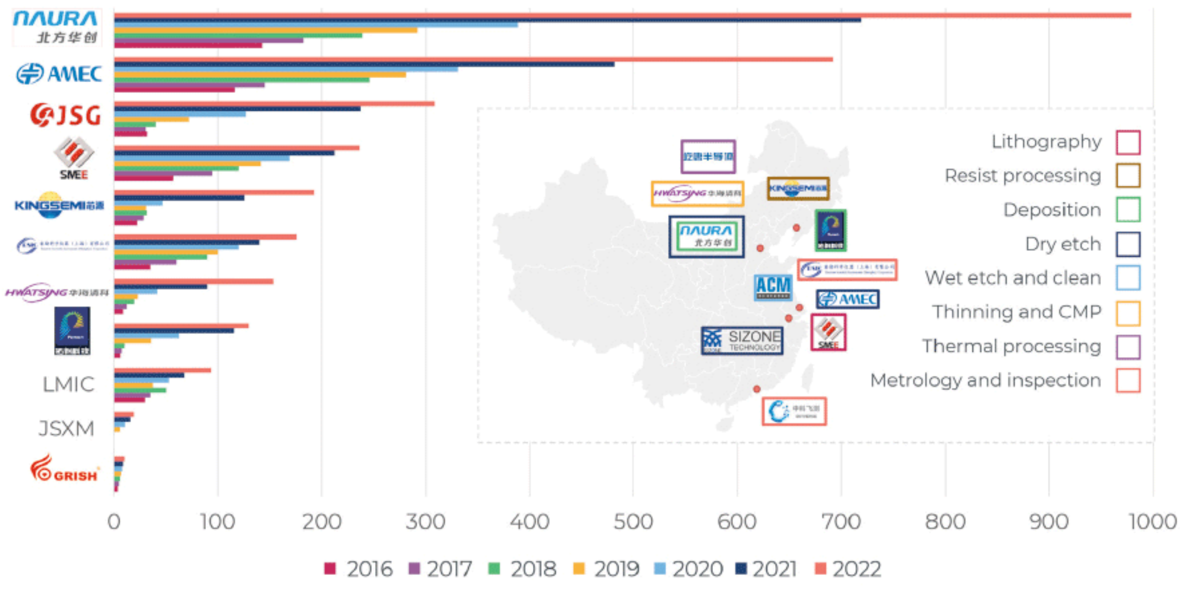
In the pure-play foundry sector, China's production share is more than twice its market share, supported by the presence of TSMC, UMC, and Samsung fabs. This contributes to China's 32% production share in this segment. Today, the country still accounts for 12.3% market share in the segment, but this figure is expected to rise in the next few years.

China is also particularly performant in the OSAT market. The country accounts for 25.4% of world revenue in this segment, with a production share closely matching its market share. The 3 key Chinese companies in the market, JCET, TFME and Tianshui Huatian, already account for 21% of the revenue generated in this market. For instance, JCET relocates some of its facilities in other Asian countries to be close to front-end fabs, like in South Korea.

However, China has a more limited presence in semiconductor design, especially in design tools like IP and EDA, where it holds only a about 3% market share.

In equipment manufacturing, China's presence is also limited, with around 4% market share in both front-end and back-end equipment. Despite this, domestic front-end equipment manufacturers have shown significant growth, acquiring technologies across various front-end processes. For instance, about 35% of Chinese fabs were supplied by domestic equipment manufacturers in 2022, whereas it was 21% in 2021. This growth suggests that in the coming years, these companies will reduce China's dependency on foreign equipment manufacturers and enhance its resilience.

Figure 49: China's wafer fab equipment ecosystem – overall revenue evolution from 2016 to 2022 (in $M)



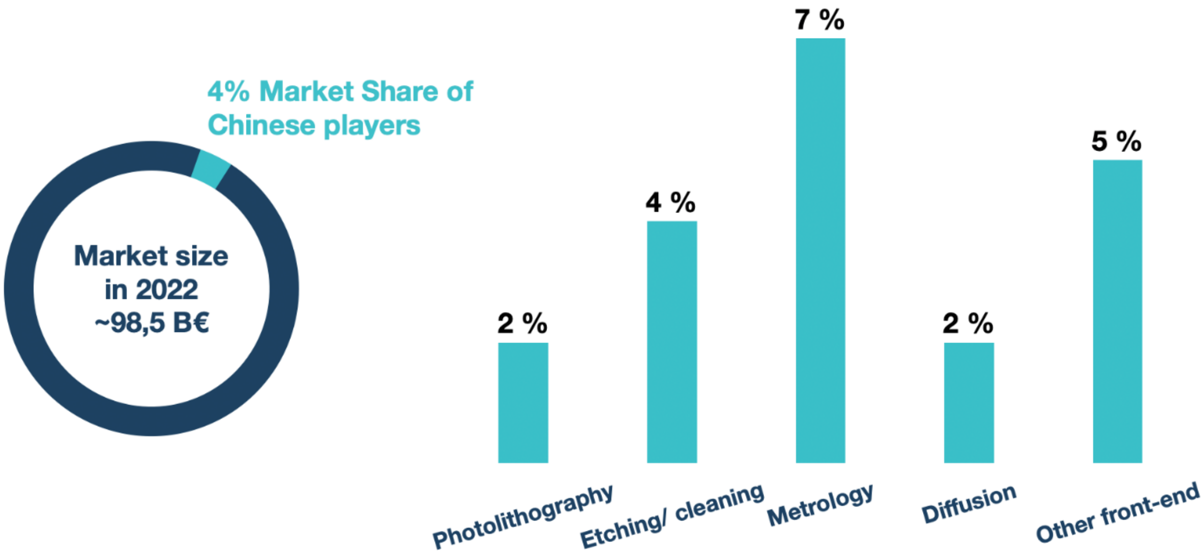
Source: Status of the Memory Industry 2023, Yole Intelligence, July 2023

Photolithography remains a process where China's presence is weak within its 4% market share in front-end equipment. That is why the country can still be considered dependent in this process. However, in late 2023, SMIC canceled an order of approximately €22 billion worth of lithography equipment from ASML, claiming they are becoming self-sufficient.

Yet, the country can produce equipment for other processes. For instance, NAURA produces equipment in several front-end processes: Etching and Cleaning, Deposition, Diffusion, and other front-end processes.

Overall, as these companies are aided by large amount of investment from the government's Made in China 2025 initiative, the market shares in all front-end processes are estimated to rise over the next years, making China a competing country among the equipment providers.

Figure 50: Spread of the Chinese market share by front-end process equipment



Global market size	~23 B€	~23 B€	~9 B€	~18,5 B€	~25 B€

Source: DECISION Etudes & Conseil

5.3.3 Front-end and back-end capacities

China accounts for approximately 1/4 of global semiconductor front-end manufacturing capacity, primarily focused on mature processes above 20nm. Only small part of this capacity is dedicated to the 20 to 10 nm range. Key players producing in this range include Chinese companies such as SMIC, Tsinghua Unigroup, and ChangXin Memory Technologies (CXMT), along with foreign companies like SK Hynix and TSMC.

A significant development in China's semiconductor industry is SMIC's production of a 7nm chip, designed by HiSilicon for Huawei smartphones. This achievement marked a significant milestone in advanced chip design and manufacturing within China. SMIC canceled a €22.8 billion order with ASML in October 2023, claiming increasing self-sufficiency. This indicates that, despite facing export control measures, especially concerning lithography equipment from ASML, China is making breakthroughs in designing and manufacturing chips in advanced process nodes.

Looking ahead, it is estimated that China may soon have the capability to produce semiconductors with geometries of less than 6nm. Achieving this would significantly reduce China's dependency on other countries for advanced node technology.

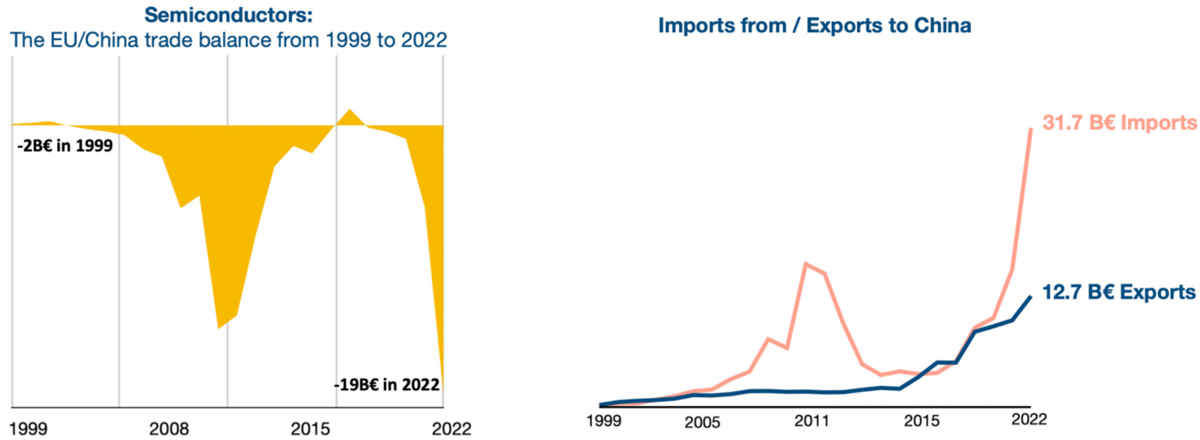
In Back-end manufacturing, China has several players that are producing advanced packaging, which includes about 9 facilities from domestic companies and 6 facilities from foreign companies.

5.4 Trade balance between the EU and China

In terms of semiconductor, the trade balance between the EU and China was stable most of the time with massive spikes in the early 2010s and in 2022. The first one is attributed to the economic crisis in Europe and the Fukushima accident in 2011, and the second one representing the recovery process after the covid crisis, reaching a trade deficit of €19 billion for the EU.

The imports from China have dramatically increased over the past few years to reach €31.7 billion whereas the exports are just at 12.7 billion. This massive trade gap is mainly attributed to the imports of optoelectronics semiconductors, mainly LEDs, from China, towards which the EU market is highly dependent. Without taking the optoelectronics components into account, the trade balance is positive for the EU.

Figure 51: The EU trade balance with China from 1999 to 2022



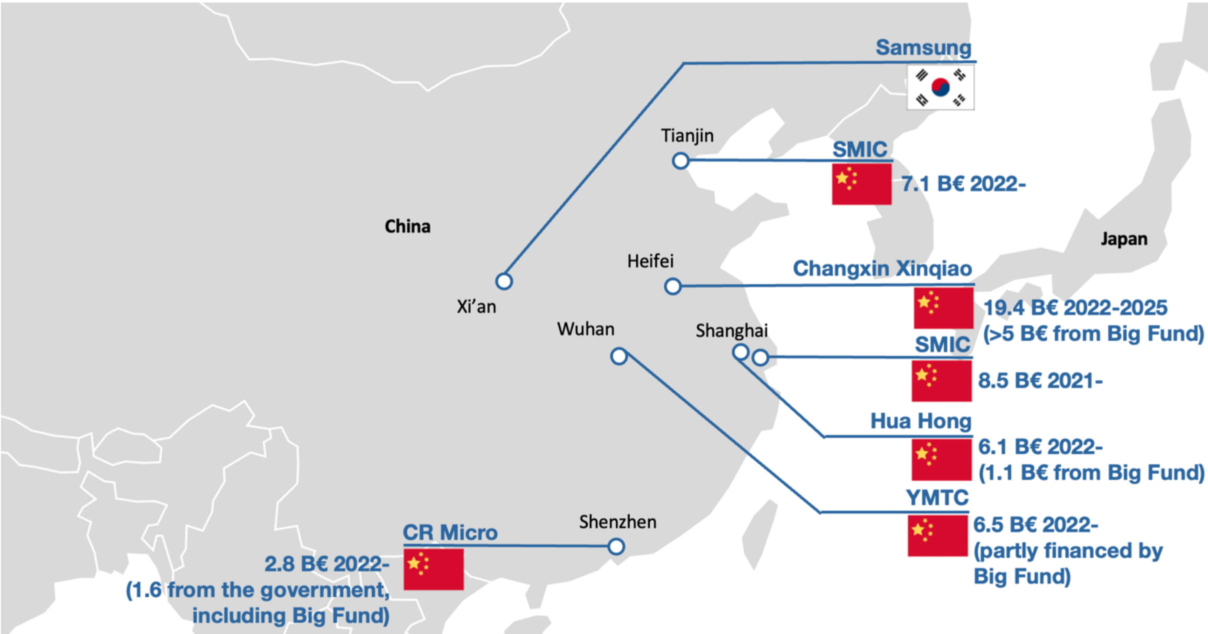
Source: DECISION Études & Conseil, from Eurostat

More than ¾ of the exports to China mainly concerns microcontrollers, reaching about €9 billion out of the €12.7 billion of total semiconductor exports.

5.5 Ongoing investments in China

With the objective to be fully self-reliant in every technology and to ensure domestic production, China has participated massively in the various investment projects, mainly with its Big Fund that raised an additional €38 billion dollar in late 2023. The map below shows the largest, > €1 billion, current investments.

Figure 52: Ongoing major investments in China



Source: DECISION Etudes & Conseil

The first beneficiaries of the investments are the foundries to ensuring domestic capacities. The largest investments are made by SMIC and Hua Hong Semiconductor:

- SMIC is investing heavily to expand its semiconductor manufacturing capabilities, with a focus on tackling the global chip shortage. It is dedicating €8.5 billion to construct a chip plant in Shanghai for technologies of 28-nanometer and above, and another €7.1 billion for a production line in Tianjin catering to 28 to 180-nanometer process nodes, with both projects backed by government funds.
- Hua Hong Semiconductor is also addressing chip scarcity by investing €6.1 billion in a new front-end manufacturing plant in Wuxi. This facility will focus on producing chips with mature technology nodes such as 65, 55, and 40-nanometers, supported by a combined investment of nearly €1.9 billion from the Big Fund and a Wuxi-based entity.

However, the government investments also tackle various technologies in which China has dependencies. The first one being memory components:

- Changxin Xinqiao has raised 39 billion yuan (€5 billion) for a 150-billion-yuan semiconductor factory in Hefei, Anhui province, to develop DRAM chips. The main investor, the "Big Fund," holds a 33% stake. The investment accelerates the factory's construction with the goal to counter US sanctions and start mass production in 2025.
- YMTC, China's only global NAND memory market player, blacklisted by the US in 2022 over concerns of technology transfer to Huawei, received a €6.5 billion investment to expand its production and R&D.

Other massive investments are also occurring like the one involving CR Micro's subsidiary Runpeng Semiconductors that will receive a €2.8 billion investment from the "Big Fund" and other state investors to build a 12-inch wafer facility in Shenzhen, aiming to boost domestic chipmaking capacity.

Finally, in late 2023, The US Department of Commerce granted Samsung Electronics and SK Hynix an exemption from regulations restricting the sale of US-made equipment for advanced semiconductor manufacturing in China. This allows Samsung to upgrade its NAND flash factory in Xi'an, China, to a 200-layer process and produce 236-layer, 8th generation NAND to maintain market leadership and address an oversupply in the market.

The investments in semiconductors across China extend beyond the major initiatives previously detailed, as there will be an emphasis put on equipment and materials. Notably, NAURA is investing about €500 million in a Beijing plant to supply leading foundries like SMIC and Yangtze Memory Technologies, with operations starting next year. Meanwhile, Advanced Micro-Fabrication Equipment, the No. 2 Chinese equipment, and tools manufacturer, is constructing a €200 million facility in Shanghai.

5.6 Strengths and dependencies

Strengths:

- Front-end Production Capacity: China holds approximately 1/4 of global front-end semiconductor capacities.
- Advanced Packaging Techniques: Chinese companies are not only proficient in advanced packaging production but are also investing heavily in research and development in this area. This commitment to innovation positions China favorably in the high-end segment of semiconductor production.
- Printed Circuit Board (PCB) Manufacturing: China is a significant production hub for PCBs accounting for over 50% of the world's PCB production (source: DECISION). This output stems from domestic Chinese firms but also from the operations of various international companies located in China.

Dependencies:

- Equipment: Despite advancements, China still depends on foreign sources for cutting-edge semiconductor equipment. However, this dependency is gradually reducing as domestic companies emerge, bolstered by government subsidies and support.
- Materials: While China is a primary source of various raw materials essential for semiconductor manufacturing, it lacks major players in specific semiconductor making materials like raw silicon wafers and photomasks. To address this gap, recent government funding initiatives are targeted at developing these capabilities within the country.

5.7 Cooperation & alliances

5.7.1 Existing cooperation framework

International relations

- The US: Since October 2022, the US have implemented strict export controls on technologies involving Advanced Computing, Artificial Intelligence (AI), and Semiconductors. These measures significantly impact China's access to advanced technological resources.
- The EU: In alignment with the US stance, ASML, a key European semiconductor equipment manufacturer, has agreed to adhere to the US ban on exporting advanced process equipment.
- South Korea: The South Korean administration expresses concern over its reliance on global supply chains, particularly as major companies like Samsung and SK Hynix have significant business interests in China, potentially complicating geopolitical alignments.
- Japan: Japan has imposed export restrictions on 23 technologies used in semiconductor production, adding another layer of complexity to China's semiconductor industry's international relations.

The Battle of Rare Earth Elements:

Rare earth elements, while relatively abundant, are costly and environmentally challenging to extract. China has leveraged its low-cost labor and relaxed environmental regulations to become the dominant supplier in the global market for these materials.

In July 2023, China announced it would impose export restrictions on gallium and germanium products, essential components in computer chips and other technologies. This move could have significant implications for the global semiconductor industry, given China's status as a leading supplier of these materials.

6 The Taiwanese semiconductor ecosystem

6.1 Overall environment and strategic objectives

Overall environment

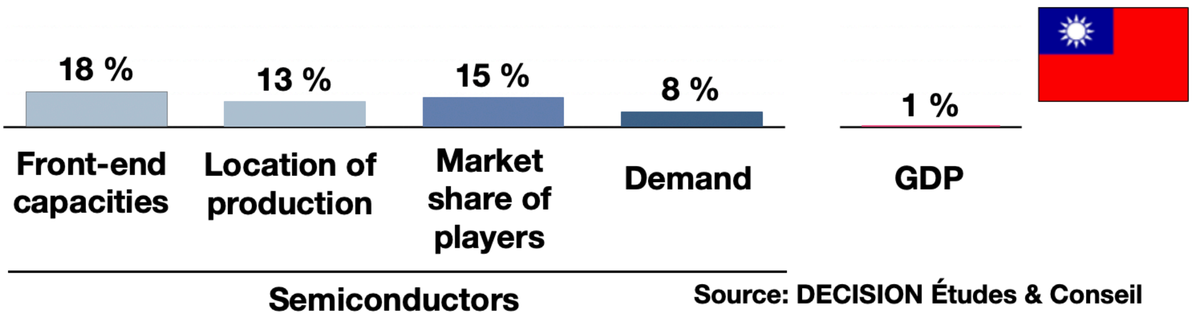
Taiwan undoubtedly leads the global foundry and OSAT markets.

In 2022, its manufacturers accounted for 60% of the worldwide foundry revenue, with TSMC alone contributing to more than 80% of this share. This dominance underscores Taiwan's central role in semiconductor fabrication. TSMC stands out as the largest manufacturer of semiconductor chips. Although US-based Intel reports higher revenue, TSMC is responsible for producing more than 80% of the world's advanced chips in volume.

Additionally, Taiwan is a key player in the OSAT sector, which is gaining strategic importance as the semiconductor industry is heading toward the limits of Moore's Law.

In essence, the global digital ecosystems rely heavily on Taiwan, a small island regarded by China as a province but whose security is a commitment of the United States. This geopolitical dynamic adds a layer of complexity to the already intricate global semiconductor landscape.

Figure 53: Position of Taiwan across the semiconductor value chain (in percentage of the World production), in 2022



Strategy

Taiwan has set an ambitious goal to construct ten new semiconductor fabs within the next five years. In the short term, TSMC announced that three new fabs focusing on advanced processes are scheduled to start production in 2024, including facilities in Japan and the United States.

To support these objectives, the Taiwanese government is also launching investment initiatives in Taiwan. Part of the plan is to offer a 15% R&D tax exemption for royalties on imported production technologies, aimed at supporting major Taiwanese semiconductor companies. This plan, however, does not encompass the entire semiconductor ecosystem. Experts and analysts have pointed out that, in fact, the Taiwanese chips act seems to be inspired by the US Chips & Science Act. Nevertheless, this initiative has not won full support from several local companies, as it does not include the IC design houses, which are seen as a weak aspect in Taiwan's semiconductor ecosystem.

In terms of global cooperation, there's a noticeable relation with the United States. Out of the major global partnerships and alliances concluded since 2021, Taiwan has been primarily involved in the US-Taiwan cooperation on supply chain resilience. In September 2023, Taiwan's President Tsai Ing-wen expressed this focus, stating, "we look forward to producing democracy chips in partnership with the US."

Historically, TSMC has maintained strong partnerships with US tech giants such as Apple, Google, and Nvidia. These relationships have been pivotal in providing them with top-tier chips for advanced devices, crucial for high-performance computing and artificial intelligence applications.

However, there are indications of Taiwan's willingness to engage in broader cooperative efforts. "The semiconductor industry has entered a new era of opportunities for global cooperation to solve some of its greatest challenges,"[47] said Terry Tsao, President of SEMI Taiwan and SEMI Chief Marketing Officer, at SEMICON Taiwan in July 2023.

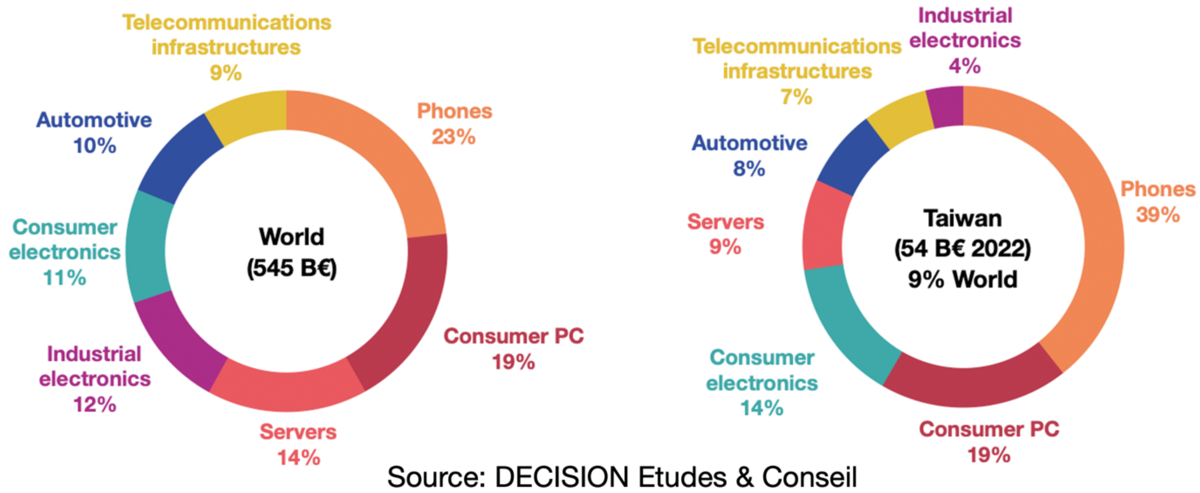
[47] https://www.semi.org/en/news-media-press-releases/semi-press-releases/semicon-taiwan-2023-kicks-off-with-press-conference-spotlighting-critical-semiconductor-industry-themes

6.2 The semiconductor market in Taiwan

In the global semiconductor market, Taiwan accounts for 9% of the overall consumption, with the Information and Communication Technology (ICT) sector driving most of this demand. This sector, encompassing markets like phones, consumer PCs, servers, and telecom infrastructures, represent over 75% of Taiwan's total semiconductor needs.

On the other hand, Taiwan has a relatively minor share in automotive and industrial applications compared to other countries, reflecting a different focus in its semiconductor usage.

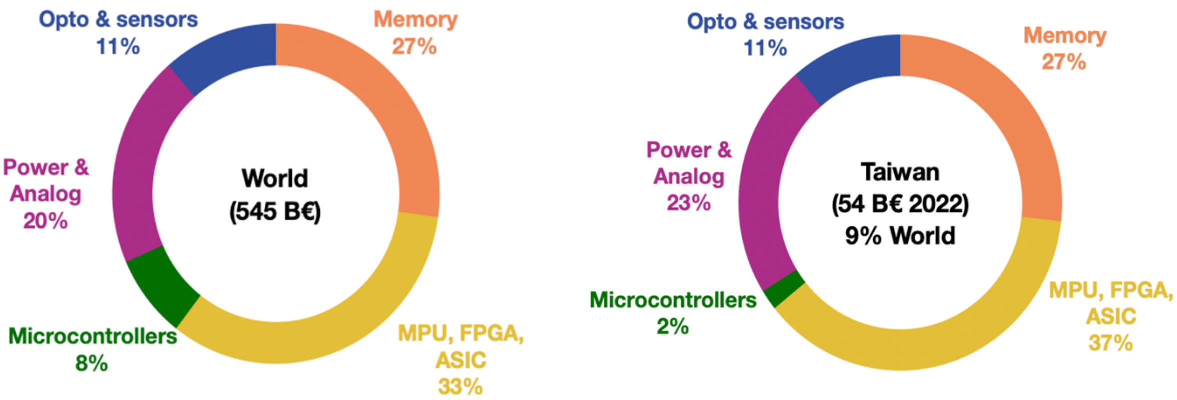
Figure 54: Spread of the Taiwanese semiconductor demand by application



In terms of product-specific demand, the consumption in ICT applications mainly revolves around MPUs and memory components, which together account for nearly two-thirds of the demand. Power and Analog components also hold a significant share, contributing to 23% of the total consumption.

Conversely, there is a lower demand for microcontrollers and opto & sensors in Taiwan, representing only 2% and 11% of the demand, respectively. This is attributed to Taiwan's less important industrial structure, which does not need these specific types of semiconductors to the same extent as other regions.

Figure 55: Spread of the Taiwanese semiconductor demand by product



Source: DECISION Etudes & Conseil

6.3 The semiconductor industry in Taiwan

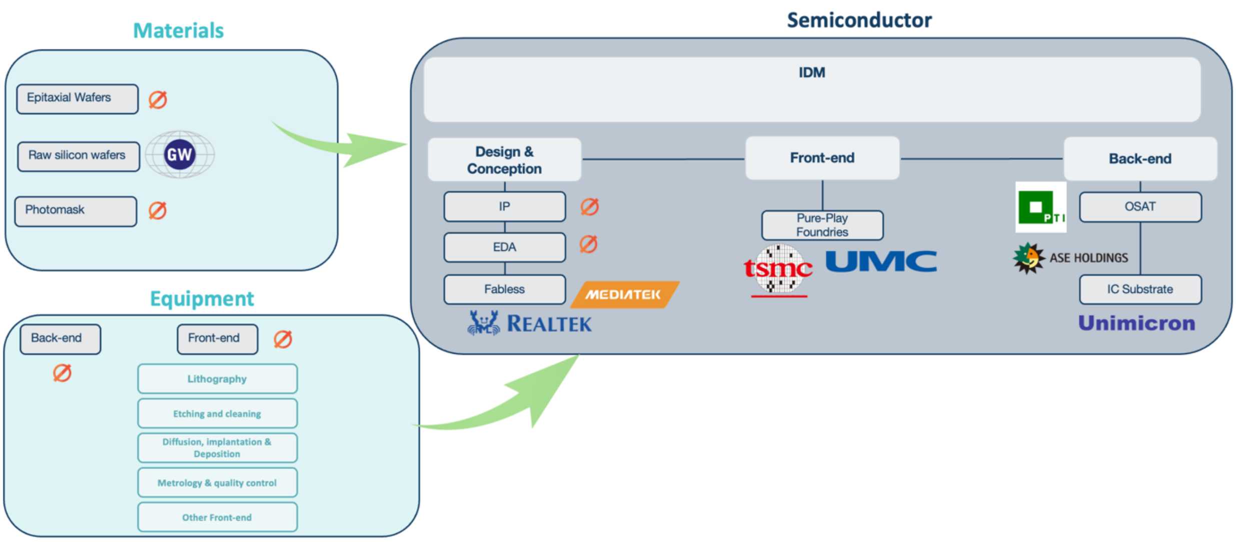
6.3.1 Key Taiwanese players in the value chain

Taiwan's semiconductor key players in the value chain reveal a notable absence of large-scale IDMs. While Taiwan does have IDMs, like Nanya Technology with €1.7 billion generated revenue in 2022 for instance, they are not of substantial size compared to other global IDMs. However, Taiwan excels in manufacturing, particularly dominating the Pure-Play Foundry and OSAT markets.

TSMC and UMC are the leaders in the foundry market, ranked respectively number 1 and number 3 at the world level. Similarly, in OSAT activities, ASE and Powertech hold prominent positions, ranking number 1 and number 5, respectively. TSMC, the leading Taiwanese player in the pure-play foundry market, is also at the cutting edge of technology. Currently, TSMC can produce 2nm node semiconductors and is expected to produce semiconductors in the angstrom range in the coming years.

The Taiwanese OSAT market also has a competitive edge. ASE, for instance, is a global leader in back-end manufacturing, mastering testing, packaging, PCB, and IC substrate production. Furthermore, Taiwanese OSAT companies are at the forefront of advanced packaging technology, capable of producing high-performance chips without relying on the smallest geometries. Unimicron, another leading Taiwanese company, specializes in supplying substrates for these advanced packaging technologies.

Figure 56: Key Taiwanese player across the value chain



Source: DECISION Etudes & Conseil

It's also important to highlight that TSMC has expanded its capabilities beyond front-end manufacturing. The company has developed relevant back-end manufacturing capacity, particularly in advanced packaging techniques. This expansion will position TSMC as an increasingly globally integrated player in the semiconductor manufacturing landscape in the following years.

In the fabless market, Taiwan is home to two relevant players, Realtek and MediaTek, two design houses that provide semiconductor for the phones, consumer PC and consumer electronics markets.

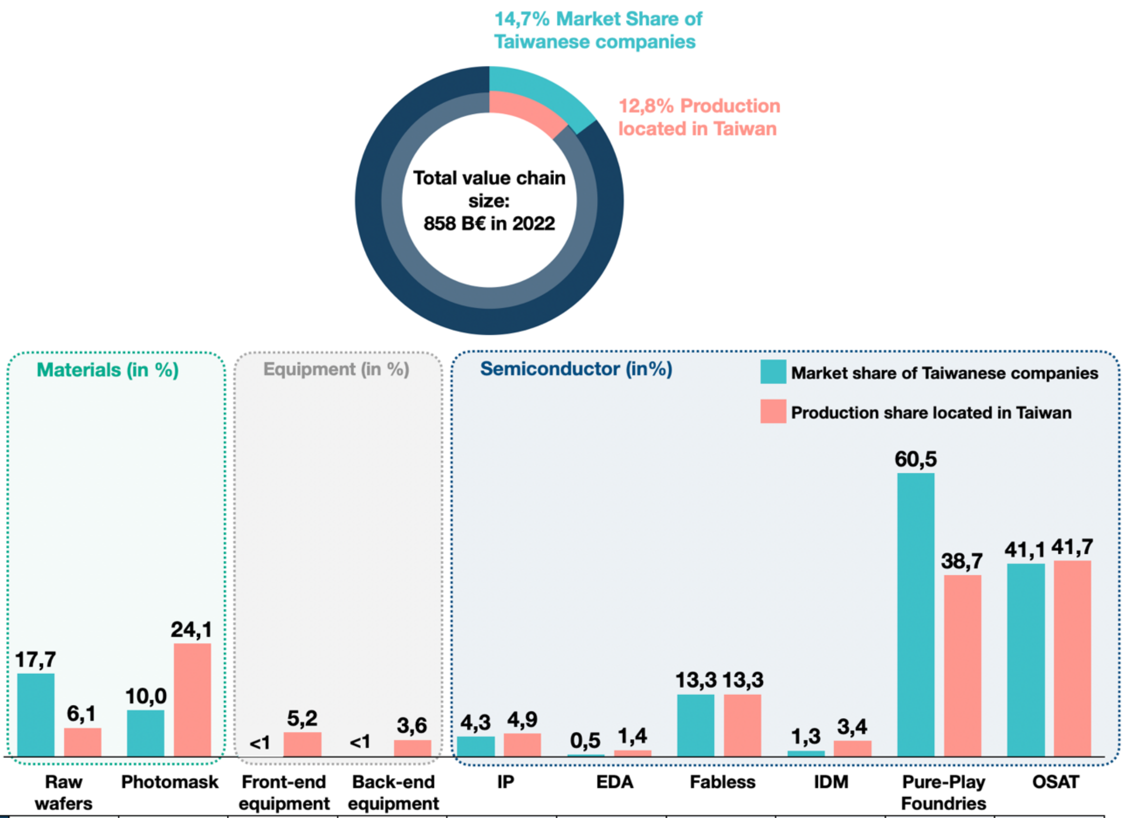
Finally, in equipment and materials, Taiwan has only one leading company, GlobalWafers, supplying raw silicon wafer for the manufacture of semiconductor.

6.3.2 Taiwanese players market share and production across the value chain

As mentioned earlier, the first thing the graph below demonstrates is the fact that Taiwan is particularly leading the manufacturing aspect in the semiconductor industry.

On the one hand, Taiwan has 60.5% market share in the Pure-play foundry, a market that is the least fragmented with a €127 billion market size and only about ten players exceeding €1 billion in revenue. However, about half of the production capacity is located in Taiwan, as the companies relocate some of their fabs abroad, particularly in close Asian countries, among which China, Japan and Singapore.

Figure 57: Market share and production share of Taiwan across the value chain in 2022



Global market size	16 B€	2.5 B€	96 B€	12 B€	6 B€	8 B€	168 B€	377 B€	127 B€	44 B€

Source: DECISION Etudes & Conseil

On the other hand, Taiwan is also the leading country in OSAT market with a 41.1% market share and 41.7% production share.

The other segments that are partaking in the supply chain, like photomask making and IP properties are partly relocated in Taiwan as well. For instance, in the photomask segment, Taiwan has a limited number of players, but the production share is relatively higher than the market share as photomask-making facilities are strategically placed closer to the manufacturing location of semiconductor.

In the fabless market, the two key players mentioned earlier are accounting for more than 90% of the 13.3% market share and production share Taiwan has.

6.3.3 Front-end and Back-end capacities

Taiwan's breakdown of technology nodes in front-end semiconductor stands out as the most balanced among all regions. Covering the entire spectrum from nodes larger than 180nm to less than 6nm, Taiwan demonstrates its comprehensive technological capabilities.

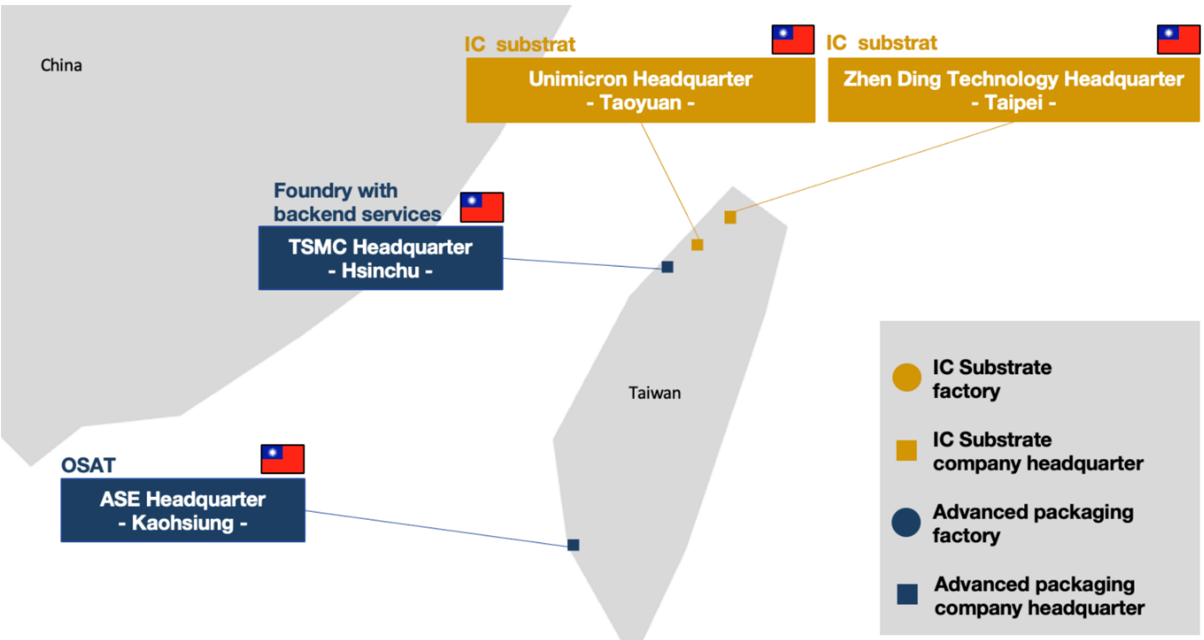
With a considerable proportion of its production dedicated to 6nm and below chips, Taiwan showcases its cutting-edge position in semiconductor manufacturing.

In addition, Taiwan also has a significant production share in semiconductors with 20nm nodes and above. This is indicative of its role in manufacturing semiconductors not just for domestic use but also for other countries.

Taiwan holds a great position in the OSAT sector, particularly in advanced packaging, with five of its companies ranking among the top 10 global players.

In addition, Taiwan is also a hub for IC substrate manufacturing. The production of IC substrates is a critical component of advanced packaging techniques, and Taiwan's capacity in this area complements its strengths in the OSAT market.

Figure 58: Map of advanced packaging in Taiwan



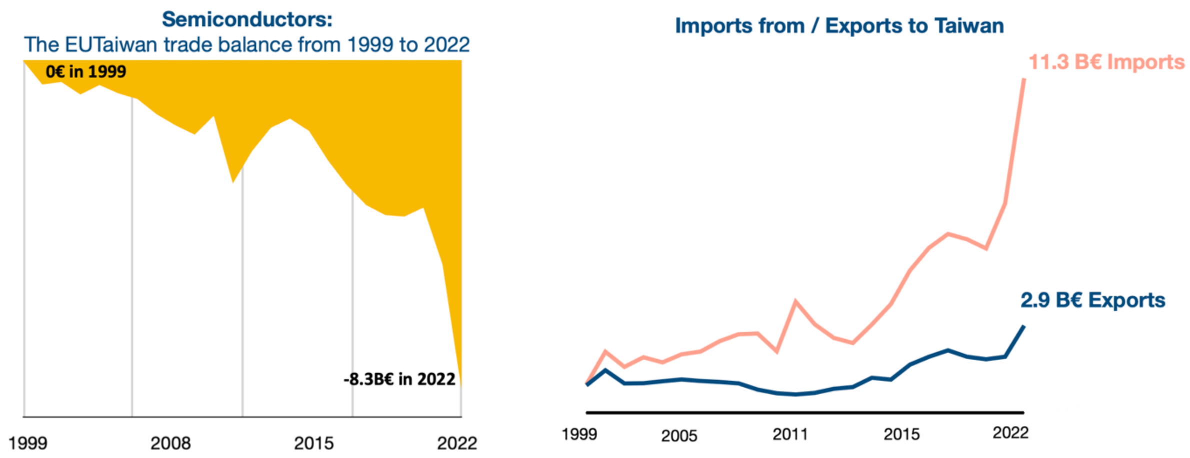
Source: DECISION Etudes & Conseil

6.5 Trade balance between the EU and Taiwan

Since 1999, the trade balance between the European Union and Taiwan in the semiconductor sector has widened, from a balanced state to a significant deficit for the EU, reaching -€8.3 billion in 2022.

This widening gap is largely attributable to the drastic reduction in the EU's semiconductor manufacturing capacities, which now represent just 7% of global front-end manufacturing. In contrast, Taiwan has expanded its capacities, currently accounting for 18% of the global front-end production.

Figure 59: The EU trade balance with Taiwan from 1999 to 2022



Source: DECISION Études & Conseil, from Eurostat

The semiconductor shortage of 2020 and 2021 due to the covid crisis further exacerbated this imbalance. During this period, there was a marked increase in the EU's semiconductor imports from Taiwan, contributing notably to the growing trade deficit.

Another contributing factor is Taiwan's role as a semiconductor manufacturing hub. Many semiconductors designed by EU companies are manufactured in Taiwan's pure-play foundries. The importation of these finished products back into the EU adds to the trade imbalance.

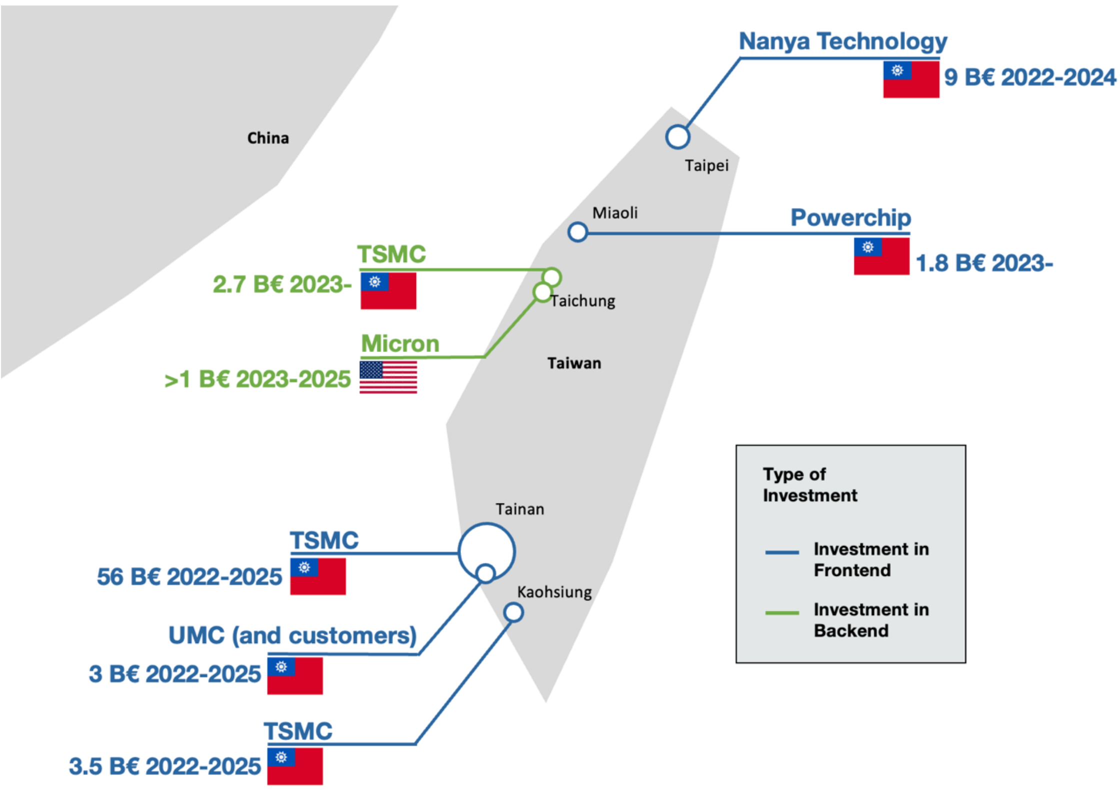
6.6 Ongoing investments in Taiwan

In Taiwan, among the major investment projects exceeding €1 billion, the Micron investment in a back-end facility in Taichung stands out as the only foreign investment.

Contrastingly, most large-scale investments are made by Taiwanese companies. For instance, in the back-end segment also, TSMC is investing €2.7 billion in an advanced chip packaging plant to capitalize on the artificial intelligence boom, indicating a shift in their business model, comprising capacity for advanced front-end manufacturing, and increasing its capacity for advanced packaging. But most investments projects are realized in the pure-play foundry sector. Key projects include TSMC and UMC's investments in southern Taiwan and Powerchip's investment in Miaoli County. The most important one is TSMC's €56 billion project in Tainan, expected to start production in 2025. This facility, initially focusing on 5-nanometer chips, has expanded its scope to include 3-nanometer chip production following an increase in investment.

Additionally, Nanya Technology, an IDM, is developing a fabrication plant in northern Taiwan with an investment of €9 billion. This facility is expected to begin operations in late 2024.

Figure 60: Map of ongoing major investment in Taiwan



Source: DECISION Etudes & Conseil

Other projects are also being carried out. For instance, in august 2023, Taiwan Government gave ASML the green light to invest €300 million to set up a plant in Linkou District, New Taipei (August 2023)

6.7 Strengths and dependencies

Strengths:

- Foundry and OSAT Leadership: Taiwan is home to leading players in the foundry and OSAT sectors, producing advanced nodes semiconductor and advanced packaging.
- IC Substrate Production: The country has relevant players in IC substrate manufacturing, a crucial component for advanced packaging.

Dependencies:

- Fabless Companies: Taiwan has a limited number of fabless semiconductor companies, indicating a gap in this segment of the industry.
- IP and EDA: The country has little to no presence in the fields of Intellectual Property (IP) and Electronic Design Automation (EDA), areas typically dominated by companies from the US.
- Equipment Manufacturing: Taiwan does not have significant equipment manufacturers, primarily relying on imports from the US, Europe, or Japan.

6.8 Cooperation & alliances

6.8.1 Position with China

Taiwan's semiconductor industry, often described as a "silicon shield," provides a strategic reason for the US and other countries to support Taiwan considering increasing threats from China. Despite this geopolitical context, Taiwanese authorities have not taken proactive steps to broaden cooperation with countries other than China. This cautious position could be attributed to China being one of TSMC’s major customers, which complicates the geopolitical dynamics and influences Taiwan’s international relations in the semiconductor sector.

6.8.2 Existing cooperation framework

Historically, Taiwanese authorities were not proactively looking at global cooperation for its semiconductor industry except with the US for geostrategic reasons. In 2021, Taiwan and the US have signed an agreement for cooperation on global semiconductor supply chain resilience. It remains a high-level agreement and no specific actions plan has been formally disclosed.

Japan's new 2 nm chipmaking alliance with IBM and IMEC is leveraged by partnership with TSMC to enable the production of legacy chips for use by Japanese industry, along with the development of advanced assembly, test, and packaging technology.

7 The South Korean semiconductor ecosystem

7.1 Overall environment and strategic objectives

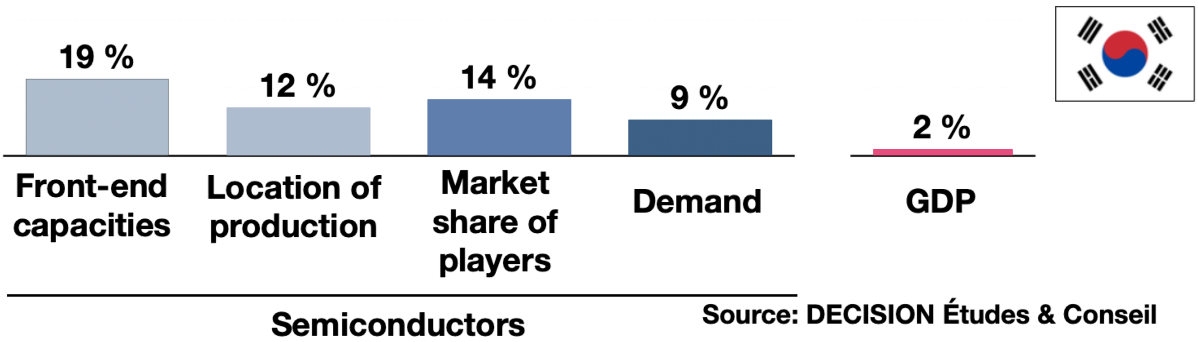
Overall environment

South Korea's semiconductor industry is one of the largest in the world, and the country particularly dominates the memory sector. In 2022, semiconductors were crucial to the nation's economy, accounting for 18.7% of its total exports. Samsung Electronics and SK Hynix, leaders in the memory sectors, are now also ambitiously expanding into non-memory semiconductor industries.

In terms of technological advancement, South Korea has begun production of 3nm chips and is on track to develop even more advanced 2nm chips by 2025, followed by 1.4nm chips by 2027. Recognizing the sector's importance, the South Korean government is actively supporting this growth. Initiatives include providing tax incentives and subsidies, as well as establishing training centers to bolster the development of the semiconductor industry.

Despite these advancements, South Korea faces significant challenges in its quest to become the leading global semiconductor powerhouse. Key obstacles include a shortage of skilled talent, the need for more advanced technology, and the localization of semiconductor equipment and materials.

Figure 61: Position of South Korea across the semiconductor value chain (in percentage of the World production), in 2022



2023: A Challenging Year for South Korea's Semiconductor Industry

The year 2023 has been particularly difficult for South Korea's semiconductor sector, marked by a decline in global demand for memory chips. This downturn has led to Samsung Electronics announcing its first quarterly deficit in the semiconductor division in 14 years. Similarly, SK Hynix reported its first quarterly deficit in a decade during the last quarter of the previous year.

Objectives & strategy

Faced with the high volatility of the memory market, a major challenge for the South Korean semiconductor industry, the government launched the K-Belt Plan in 2022. This comprehensive strategy aims to bolster the industry through several key initiatives:

- **Establishment of a 'K-semiconductor belt':** The plan envisions creating a geographic cluster dedicated to semiconductor production.
- **Doubling the Workforce:** A significant focus is placed on expanding the industry's workforce to support growing production needs.
- **Investment Tax Credits:** The plan introduces tax credits for manufacturing investments to stimulate further growth in the sector.
- **R&D Tax Credits:** To encourage innovation, the plan offers up to 50% in R&D tax credits.

The K-Belt National Chip Plan includes incentives totaling between €52 billion to €62 billion over three years, with the goal of attracting cumulative investments of approximately €427 billion by 2030.

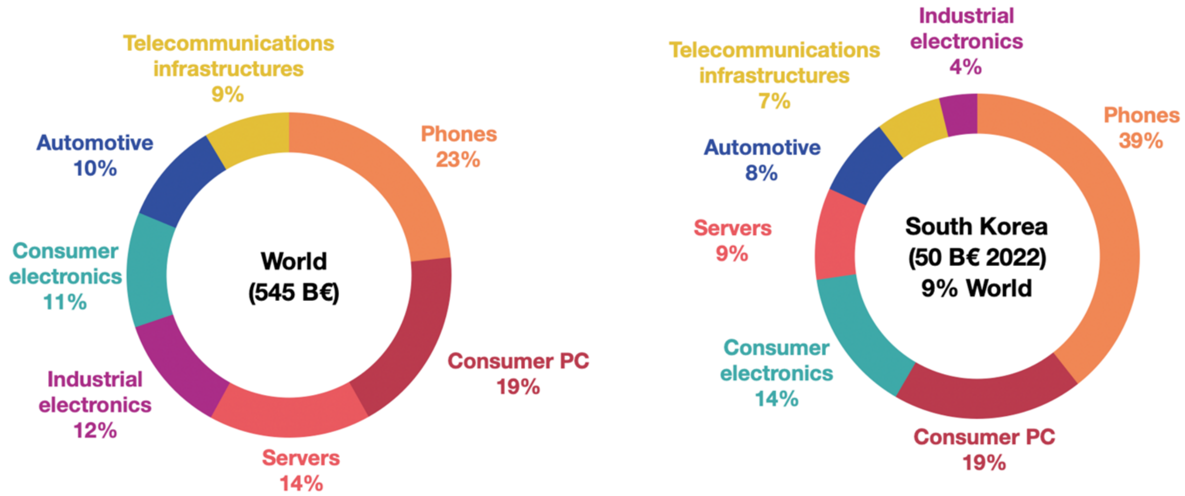
The South Korean administration is also focusing on developing a mega semiconductor cluster domestically, concentrating on logic semiconductor production. This includes an ambitious plan by Samsung to construct five foundries within this cluster, aiming to rival Taiwan's TSMC in the logic chip manufacturing market.

As the global economy transitions into Industry 4.0, it is becoming increasingly crucial for South Korea to diversify into non-memory sectors. This strategic shift is intended to position South Korea as a competitive force against industry leaders like TSMC and others, expanding its footprint beyond the memory market.

7.2 The semiconductor market in South Korea

South Korea is known for its prominent electronic chaebols, such as Samsung and LG, which have a strong presence in the fields of mobile phones, consumer PCs, and electronic appliances. These three sectors combined account for over 70% of the total semiconductor demand in South Korea.

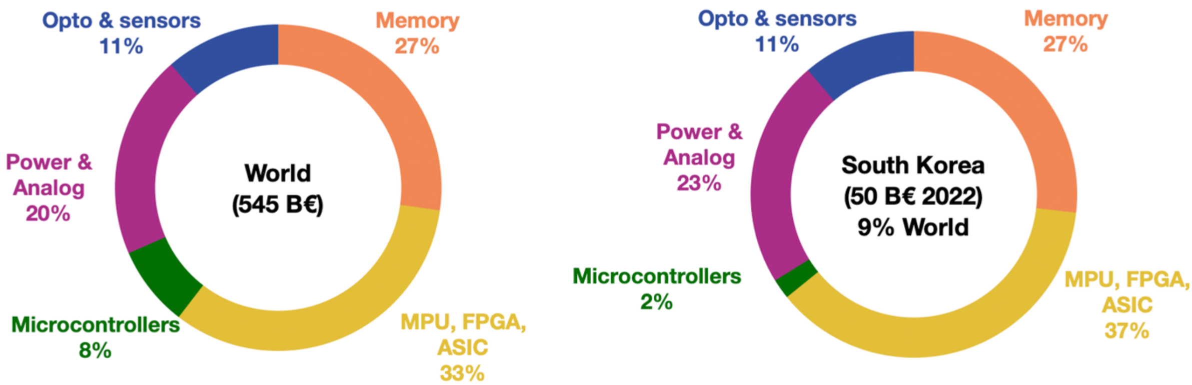
Figure 62: Spread of the South Korean semiconductor demand by application



Source: DECISION Etudes & Conseil

Given the dominance of mobile phones, consumer PCs, and electronic appliances in the South Korean market, the highest product-specific demand in the semiconductor industry is for memory chips, MPUs/ASICs, and Power Analog components.

Figure 63: Spread of the Japanese semiconductor demand by product



Source: DECISION Etudes & Conseil

7.3 The semiconductor industry in South Korea

7.3.1 Key South Korean players in the value chain

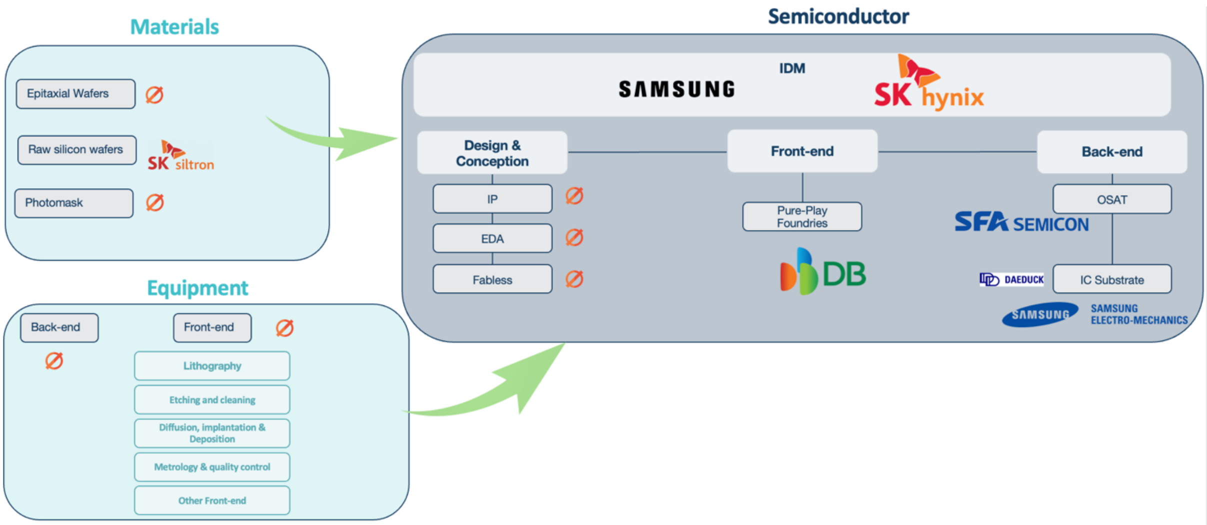
South Korea's semiconductor market is characterized by the presence of conglomerates that operate across multiple segments, beyond the scope of traditional IDMs. For example, Samsung is not just involved in semiconductor design and manufacturing; it also plays a significant role in IC substrate production. Similarly, the conglomerate SK Group, through its subsidiary SK Siltron, is active in raw silicon wafer manufacturing.

The country is a global leader in memory components, with Samsung and SK Hynix ranking as the top two companies not just in South Korea but also worldwide in this sector.

While South Korea may not dominate the foundry and OSAT markets to the same extent, it still has noteworthy players such as DB Hitek in the foundry sector and SFA Semicon in OSAT.

However, a notable gap is the lack of domestic players in the equipment manufacturing segment. This deficiency leads to a significant dependency on equipment suppliers from the US, EU, and Japan. South Korean companies rely on these foreign manufacturers for the essential machinery and tools required in semiconductor production, highlighting a key area of external reliance within an otherwise robust industry.

Figure 64: Key South Korean players across the value chain



Source: DECISION Etudes & Conseil

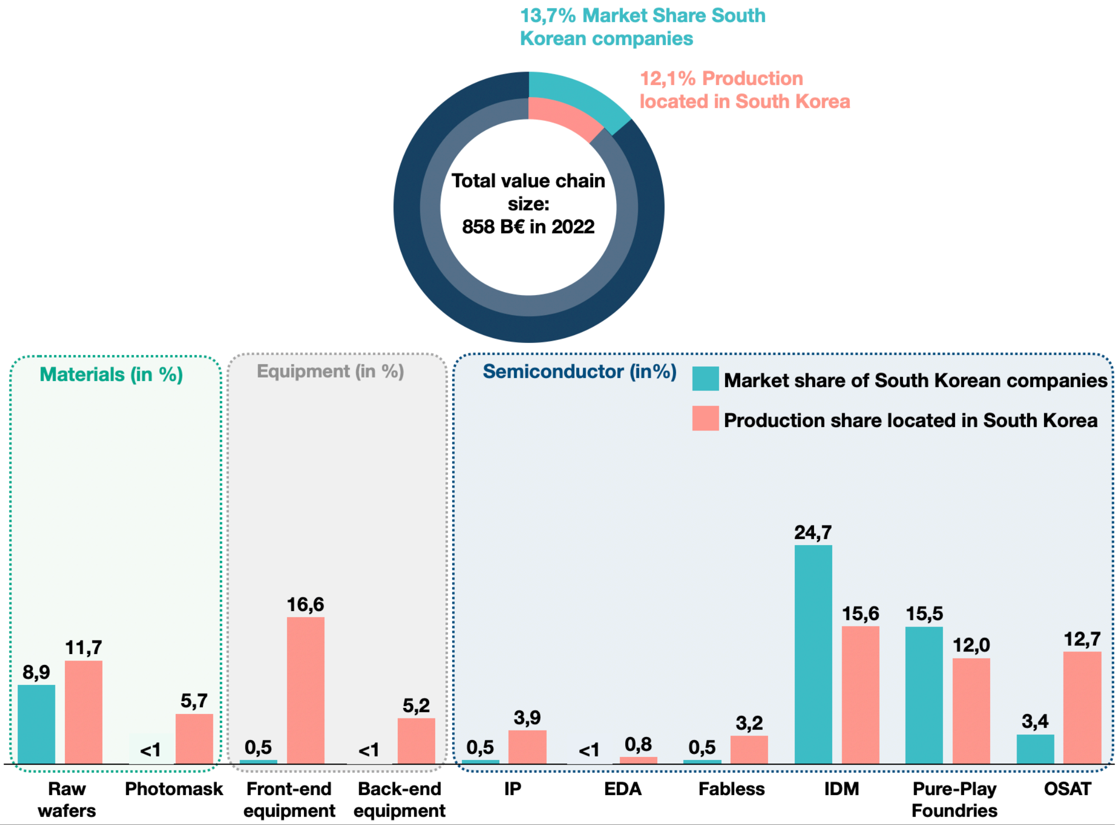
7.3.2 South Korean players market share and production across the value chain

Overall, the South Korean semiconductor industry accounts for 13.7% of the market share and 12.1% of production in the industry's €860 billion value creation.

In IDM activities, Samsung and SK Hynix are leading players, together representing nearly the entire 24.7% market share held by South Korea.

The country also accounts for 15.5% of the global revenue in the pure-play foundry market. This share is largely attributed to DB Hitek and Samsung's foundry operations, with Samsung alone generating over €17 billion in revenue in 2022, ranking it second only to TSMC, which generated revenues of €60 billion in pure-play foundry activities in the same year.

Figure 65: Market share and production share of South Korea across the value chain in 2022



Global market size	Raw wafers	Photomask	Front-end equipment	Back-end equipment	IP	EDA	Fabless	IDM	Pure-Play Foundries	OSAT
	16 B€	2.5 B€	96 B€	12 B€	6 B€	8 B€	168 B€	377 B€	127 B€	44 B€

Source: DECISION Etudes & Conseil

In the OSAT market, South Korea has a 3.4% market share but a significantly higher 12.7% production share. This discrepancy is due to the relocation of some key OSAT facilities to South Korea by major international companies like Taiwan's ASE, the US's Amkor, and China's JCET.

Conversely, South Korea has a limited market share in Equipment and global design sectors, including IP, EDA, and Fabless companies. The absence of domestic Equipment manufacturers creates a major dependency on foreign suppliers. However, this dependency is somewhat mitigated by the presence of international equipment manufacturers within South Korea, such as Applied Materials.

7.3.3 Front-end and Back-end capacities

The South Korean semiconductor industry, with a strong emphasis on flash memories, mainly allocates its front-end capacities to specific technological nodes. Approximately half of this capacity is dedicated to the 10-20nm range. Samsung is one of the few companies globally that possesses the capability to produce chips with geometries below 6nm.

In October 2023, Samsung Foundry unveiled its advanced and wide-ranging automotive process solutions, from the most advanced 2nm process to the 8-inch legacy.

In the global OSAT market, South Korean players hold a relatively modest share, accounting for just 3% of the overall market. This segment is primarily represented by Samsung, a major domestic player in the OSAT space. Contrastingly, the presence of several foreign companies operating within South Korea, including those from China, significantly boosts the country's involvement in this sector.

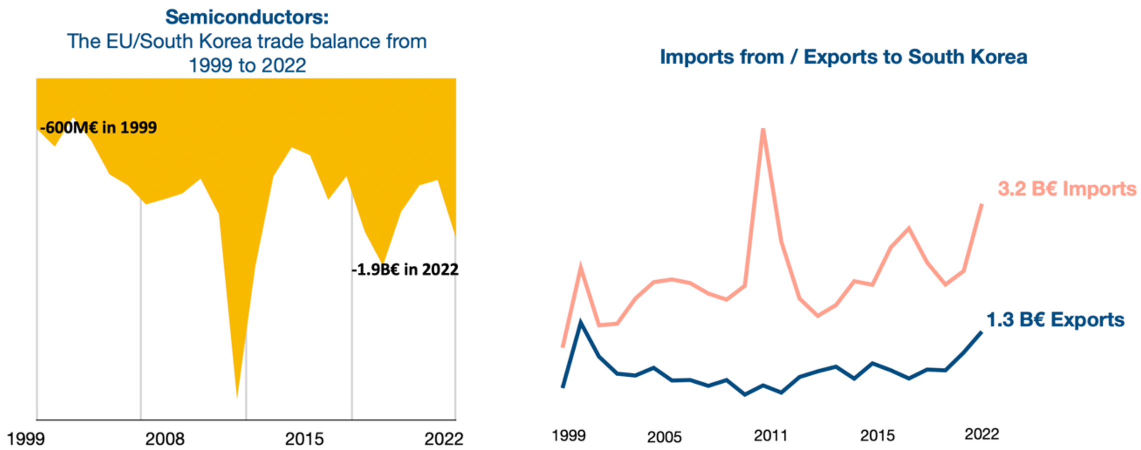
7.4 Trade balance between the EU and South Korea

Over the past two decades, the trade balance between the EU and South Korea in the semiconductor industry has widened. Initially, the EU faced a deficit of -€600 million, which has nearly tripled to -€1.9 billion, with a notable spike occurring in the early 2010s due to the Fukushima accident in Japan.

In 2022, the EU's imports of semiconductors from South Korea totaled €3.2 billion, predominantly consisting of processors and microcontrollers.

Looking ahead, this trade deficit could further expand if the EU's demand for high-end Microprocessor Units (MPUs) and memory components continues to increase, leading to a major dependency for the EU.

Figure 66: The EU trade balance with South Korea from 1999 to 2022

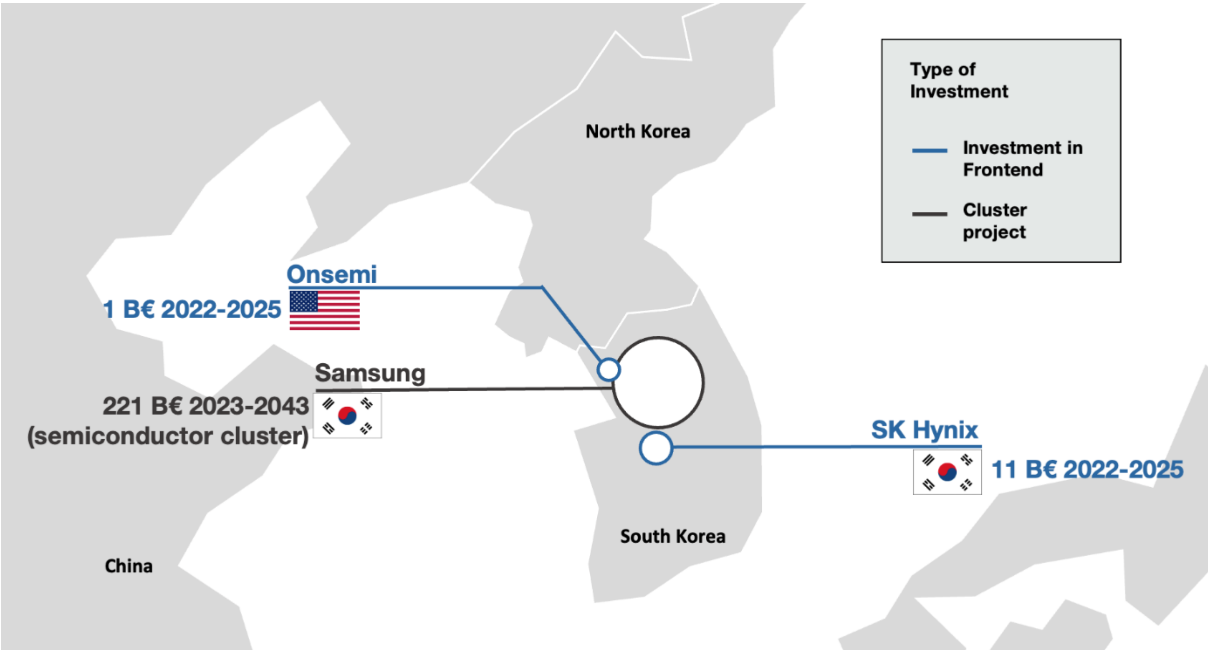


Source: DECISION Études & Conseil, from Eurostat

7.5 Ongoing investments in South Korea

Samsung Electronics plans to invest €221 billion over 20 years to create the world's largest semiconductor manufacturing base in Gyeonggi Province, South Korea. This "mega cluster" will feature five new Samsung plants producing memory and logic chips and aims to attract 150 related companies. The initiative is part of a broader government effort to invest in six key tech sectors, with hopes to draw about €350 billion in investments by 2026.

Figure 67: Ongoing major investments in South Korea



Source: DECISION Etudes & Conseil

Among the other relevant investments, SK Hynix announced a €11 billion investment to build a new chip plant in Cheongju, South Korea, with completion expected by early 2025. The plant, M15X, will manufacture memory chips, with the type—DRAM or NAND flash—dependent on market conditions at the time.

And finally, the US chipmaker ONSEMI will invest €1 billion to construct a research center and manufacturing facility in Bucheon, Gyeonggi, by 2025. The facility will produce silicon carbide (SiC) power semiconductors for use in electric vehicles.

7.6 Strengths and dependencies

Strengths:

- Leadership in Memory Semiconductors: South Korea, particularly through its IDM (Integrated Device Manufacturer) model, stands as a global leader in memory semiconductors.
- Extensive Capacities for Advanced Processes: The country possesses considerable manufacturing capacities, capable of producing advanced process nodes. For instance, Samsung offers foundry services for other companies.

Dependencies:

- Equipment and Materials: South Korea relies heavily on importing key semiconductor manufacturing equipment and materials, indicating a dependency on external sources for these crucial components.
- EDA (Electronic Design Automation) and IP (Intellectual Property): The country also shows a dependency in EDA and IP.

7.7 Cooperation & alliances

7.7.1 Position against China

The South Korean administration is increasingly mindful of its industry's dependence on global supply chains. Major companies like Samsung and SK Hynix have substantial business operations and interests in China. In fact, the Chinese market constitutes over 40% of South Korea's semiconductor revenues. Moreover, there is the example of the Samsung plant in Xi'an, China, that accounts for over 40% of Samsung's total NAND production. Additionally, the South Korean semiconductor industry relies heavily on materials imported from China. This reliance extends beyond just market share and revenue, as it encompasses essential raw materials and components necessary for semiconductor manufacturing.

7.7.2 Existing alliances

The Chip 4 alliance, which aims to unite the United States, Japan, Taiwan, and South Korea in the semiconductor field, holds the promise of becoming a major collaborative force. However, South Korea's participation in this alliance is uncertain for several reasons:

One significant factor is the potential response from China. South Korea's semiconductor industry is linked with China, which is its largest trading partner in this sector. Notably, over 48% of South Korea's memory chip exports are destined for China, highlighting the dependency on Chinese markets. Joining an alliance perceived as countering China's interests could have substantial implications for South Korea's trade relations.

Additionally, the longstanding and complex historical conflict between South Korea and Japan, stretching back over a century, adds another layer of complexity to South Korea's decision to join the Chip 4 alliance. These deep-rooted tensions could impede the formation of a cohesive and effective partnership within the alliance.

7.7.3 Existing cooperation framework with the EU

In June 2023, the inaugural Digital Partnership Council meeting between the EU and the Republic of Korea was held in Seoul. During this meeting, both partners agreed to collaborate on several key technology areas, including semiconductors, High-Performance Computing (HPC), quantum technology, 5G and beyond, the platform economy, artificial intelligence (AI), and cybersecurity. The next Digital Partnership Council is scheduled for early 2024 in Brussels, where progress will be reviewed, and further steps will be taken to deepen the EU-Republic of Korea digital partnership.

Thierry Breton, the European Commissioner for Internal Market, has expressed the European Union's eagerness to cooperate with South Korea in the fields of chips, digital trade, and clean technology. This sentiment comes amid increasing geopolitical uncertainties.

In June 2023, Infineon Technologies signed a Memorandum of Understanding (MoU) with South Chungcheong Province in Korea to establish the Renewable Energy Technology Center (tentative name) within the Chungnam Knowledge Industry Centre located in Cheonan.

In November 2022, ASML announced plans to construct a 16,000-square-meter facility in Hwaseong city, a suburb of Seoul, South Korea, with an investment of €172 million. Operations at this facility are expected to commence in the second half of 2024. Additionally, in May 2023, ASML opened a global Extreme Ultraviolet (EUV) training center in South Korea.

STMicroelectronics is collaborating with Hyundai Autron to establish the Autron-ST Development Lab (ASDL) in Seoul, Korea. This joint development lab will focus on providing solutions for eco-friendly vehicles, emphasizing powertrain controllers.

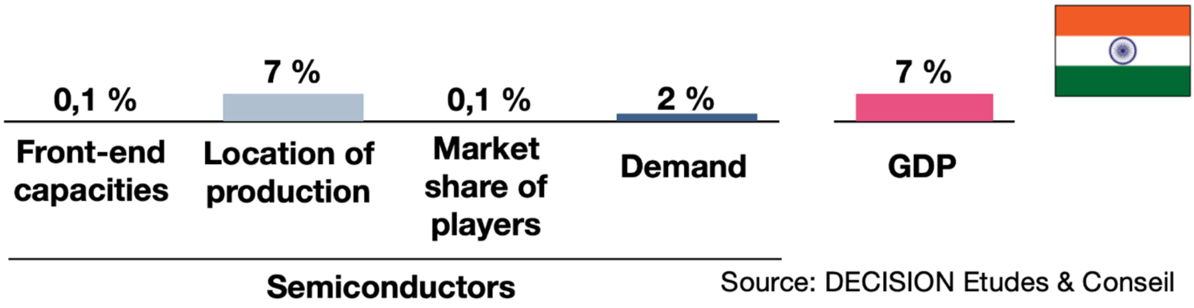
8 The Indian semiconductor ecosystem

8.1 Overall environment and strategic objectives

Overall environment

India's semiconductor manufacturing, particularly in front-end, is still developing. India's share remains small, but its semiconductor market is estimated to reach €60 Billion by 2026. Semiconductor manufacturing involves complex and capital-intensive processes, and India currently lacks a robust ecosystem for domestic wafer fabrication. The National Policy on Electronics 2019 (NPE 2019) aims to position India as a global hub for Electronics System Design and Manufacturing (ESDM), with strategies to set up semiconductor wafer fabrication facilities. There have been historical challenges in setting up manufacturing fabs units in India for a long time: lack of infrastructure and skilled labor in the country, workforce specialized in design and software aspects, competition with China, Vietnam, etc.

Figure 68: Position of India across the semiconductor value chain (in percentage of the World production), in 2022



There are also a few initiatives in the field of OSAT. For instance, Sahasra is an OSAT company who intend to package basic memory products like MicroSD cards and chip-on-board, to be followed by advanced packaging of products like internal memory chips. Building OSAT capabilities in India is seen as a key step towards accelerating efforts to establish semiconductor fabs.

Finally, India has a strong footprint in semiconductor design, with 20% of the world's semiconductor design engineers and a few startups & academic projects are emerging such as:

- Signalchip: 4G and 5G modem chips
- Saankhya Labs: chipsets for defense application, satellite communication and broadcast
- Shakti: aims at building an open-source IP ecosystem for microprocessors in mobile computing devices. (from a ITT Madras Technical University initiative)

Despite the thriving design ecosystem and a considerable talent pool, most Intellectual Property (IP) generated is held by foreign companies and India's domestic semiconductor design industry remains weak. The total electronic design market in India is growing rapidly, necessitating the development of domestic semiconductor design capabilities.

Objectives

India had historically a plan to create a strong semiconductor manufacturing sector with the ambition to have access to advanced technologies and be an important semiconductor hub. However, India failed to convince large companies such as TSMC to set-up operations in the country. The government must now review its ambition and settle less advanced chips manufacturing.

Strategy

To position India as a global hub for Electronics System Design and Manufacturing (ESDM), the Government of India has approved a comprehensive program for the development of the semiconductor and display manufacturing ecosystem. This program, with an outlay of > €10 billion, includes various schemes to boost investment in semiconductor and display manufacturing.

1. Fiscal Support for Semiconductor and Display Fabs: The program offers a 50% fiscal support for setting up semiconductor fabs in India, covering all technology nodes. Similar support extends to the establishment of display fabs.
2. Support for Compound Semiconductors and OSAT Facilities: There is also a provision of 50% fiscal support for capital expenditure in setting up compound semiconductor, silicon photonics, sensors (including MEMS), and discrete semiconductor fabs, as well as semiconductor ATMP (Assembly, Testing, Marking, and Packaging) / OSAT facilities. The scheme aims to establish at least 20 units of compound semiconductors and semiconductor packaging with government backing.
3. Encouraging Semiconductor Design: The Design Linked Incentive (DLI) Scheme offers up to a 50% incentive on eligible expenditures linked to product design, and a 6%-4% incentive on net sales for product deployment over five years. The scheme targets supporting 100 domestic semiconductor design companies, fostering the growth of at least 20 such companies to achieve a turnover of over €180 million within five years.
4. Development of an R&D ecosystem: India is planning to establish the India Semiconductor Research Center (ISRC) at a cost of US$8 billion over five years, aiming to become a global leader in semiconductor research and development, similar to the IMEC, and to boost the country's chip manufacturing and fabless ecosystem. The SCL is also partly benefiting from the investments, meeting its modernization objective. The SCL is indeed exploring 2 scenarios: becoming a

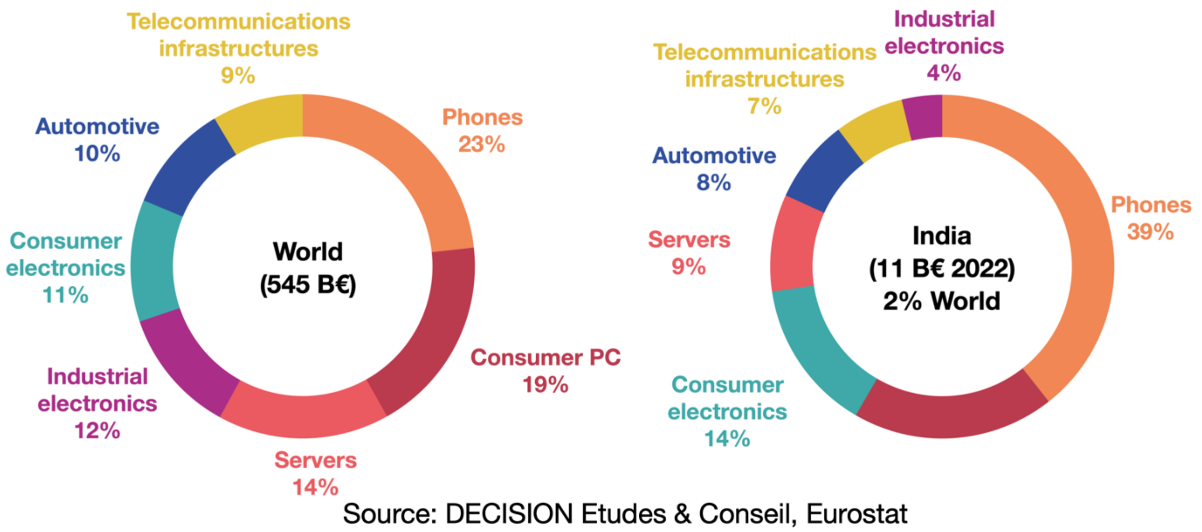
R&D-focused Center of Excellence or an At-scale manufacturing focused entity[48].

5. India Semiconductor Mission (ISM): An independent entity, the India Semiconductor Mission, led by global semiconductor and display industry experts, has been established to drive long-term strategies for developing a sustainable semiconductor and display ecosystem. This mission will act as the nodal agency for the effective implementation of these schemes.

8.2 The semiconductor market in India

Despite an underdeveloped domestic semiconductor industry, in 2022, the country consumed approximately 2.5% of the world's semiconductors, translating to around €12 billion. A considerable part of this demand is driven by the mobile phone and consumer electronics sectors. The high demand for semiconductors in the phone industry is partly due to the presence of manufacturing giants like Foxconn, which produce the latest iPhone models in India. While semiconductor demand in other applications is currently less significant, sectors such as automotive are expected to see increased semiconductor consumption due the increased functionalities in vehicles.

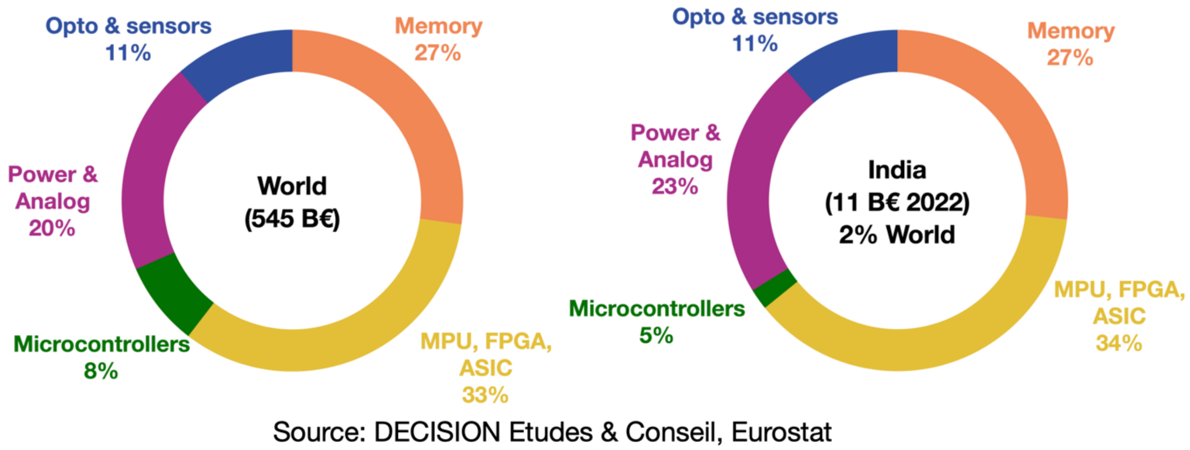
Figure 69: Spread of the Indian semiconductor demand by application



The main semiconductor products consumed in India are memory components, MPUs/FPGAs/ASICs, and Power/Analog components. These categories align with the requirements of the phone industry, which constitutes a major segment as seen above. Conversely, there is a relatively lower demand for Microcontrollers and Opto & Sensors, which is consistent with the current breakdown of applications in the country.

[48] More details on https://www.meity.gov.in/writereaddata/files/EoI-SCL%20Modernization.pdf

Figure 70: Spread of the Indian semiconductor demand by product



8.3 The semiconductor industry in India

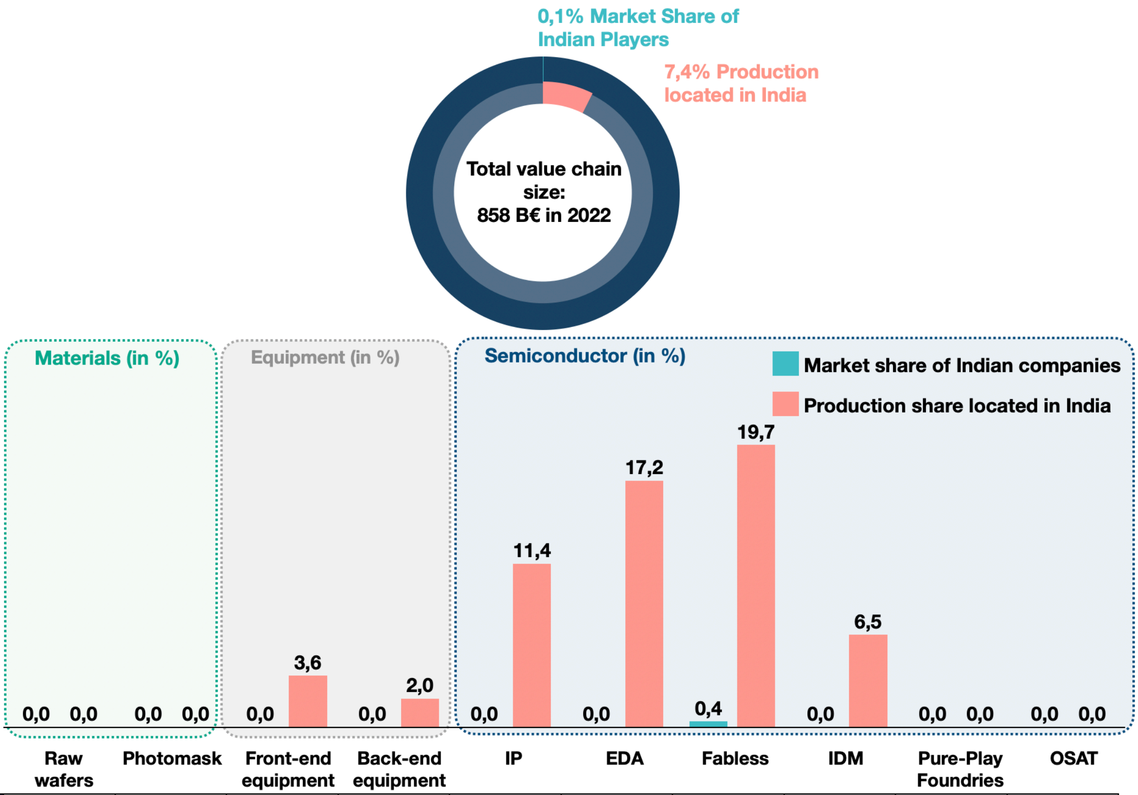
8.3.1 Indian players market share and production share across the value chain

As India has no relevant player in the semiconductor industry, its market share accounts for less than 1% of the total sales across the whole value chain. However, the country is responsible for 7.4% of the production. Mainly in R&D for equipment, in IP and EDA, design engineers for fabless and IDM companies.

India has a significant presence in the design of semiconductors. The country accounts for 11.4% and 17.2% of the global production in the IP and EDA segments, respectively. This success is partly attributed to technology hubs like in Bangalore, where major companies like Arm, Synopsys, and Cadence have established operations, along with other smaller players.

In the Fabless and IDM sectors, India contributes primarily in design, leveraging its substantial pool of design engineering talents. The country holds a 19.7% production share in the Fabless market and 6.5% in the IDM market, exclusively in design-related activities.

Figure 71: Market share and production share of India across the value chain



	Raw wafers	Photomask	Front-end equipment	Back-end equipment	IP	EDA	Fabless	IDM	Pure-Play Foundries	OSAT
Global market size	16 B€	2.5 B€	96 B€	12 B€	6 B€	8 B€	168 B€	377 B€	127 B€	44 B€

Source: DECISION Etudes & Conseil

India also hosts research and development labs contributing to equipment manufacturing, with 3.6% of the production share in front-end equipment manufacturing and 2% in back-end equipment manufacturing.

Despite these strengths, India faces significant challenges in semiconductor manufacturing. The country has minimal or nearly non-existent market shares across all segments of the semiconductor value chain. Furthermore, it struggles with the actual manufacturing aspect of semiconductors, lagging behind in both front-end and back-end manufacturing.

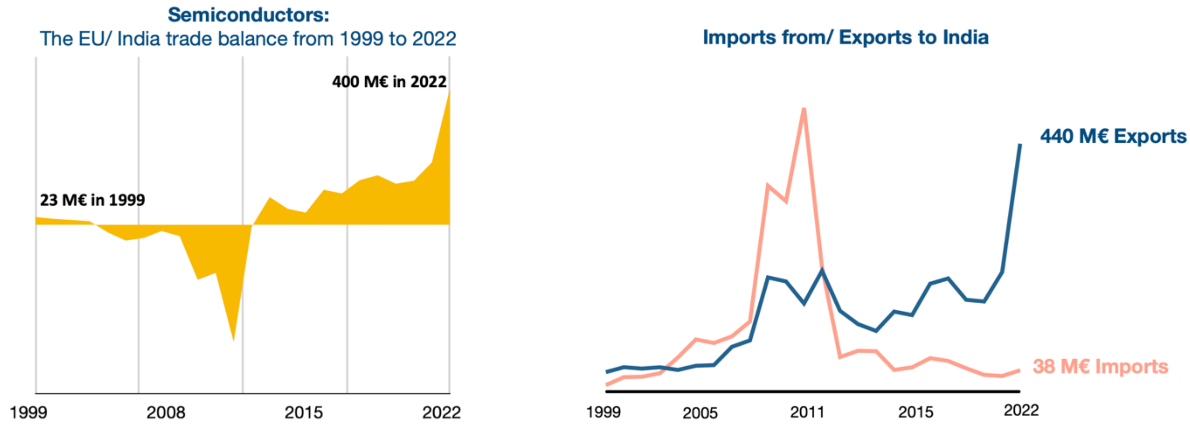
8.3.2 Front-end and back-end capacities

The current limited production in India primarily serves R&D purposes.

Recognizing the need to catch up, the Indian government has introduced targeted investment incentives aimed at modernizing and expanding India's semiconductor production capabilities. These incentives are specifically designed for fab projects producing semiconductors with less than 65nm nodes. The objective is to accelerate India's progress in the semiconductor industry and better support emerging domestic industries that require advanced semiconductor technologies.

8.4 Trade balance between the EU and India

Figure 72: The EU trade balance with India



Source: DECISION Études & Conseil, from Eurostat

The trade balance between the EU and India in the semiconductor sector has seen a shift over the years. Beginning with a deficit of €23 million in favor of the EU, the gap expanded to €400 million in favor of the EU in 2022. However, there was a notable spike in imports from India in 2010, driven by the EU's import of optoelectronics components, which temporarily created a negative deficit for the EU.

The primary exports from the EU to India in this sector are microcontrollers and other electronic integrated circuits. These components are essential to various segments of the Indian industry, particularly in areas like automotive and industrial applications.

Looking ahead, the trade deficit between the EU and India in the semiconductor sector is expected to widen (in favor of the EU). This trend is driven by increasing semiconductor content in the automotive and industrial sectors and the rising importance of AI and 5G technologies. Unless India develops its own semiconductor industry, this trade gap is likely to continue expanding.

8.5 Ongoing investments in India[49]

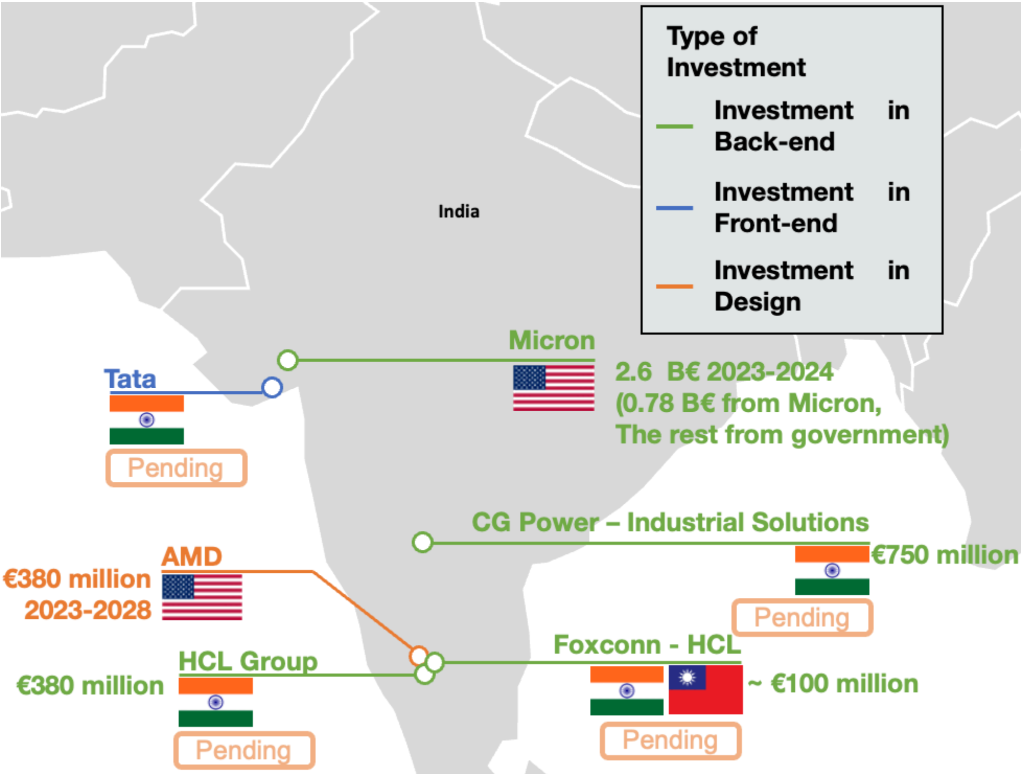
Micron remains the only concrete project for now. The company has announced a significant investment of up to €780 million to establish a new assembly and test facility in Gujarat, India, focusing on DRAM and NAND products. This project is set to begin construction in 2023 and become operational by late 2024. Supported by India's "Modified Assembly, Testing, Marking and Packaging (ATMP) Scheme," the investment will receive 50% fiscal support from the Indian central government and 20% from the state of Gujarat, totaling up to €2.6 billion with government contributions.

Conversely, India has yet to secure a feasible application for the construction of a semiconductor fab. There have been 3 important projects that have failed or stalled within one year:

- ISMC Project: The international consortium ISMC, backed by Abu Dhabi's Next Orbit and Tower Semiconductor, withdrew its proposal to set up a €2.85 billion semiconductor fab in Karnataka due to a pending merger between Intel and Tower Semiconductor.
- Vedanta-Foxconn Joint Venture: A joint venture between Foxconn and Vedanta to establish a €18.5 billion chip plant came to an abrupt stop when Foxconn announced its withdrawal from the partnership.
- ISGG Ventures: The project has been given less importance compared to other projects, which led to its cancellation.

[49] Every investment projects involving support from Government can be followed at: https://www.india-briefing.com/news/setting-up-a-semiconductor-fabrication-plant-in-india-what-foreign-investors-should-know-22009.html/

Figure 73: Current state of major semiconductor investments in India



Source: DECISION Etudes & Conseil

However, there are over relevant investment projects in India:

Major investments in OSAT

- HCL is holding active discussions with the Karnataka state government to set up an OSAT facility (chip packaging unit), per an Economic Times report. The company is planning to make an investment of about US$ 400 million to set up a "small-to-medium sized" facility.
- HCL and Foxconn have announced a JV for chip testing & packaging.
- CG Power and Industrial Solutions, a part of the Murugappa Group, stated that it has formally applied to the Ministry of Electronics and Information Technology to establish an outsourced semiconductor assembly and test (OSAT) facility. The proposed investment for this venture amounts to US$791 million (INR 65.92 billion), to be spread over a five-year period.
- SPEL pioneered the Indian OSAT market and continues to steadily grow. SPEL is a trusted & strategic contract manufacturing partner for many of the world's leading Semiconductor companies.

- **Qualcomm** told media that it will outsource manufacture of semiconductor chips to India when the country has set up its own fab plants and OSAT facilities.

Mid-long-term plan on Front End manufacturing

- Union Minister for Electronics and Information Technology, Ashwini Vaishnaw, told media that India expected **three new semiconductor fabrication units in the coming months**, with a combined investment ranging from US$8 to US$12 billion, inclusive of government incentives.
- A report in the Economic Times says Israel's chipmaker **Tower Semiconductors** has resubmitted a proposal to set up a semiconductor fabrication unit for 65 nm and 40 nm chips in India. There is speculation in the industry that Tower Semiconductors' new partner in the latest proposal could be the **BC Jindal group**, a major manufacturer of packaging and labelling products.
- **Tata Group** announced plans to set up a large semiconductor fabrication plant in Dholera, Gujarat. The project is reportedly in its final stages of negotiations and operations would commence within the year.

Reinforcement of design capabilities

- **AMD** inaugurated its largest global design centre, the Technostar research and development campus, on November 28 2023, in Bengaluru

Other major initiatives

- **SemiconIndia Future design:** ambition to encourage chip design startups.
- **Digital India Risc V:** build IP and devices on Risc V open source[50].
- **India Semiconductor Research Centre:** R&D on advanced process, system in package and chip design.

[50] For more information: https://riscv.org/blog/2023/07/the-incredible-growth-of-risc-v-in-india/

8.6 Strengths and dependencies

Strengths:

- **Design Capabilities:** As of 2021, the region boasts 20% of the world's semiconductor design engineers. However, a majority of this workforce is employed in global companies, and domestic players contribute little to no revenue.

- **Skilled Workforce:** Annually, India produces thousands of graduates from electronics programs. This is particularly advantageous given the skill shortages experienced in other major regions like the US and the EU.

- **Investment power:** India's strong economic position, having one of the highest growth rates globally, supports its ambition to emerge as a semiconductor hub. The Indian government has the financial capacity to invest significantly in the semiconductor sector.

Dependencies:

- **Value Chain Vulnerabilities:** The region shows dependencies across every segment of the semiconductor value chain, particularly in equipment & Materials.

- **Advanced Technologies:** There is a significant lag in advanced technology adoption and development.

8.7 Cooperation and alliances

8.7.1 Existing cooperation framework

India and Japan have formally signed a MoU and agreed to establish a joint mechanism aimed at facilitating collaboration between their respective governments and industries in the field of semiconductors. Rapidus, will be an important part of the India-Japan MoU,

This MoU covers five key areas of cooperation, which include semiconductor design, manufacturing, equipment research, talent development, and enhancing the resilience of the semiconductor supply chain.

There are also other cooperation:

- Europe-India Trade and Technology council
- US-India initiative on critical emerging technologies, and commercial dialogue

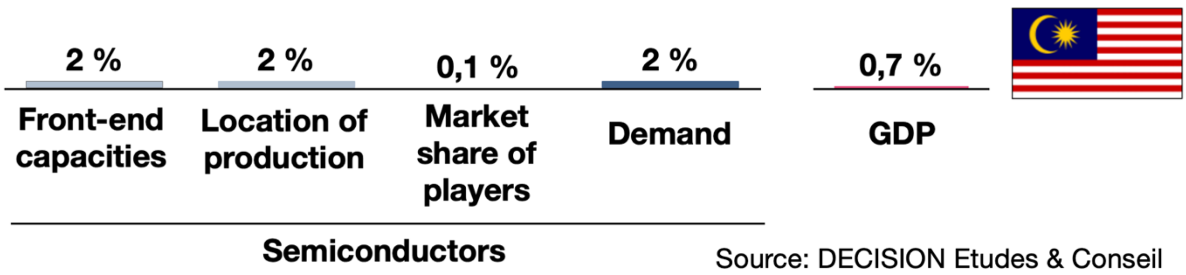
9 The Malaysian semiconductor industry

9.1 Overall environment and strategic objective

Overall environment

The origins of the Malaysian semiconductor industry can be traced back to the 1970s, driven by the desire to relocate assembly operations from countries such as the US and Japan to countries with cheapest labor. Since then, Malaysia has emerged as a significant player in the global semiconductor manufacturing landscape, consistently ranking within the top 10 countries. In 2022, around 32.64 billion semiconductors were produced in Malaysia[51], underscoring the importance of its electrical and electronics industry. This growth is further evidenced by the attraction of major companies like Tesla to Malaysia. The country's journey in the semiconductor sector dates to the 1970s with the establishment of the first Free Trade Zone, strategically drawing multinational electronics firms. Over the decades, Malaysia has evolved from focusing on assembly operations to embracing more complex manufacturing and R&D activities in the semiconductor field.

Figure 74: Position of Malaysia across the semiconductor value chain (in percentage of the World production), in 2022



Objectives

Malaysia's semiconductor industry, while grappling with global challenges like supply chain disruptions and skill shortages, is projected to continue growing, with an expected CAGR of 7%, aiming for an output of €44 billion by 2028. While the country is a relevant player in the back-end manufacturing, Malaysia's objective is to expand to front-end and circuit design. The Twelfth Malaysian Plan outlines a comprehensive national E&E roadmap, targeting key subsectors like semiconductors and solar photovoltaics. These initiatives are poised to strengthen the industry's ecosystem and enhance Malaysia's position in the global semiconductor value chain.

[51] https://www.statista.com/statistics/719265/semiconductor-production-malaysia/

Strategy

To maintain competitiveness and growth, Malaysia is focusing on moving up the value chain in the E&E industry. This involves formulating strategies for higher-value semiconductor activities, embracing automation, and utilizing advanced technologies like AI and IoT. The Malaysian government's roadmap and incentives aim to facilitate collaboration with research institutions and between the public and private sectors. Promoting the manufacturing of advanced semiconductors and restructuring incentives for the E&E industry are key aspects of this strategic approach.

9.2 The semiconductor industry in Malaysia

Malaysia is exclusively involved in the manufacturing aspect of the semiconductor value chain.

In front-end manufacturing, the country houses seven front-end companies, including two Malaysian firms. The country is exclusively producing mature node semiconductors.

However, in back-end manufacturing, Malaysia boasts six OSAT companies, with two of these - Carsem and Unisem - ranking in the global Top 20. In 2022, Carsem generated approximately €520 million, and Unisem approximately €385 million in revenue. Geographically, every major facility is strategically located along the West Coast of Malaysia, encompassing key areas such as Kedah, Penang, Kuala Lumpur, and Seremban.

- Carsem's Operations: With three facilities - two in Ipoh, Malaysia, and one in Suzhou, China - Carsem serves a diverse range of market sectors including industrial, telecommunications, IT, consumer, and automotive. The company is involved in both classic packaging and advanced packaging technologies, notably Flip Chip and System in Package (SiP).
- Unisem's Capabilities: Unisem operates four facilities: two in Ipoh, Malaysia, one in Batam, Indonesia, and one in Chengdu, China. The company offers a wide array of services encompassing both classic and advanced packaging solutions. These include wafer bumping, design and fabrication of redistribution layers, flip-chip interconnect, wafer-level chip-scale packaging (WLCSP), and a variety of lead frame and substrate IC packages.

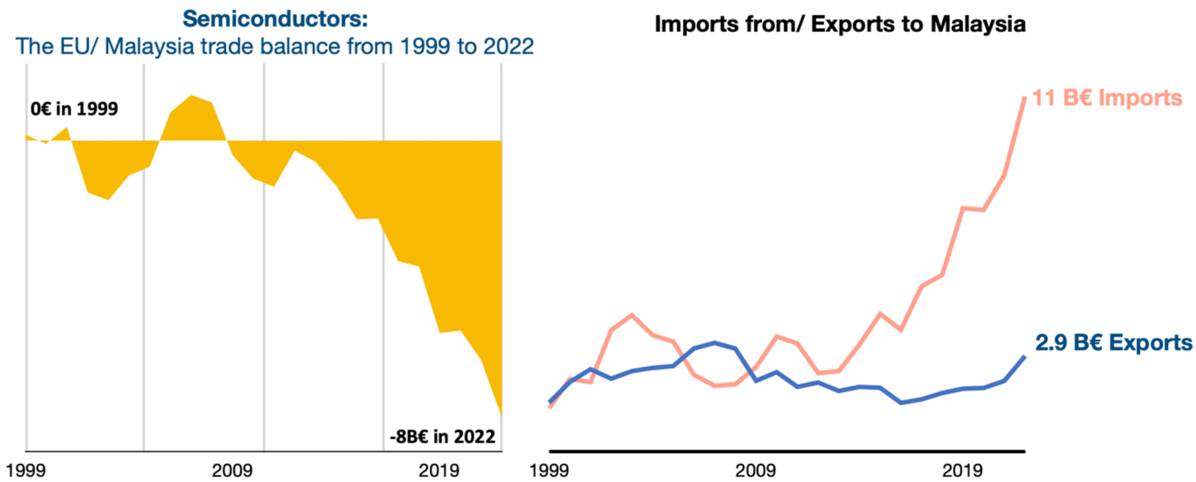
Moreover, several international IDMs also contribute to Malaysia's semiconductor landscape, offering Packaging & Test services. Notable players include Infineon (3 facilities), Intel (2 facilities), Micron (1 facility), Nexperia (1 facility), NXP (1 facility), ONSEMI (1 facility), Qorvo (1 facility), Renesas (3 facilities), STMicroelectronics (1 facility), and Texas Instruments (2 facilities).

But in 2021, Malaysia expanded its semiconductor capabilities with the inauguration of a Lam Research manufacturing plant in Batu Kawan. Representing an investment of approximately €200 million, this facility broadens Malaysia's presence within the semiconductor supply chain.

9.3 Trade balance between the EU and Malaysia

Over recent years, the trade balance between the European Union and Malaysia has significantly evolved, transitioning from a state of equilibrium to a deficit of approximately €8 billion for the EU. This shift can primarily be attributed to Malaysia's industrialization and its emergence as a critical hub for semiconductor manufacturing, particularly in the back-end segment.

Figure 75: The EU trade balance with Malaysia from 1999 to 2022



Source: DECISION Études & Conseil, from Eurostat

The widening trade gap is largely composed of microcontroller products, whose manufacturing processes have been partly relocated to Malaysia, both in back-end manufacturing facilities of EU IDMs that have expanded operations abroad and in Malaysian OSAT companies.

9.4 Ongoing investments

The map below illustrates that the country has attracted several significant investments in the semiconductor industry, with the majority being back-end facilities, aligning with Malaysia's expertise in this area. However, this focus does not fully align with the country's plan to expand its expertise across the semiconductor value chain.

Figure 76: Ongoing major investments in Malaysia

Source: DECISION Etudes & Conseil

Among the major investments, there are:

- Infineon is significantly expanding its Kulim fab, investing up to €5 billion in the next five years. This expansion aims to make it the world's largest 200-millimeter SiC Power Fab, targeting annual SiC revenue of about €7 billion by the end of the decade. Supported by approximately €1 billion in pre-payments and €5 billion in new design-wins, this investment focuses on advanced SiC technology for automotive and industrial applications.

- Intel is constructing its first overseas advanced packaging facility in Penang, Malaysia, which will become its largest 3D advanced packaging facility upon completion. This is part of a €7 billion investment in Malaysia that also involves an extension of another facility in Kulim.

- Micron Technology is investing an additional €1 billion in its new assembly and test facility in the Penang region, aiming to increase production of NAND, PCDRAM, and SSD modules.

- Texas Instruments is expanding in Malaysia with investments of up to €2 billion in Kuala Lumpur and €1 billion in Melaka for assembly and test factories. The company's focus is on internal manufacturing, with a goal to carry out 90% of manufacturing in-house by the end of the decade.

Additionally, there are smaller yet significant investments. For instance, in August 2023, Bosch inaugurated its new back-end site in the Penang region, with an investment of €350 million. This facility is dedicated to the final testing of semiconductors and sensors for mobility applications.

9.5 Strengths and dependencies

Strengths

- Back-end manufacturing: The country is a relevant player in the OSAT market for back-end manufacturing, with strong domestic companies and foreign companies established in the country.

Dependencies

- Low range of expertise: The country is only specialized in one aspect of the value chain.

10 The Singaporean semiconductor ecosystem

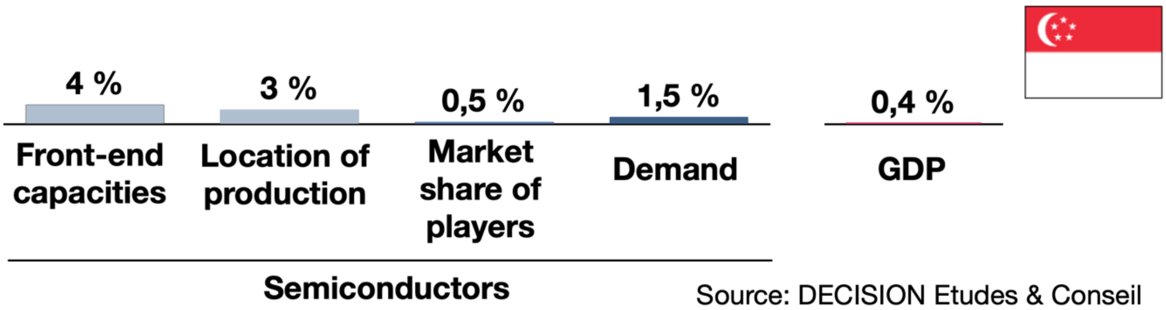
10.1 Overall environment and strategic objective

Overall environment

Singapore's strategic location, political stability and safe environment have made it a recognized player in the semiconductor industry. The semiconductor industry accounts for 7% of Singapore's GDP.

Singapore has "a stable government, business-friendly environment, and comprehensive infrastructure required for semiconductor manufacturing, coupled with strong IP protection and a world-class education system," Tan Yew Kong, senior vice president and general manager at GlobalFoundries Singapore said in a recent statement. Singapore is also the home of several EMS including local and foreign companies such as Flextronics.

Figure 77: Position of Singapore across the semiconductor value chain (in percentage of the World production), in 2022



Objective

As part of its ambitions to expand the manufacturing sector by 50% by 2030, Singapore government aims to further grow its electronics sector, with the semiconductor industry as its backbone. The objective is to ensure Singapore will remain a critical node in the global semiconductor value chain amidst the intensified competition from China and other countries such as Vietnam and Malaysia.

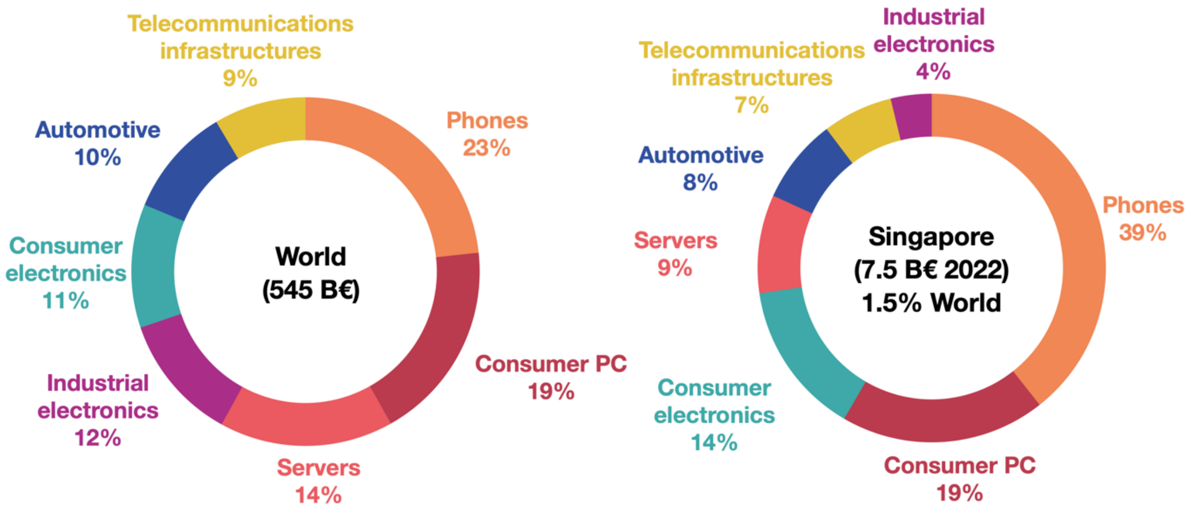
Strategy

To support the growth in the semiconductor sector, the government has continued to partner key companies across the value chain, many of whom are global leaders in the sector, to invest in leading edge manufacturing capacities and workforce training in Singapore.

The government also works with partner manufacturers to conduct complementary activities in Singapore, including in R&D and supply chain management, to diversify their base of activities and deepen their operations here.

10.2 The Singaporean semiconductor market

Figure 78: Spread of the Singaporean semiconductor demand by application

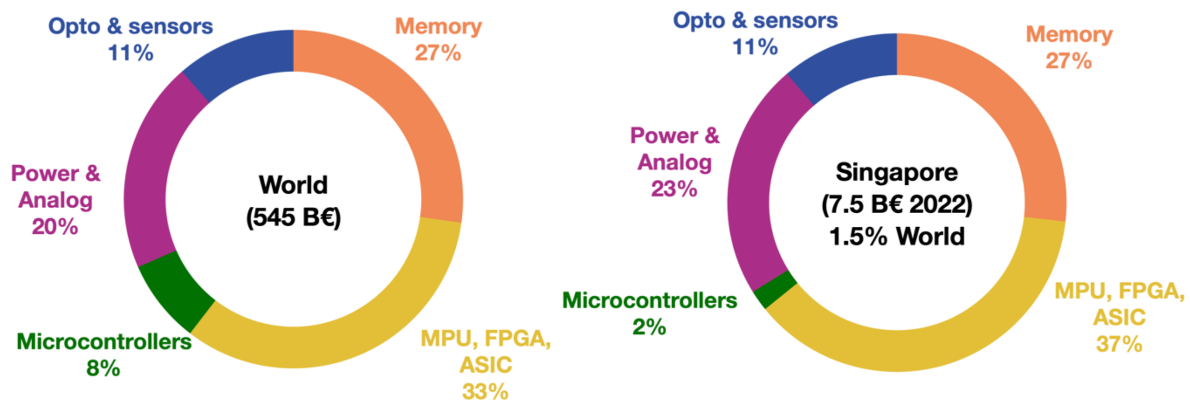


Source: DECISION Etudes & Conseil

Singapore's demand for semiconductors, 1.5% of global consumption, is relatively modest compared to other countries. This demand is primarily driven by the phone market, followed by consumer PCs and other consumer electronics.

In terms of product breakdown, the trends align with the market demands. There is a higher demand for memory components and MPUs/ ASICs/ FPGAs. Conversely, the demand for optoelectronics/sensors and microcontrollers is comparatively lower.

Figure 79: Spread of the Singaporean semiconductor demand by product



Source: DECISION Etudes & Conseil

10.3 The Singaporean semiconductor industry

According to Singapore authorities, there are over 300 semiconductor-related companies in Singapore, including 40 IC design firms, 14 silicon wafer fabs, eight wafer fabs, and 20 packaging and testing companies.

Many Asia-Pacific headquarters of IC design companies such as Texas Instruments, STMicroelectronics, Infineon, and Micron are in Singapore.

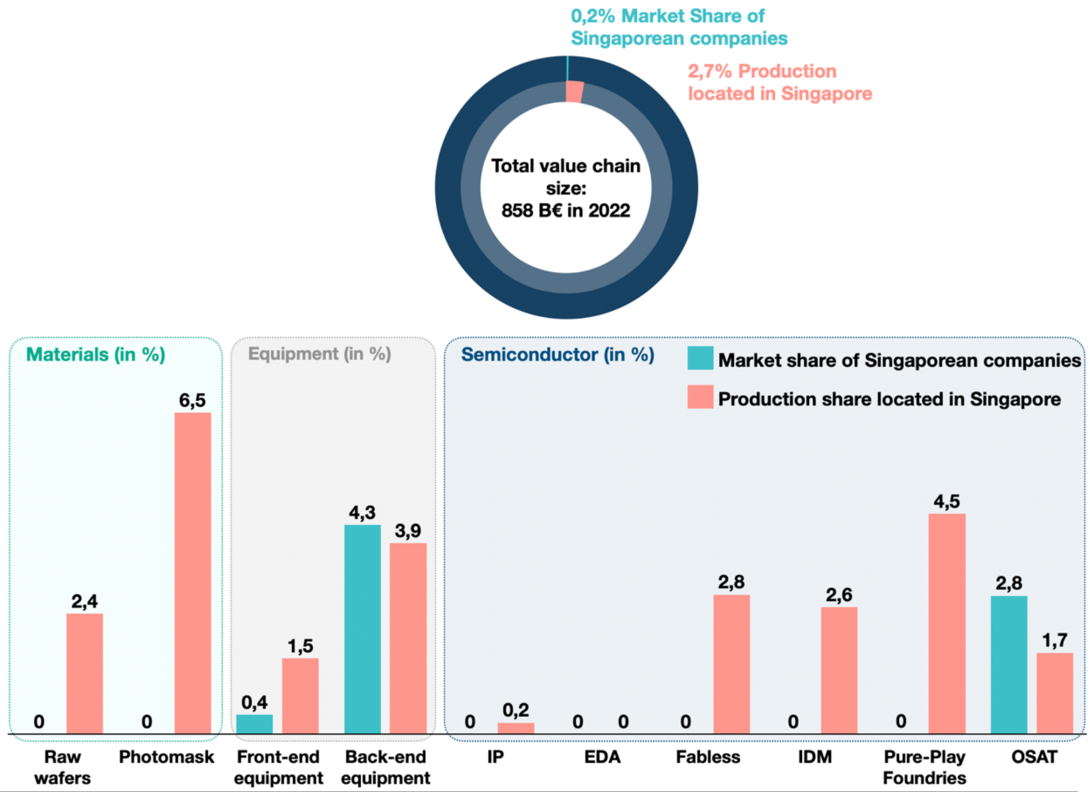
A vast ecosystem of suppliers and partners from all over the world has established itself in Singapore, covering the entire semiconductor industry chain from upstream to downstream.

10.3.1 Singaporean players market share and production share across the value chain

Singapore is a rather minor semiconductor hub, primarily recognized for its contributions to manufacturing with a production share of approximately 3% across the value chain, which is largely attributed to foreign players operating within its borders.

Singapore maintains a production share of 2 to 7% across various segments of the value chain. In front-end manufacturing, the country hosts fabs from IDMs like Micron and STMicroelectronics, as well as from pure-play foundries such as GlobalFoundries and UMC.

Figure 80: Market share and production share of Singapore across the semiconductor value chain



	Raw wafers	Photomask	Front-end equipment	Back-end equipment	IP	EDA	Fabless	IDM	Pure-Play Foundries	OSAT
Global market size	16 B€	2.5 B€	96 B€	12 B€	6 B€	8 B€	168 B€	377 B€	127 B€	44 B€

Source: DECISION Etudes & Conseil

In back-end manufacturing, Singapore is home to facilities from IDMs like STMicroelectronics, Infineon, AMS, and Micron. In the OSAT market, Singapore boasts the presence of its national OSAT company, UTAC, which generated more than €1.2 billion in 2022, ranking 7th among global OSAT companies. Additionally, the country hosts three facilities from JCET, the leading Chinese OSAT.

10.3.2 Front-end capacities

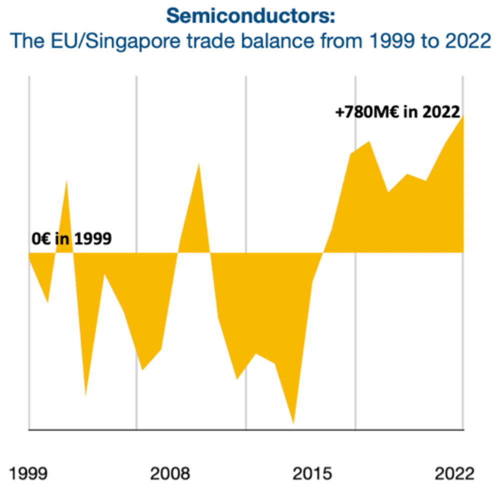
Singapore accounts for minor percentage of the world front-end production capacity, with nodes of 20nm and above. Notably, the 20nm semiconductors are produced by Micron's facilities in Singapore. GlobalFoundries and UMC are the primary producers of semiconductors ranging from 40nm to 20nm in the country.

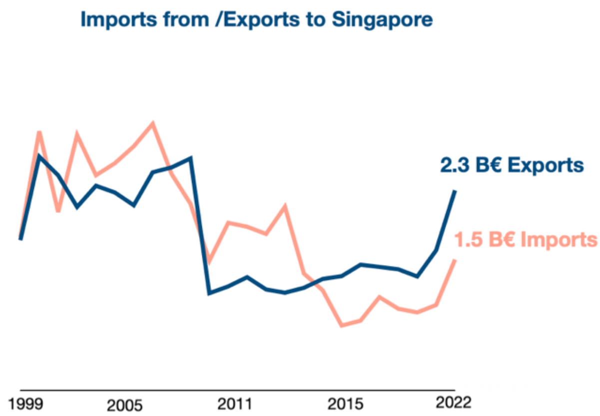
Most of this capacity is attributable to foreign companies that have established their operations in Singapore.

10.4 Trade balance between the EU and Singapore

The trade balance between the EU and Singapore in the semiconductor sector has been relatively stable, with the EU maintaining a positive trade surplus since 2015 which reached €780 million in favor of the EU in 2022. The trade exchanges between the EU and Singapore mainly revolve around microcontroller components. Notably, a significant portion of these components originates from production facilities that have been relocated. This reflects a situation where neither the EU nor Singapore is heavily dependent on the other for semiconductor products.

Figure 81: The EU trade balance with Singapore from 1999 to 2022





Source: DECISION Études & Conseil, from Eurostat

10.5 Ongoing major investments in Singapore

There are various investments being carried out in Singapore:

- UMC plans to invest €4.7 billion in a new fab in Singapore, targeting production beginning in late 2024. This facility will focus on 22/28nm technologies, driven by demand in 5G, IoT, and automotive sectors.

- Vanguard International Semiconductor (VIS), affiliated with TSMC, considers investing at least €1.9 billion in Singapore for a plant aimed at automotive chip demand, marking a significant move to diversify production locations.

- GlobalFoundries opened a €3.8 billion expansion fab in Singapore, increasing its capacity by 450,000 wafers annually, reinforcing its global manufacturing footprint.

- Soitec is investing in a 300mm SOI substrate manufacturing plant expansion in Singapore, aiming at doubling its annual production capacity to approximately two million substrates by 2024.

10.6 Strengths & dependencies

Strengths

- R&D and advanced packaging are definitively the greatest strengths of the Singaporean semiconductor industry. For instance, advanced R&D is done on wafer to wafer and chip to wafer bonding, hybrid bonding, and chiplet packaging.
- Skills: Currently, there are about 9,000 semiconductor R&D persons in the private sector in Singapore. Plans are underway to invest more in local tertiary education institutes to encourage more students to graduate with microelectronics skills.

Dependencies

There are no world class Singaporean players in the global value chain. It means that the Singaporean semiconductor industry is heavily dependent on the foreign companies based in the country.

For instance, advanced R&D will require manufacturing capacities in finer node, and there is no pilot line in Singapore on advanced processes.

10.7 Cooperation & alliances

10.7.1 Existing cooperation framework

Existing cooperation

- In response to the US-China chip conflict, Soitec, Applied Materials and GlobalFoundries have increased their manufacturing capacities in Singapore, with the objective to diversify their supply chain.
- For instance, in September 2023, GlobalFoundries has announced an investment of €4 billion in Singapore to expand its fab and meet demand for the EU & Singapore digital partnership.

EU & Singapore digital partnership: Both sides intend to explore possibilities of advanced research including advanced packaging to strengthen their resilience across the semiconductor value chain.

Lab-in-Fab" R&D line: Partnership announced in 2020 between A*STAR's IME and ULVAC, a leading Japanese manufacturing-tool vendor. to set up and operate a 200mm R&D line focused on Piezo MEMS technology within ST's existing manufacturing facility in Singapore.

11 Positioning of the EU and the 6 other countries in ICOS in the semiconductor-based photonics ecosystem

11.1 Photonic Integrated Circuits (PIC): Definition and key applications

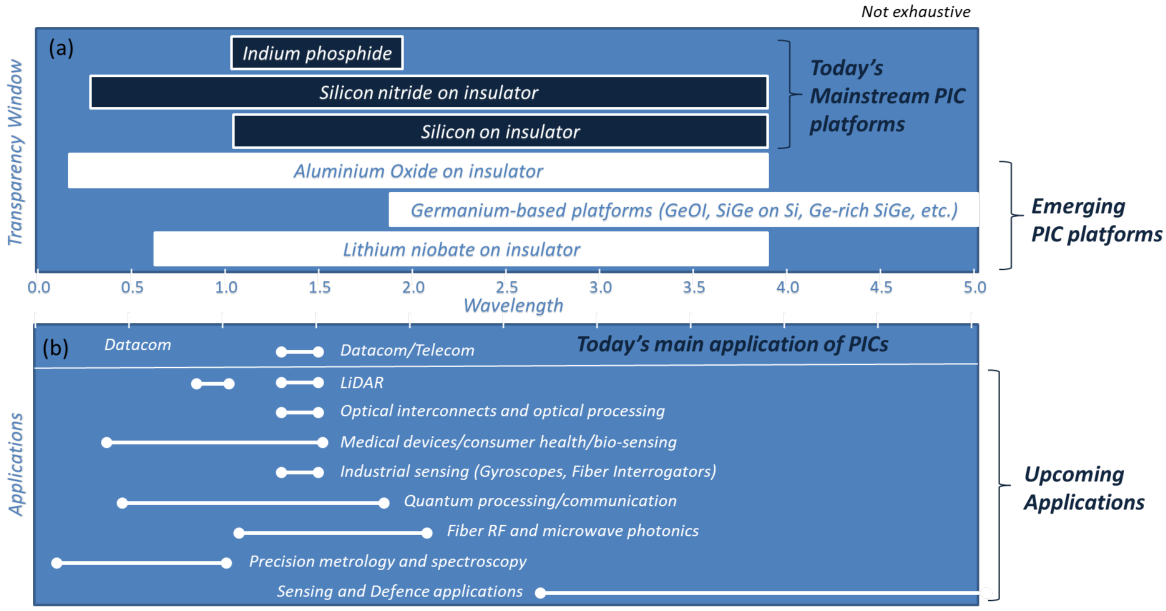
The field of integrated photonics encompasses manufacturing complex optical functions through photonic circuits to generate, process, and detect optically confined light on a chip.

The manifestation of integrated photonics appears in different material systems, where the optical transparency of the materials enables applications for digital connectivity, computing, agri-food, natural resources, security, transportation, industrial automation, aerospace, consumer electronics, healthcare, and many other industries. A recent whitepaper by the European Associate by Smart Systems Integration (EPoSS)[52] on Integrated Photonics provides a comprehensive coverage of the application of integrated photonics and their relevance for European industry, and its priorities in achieving strategic sovereignty, development of a secure digital society with mindfulness on sustainability (Green Deal).

The Figure 124 (a) enlists the mainstream and emerging material systems for photonic integrated circuits (PICs), and (b) lists existing and upcoming applications associated with these material systems. Today, the main application of PICs is in high-speed transceivers offering energy efficient and low latency optical connectivity for distances ranging from chip scale to trans-oceanic scale and any distance in between.

[52] https://www.smart-systems-integration.org/news/white-paper-integrated-photonics-published

Figure 82: Mainstream and some emerging material systems for Photonic Integrated Circuits (PICs) and their associated applications. The list is not exhaustive.



The origin of material diversity for PICs hails from the inability of any single platform to offer all the necessary technical attributes required by diverse range of applications (from mundane use cases for everyday life to exceptionally advanced tasks). Today, the field of integrated photonics is following four technological trends:

a. Wafer-scale heterogeneous integration of different PIC material systems to offset the missing functionality of a certain PIC platform.

b. PIC manufacturing (especially for silicon photonics) on wafers with larger diameters (today, multiple silicon photonics fabs use 300mm wafers for PIC manufacturing) to achieve superior process control.

c. Enhanced intimacy between electronic ICs and photonic IC either through monolithic approaches or through advanced packaging techniques.

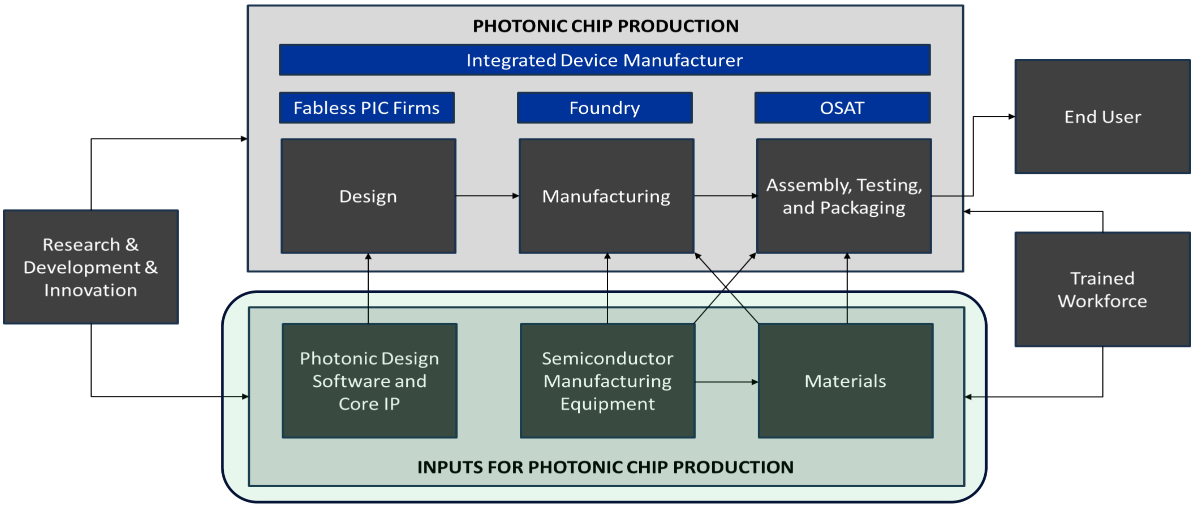
d. Improvement in the functional performance of key photonic IC building blocks.

More details on these technological trends are available in[52].

11.2 The value chain of Photonic Integrated Circuits (PIC)

The integrated photonics value system and the associated business models for PIC manufacturing are not different from its semiconductor electronics counterpart. Figure 125 shows a block-level representation of the PIC supply chain, their dependencies on different segments, and the associated business models for photonic chip production.

Figure 83: A block level representation of photonic chip production supply chain. It is very similar to its CMOS electronics counterpart (inspired from CSIC)



The continued technological maturity of photonic IC technologies as well as the market needs in high-speed energy-efficient optical connectivity (for telecom, datacom, and at chip scale) and business opportunities in new markets (see Figure 124 (b)) has attracted prominent players of the semiconductor electronics supply chain to the photonic IC supply chain. This trend is visible in the silicon photonics supply chain because this technology heavily leverages the existing CMOS infrastructure and process toolsets to manufacture photonic ICs.

11.3 Global economic landscape

Figure 126 provides an overview of some of the most prominent players in the silicon photonics supply chain. One can observe the presence of several tier-1 CMOS industry players (TSMC, GlobalFoundries, STMicroelectronics, Cadences, SYNOPSYS, ANSYS, and many others).

Figure 84: A non-exhaustive list of some of the prominent players of silicon photonic IC supply chain. The logos with a dashed line underneath represent photonics-only firms

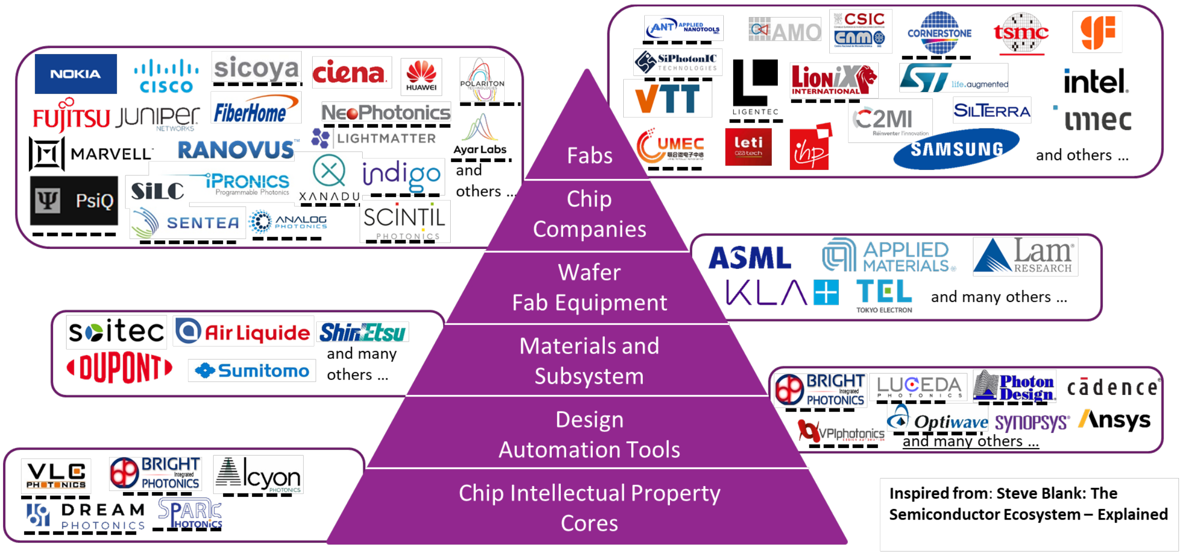
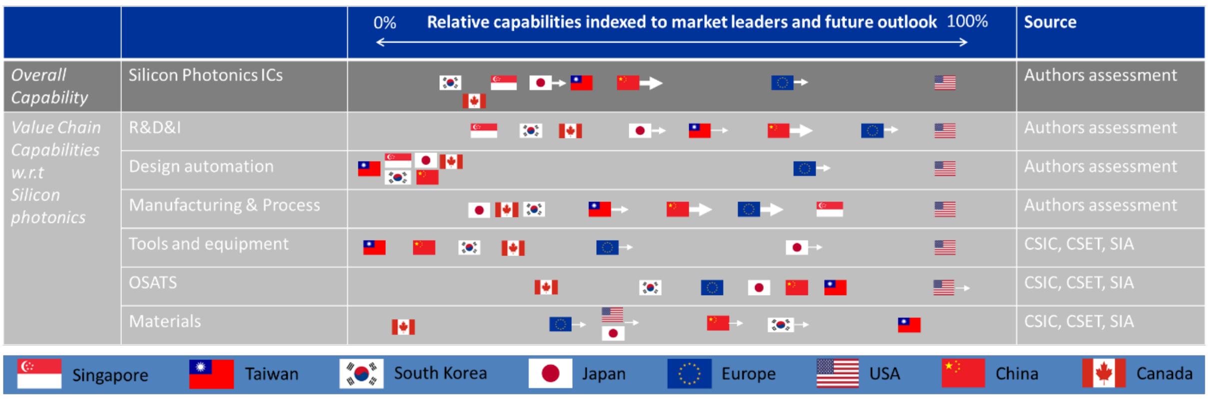


Figure 127 positions the technological maturity of silicon photonics for different geographic regions. The lower half of Figure 127 also summarizes their value chain capabilities in silicon photonics. Overall, the US firms are in leadership. They own a mature technology and capture the largest market share (consult[52] for the European situation for all PIC technologies.). Europe has a variety of pilot-scale silicon photonics technologies with excellent capabilities. The lack of a tier-1 volume manufacturing facility weakens Europe's position. A recent initiative[53], sponsored by the public-private partnership, targets to strengthen Europe's PIC supply chain holistically (design, manufacturing, packaging, testing).

Figure 85: The position of different geographic regions for various sectors of the PIC supply chain[54]



[53] https://optics.org/news/14/6/21

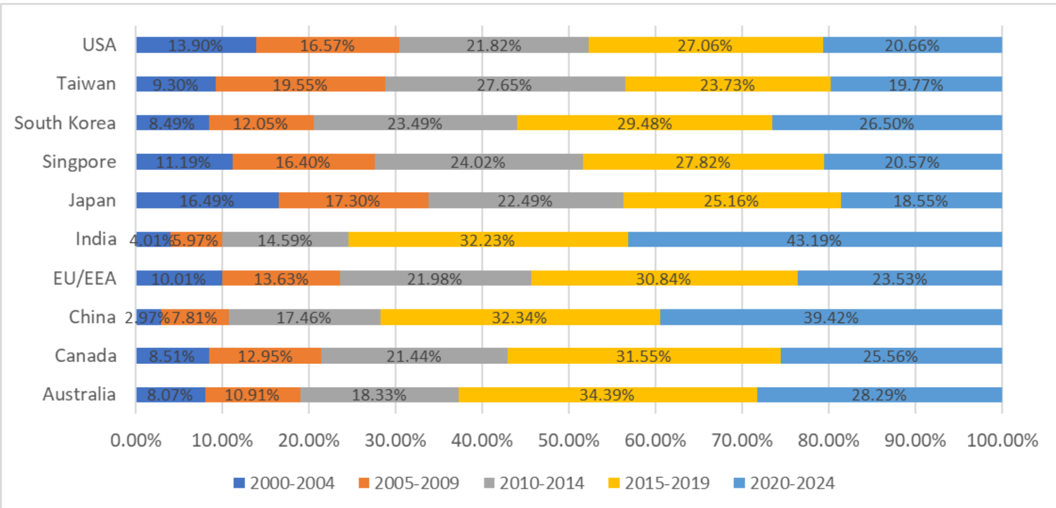
[54] Arrow thickness indicates the thrust of progress in a value chain capability. No arrow indicates that the region is maintaining its position or has no substantial investment to grow its capability. The ranks are based on public information or through the assessment by the author. The assessment includes the US, Europe, China, Taiwan, Singapore, South Korea, Canada and Japan. An absence of a country on the assessment bar indicates a lack of knowledge about the position. India is not shown in this figure since

The following section provides an analysis of various segments of the silicon photonics supply chain.

11.3.1 Research & Development & Innovation

Europe and US have a strong position in R&D&I in integrated photonics technologies. The US has been more successful in translating these R&D&I actions into market-ready solutions. In some cases, the US firms benefit from the excellence of European R&D&I in silicon photonics to develop market-ready solutions. US dominated the R&D&I in the first decade of this century. The second decade was led by Europe. Since, 2020, China has demonstrated a strong thrust in silicon photonics R&D&I in the last few years[55]. The pace of this thrust has outpaced Europe, Japan[56] and US, which are a stronghold for silicon photonics R&D&I. Figure 128 symbolizes the R&D&I impact of different regions by accounting the number of publications in silicon photonics and disciplines related to silicon photonics. The percentages indicate the fraction of research publications in a five-year period over total number of publications by a region.

Figure 86: Number of scientific reports published by different regions/countries in the world[57]



11.3.2 PIC Design and PIC Design Automation

Both Europe and US have a strong position for PIC Design and photonic design automation (PDA). The remaining countries lack a significant presence in the PIC design and PDA sector. Major EDA vendors (mostly US-centric organizations) started offering integrated photonics design frameworks. Siemens, as the main EU EDA vendor, has a limited photonic IC design capability as compared to US organizations (such as Ansys, Synopsys and Cadence). European design companies are SMEs, and they provide best-

its PIC supply chain activities are largely limited to research in academia and at IISc (Bangalore). Nevertheless, the Indian Semiconductor Mission (ISM) has declared silicon photonics as a thrust area.

[55] https://www.globaltimes.cn/page/202210/1277405.shtml

[56] http://www.petra-jp.org/en/

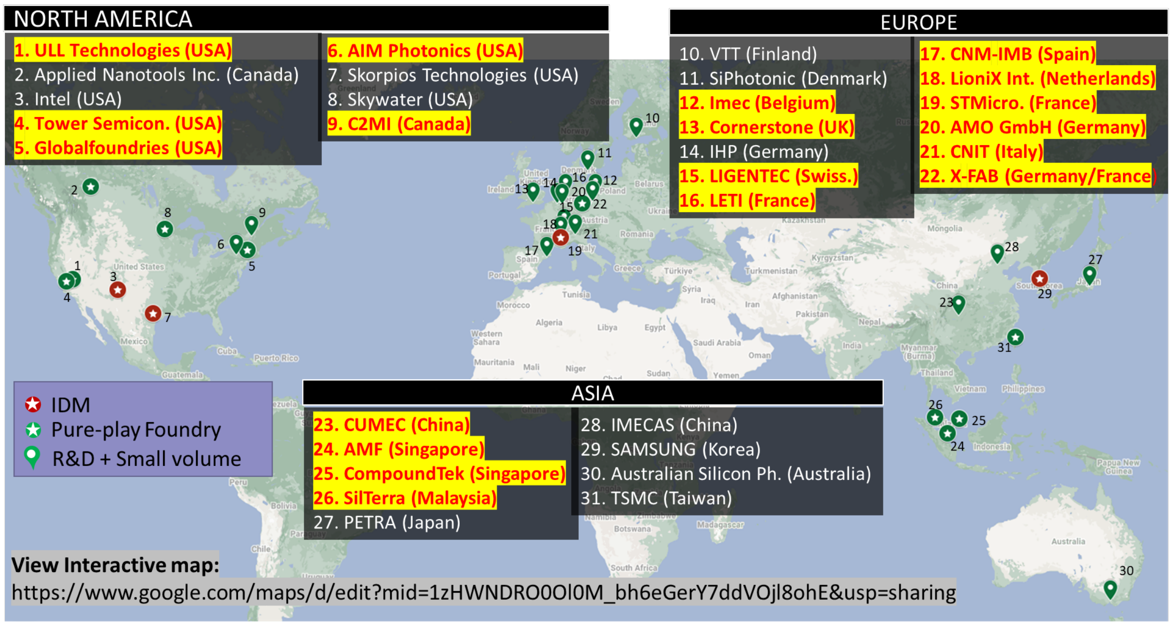
[57] The plot is based on the following keywords: (silicon AND photonics) OR (integrated AND photonics) OR (photonic AND integration) OR (silicon AND nitride) OR (Indium AND phosphide AND silicon).

in-class performance. The non-EU EDA vendors are in a stronger position to win the future narrative for standardization due to their stronger ties with the CMOS industry.

11.3.3 Manufacturing and Manufacturing Equipment

The silicon photonics chip production (including silicon-on-insulator and silicon nitride-on-insulator) leverages the existing CMOS infrastructure. The US has a dominant position as it has a full spectrum of capabilities (see Figure 129). The US has pilot-scale prototyping facilities, large-volume IDMs, and large-volume pure-play fabs. Singapore also has a strong position as it also offers both pilot-scale prototyping and large-volume manufacturing of silicon photonic ICs.

Figure 87: Prototyping and manufacturing facilities for silicon photonic ICs[58]



Europe has a diverse cluster of R&D fabs for prototyping services. Furthermore, STMicroelectronics in Europe has a proprietary full stack 300mm silicon photonics process flow. Today, Europe lacks a pureplay tier-1 fab. Europe may develop its own volume manufacturing capacity through a recent EU project involving XFab, imec and LIGENTEC.

China has invested heavily in establishing a local prototyping pilot line and a volume manufacturing fab for silicon photonics. Samsung is the most prominent player that has a proprietary silicon photonics platform. Initially, this platform was developed for optical IO. Later on, they retrofitted it to use it for the LiDAR application. TSMC has also developed a silicon photonics platform. The platform offers state-of-the-art

[58] The red highlighted fabs offering silicon nitride only or SOI+SiN technologies.

performance, and fabless US corporates have engaged with TSMC to develop silicon photonics-based products using their platform[59].

11.3.4 Materials

Silicon photonics relies on several manufacturing materials, such as photomasks, photoresists, and additional chemicals, commonly used in the CMOS electronics industry. Therefore, the value chain capabilities for this sector are not very different from the value chain capabilities for CMOS electronics manufacturing. Though, there are a few exceptions. Access to these specialized materials for silicon photonics ICs results in a slight change in the position of some regions. For example, Europe has one of the largest SOI wafer manufacturers (SOITEC), and SOITEC dominates the market share of SOI wafers for silicon photonic IC manufacturing. The close collaboration of EU R&D fabs and substrate manufacturers to meet future substrate demands (wafer sizes, uniformity) helps maintain Europe's position. The next generation of silicon photonics ICs may rely on some novel materials to improve the capabilities of the technology. One such example is thin film lithium niobate, where China has a dominant position in terms of substrate manufacturing.

11.3.5 Outsourced assembly and testing (OSAT)

European firms made impressive progress in developing PIC assembly and packaging pilot lines (i.e., PIXAPP) and low to medium-volume PIC assembly and packaging facilities (i.e., PHIX). European SMEs have developed packaging and assembly tools for photonic ICs. In some cases, these firms have a very strong market position. Europe also has a strong position in terms of know-how for the packaging, assembly, and testing of PICs. Today, most of the packaging solutions available in Europe rely on legacy approaches.

As enhanced intimacy between electronic ICs and photonic ICs is imminent, advanced packaging, such as co-packaged optics, becomes more important to support high-bandwidth applications such as Ethernet switching, artificial intelligence/machine learning (AI/ML), and high-performance computing (HPC). Large US firms (i.e., Broadcom, CISCO) are leading the way in developing these advanced packaging solutions. Countries with strong positions in the electronics OSAT sector can use the demand for advanced packaging of electronics and photonics for their benefit by developing new equipment or retrofitting their existing equipment to offer solutions for advanced packaging solutions. Similarly, OSATs are developing new processes to develop advanced packaging solutions. Japan has a leading position with respect to the manufacturing of assembly equipment for the electronics industry. With respect to the manufacturing of test equipment, Japan and the US have a strong position. Japan is a major supplier of assembly and testing equipment to countries such as China, South

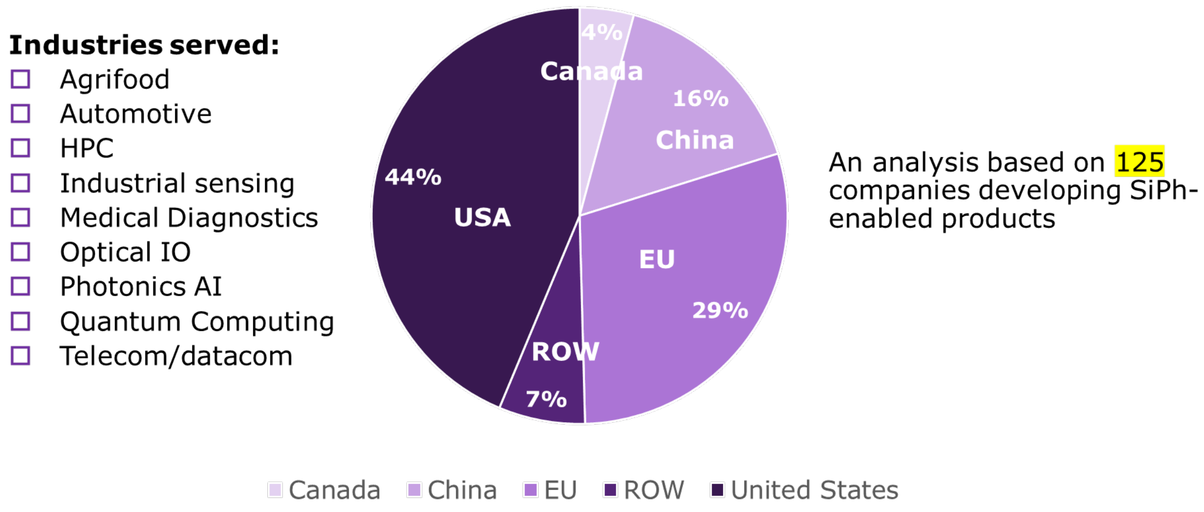
[59] https://technode.com/2023/09/12/tsmc-cooperates-with-broadcom-and-nvidia-to-develop-advanced-silicon-photonics-technology-report/

Korea, Taiwan, and the US. The emergence of co-packaged optics puts these regions in a stronger position to offer solutions for Co-Packaged Optics (CPO) as compared to Europe. Testing and packaging is probably the most severe vulnerability of the European PIC industry.

11.3.6 End Users

Today, telecom and datacom end-user dominate the silicon photonics industry. A majority of these end-users are based in the US or China, as depicted in Figure 130.

Figure 88: Global spread of silicon photonics end-users



Europe has a strong position in silicon photonics sensing solutions developed for medical diagnostics, industrial sensing, agri-food and automotive. Figure 130 shows a breakdown of silicon photonics applications developed by firms from different geographic regions. The analysis considers more than 120 silicon photonics firms. Most US firms are focused on market-pull applications whereas most European firms are focused on technology-push applications.

11.3.7 Workforce

The shortage of trained workforce is a challenge faced by all countries which are strong in the PIC industry. The US are putting concrete efforts to develop a workforce for photonic ICs. For example, AIM Photonics through its AIM Academy[60] leads the workforce development for the US PIC industry and it uses advanced training methodologies such as Massively Open Online courses (MOOCs) and gamification to

[60] https://www.aimphotonics.com/summer-academy

attract younger generation to photonics. A broad range of academic institutes (high schools to universities) are pooling resources to make a pipeline for grooming talent for their PIC industry needs. Canada has developed an impressive SiEPIC program[61] to train workforce for the PIC industry. The SiEPIC is probably the best model for work force development. The European strategy on workforce development for the PIC industry is fragmented. In Europe, there are several initiatives which are complementary to each other. For example, ePIXfab – the European silicon photonics alliance[62], hosted and bootstrapped by Ghent University, through the support of its members offers a comprehensive range of training activities. Another example is the PhotonHub Europe[63] project, which offers a wide range of training and reskilling in photonics disciplines including photonic ICs. Asian countries have limited number of cohesive workforce development initiatives.

11.4 Proposals of cooperation between the EU and other countries

- Education, workforce development, and talent rotation programs
- Standardization and road mapping
- Joint development labs
- Pre-competitive R&D&I programs
- Resilient supply chain

[61] https://siepic.ca/
[62] https://epixfab.eu
[63] https://www.photonhub.eu/

Non-exhaustive list of selected global silicon photonics players:

Country	Pilot-scale prototyping facilities	Large-volume IDMs	Large-volume pure-play fabs	Packaging, testing, Assembly	World-class R&D labs	IP	EDA
The EU/EEA	LioniX Int., LIGENTEC	STMicroelectronics	XFab	PHIX, PIXAPP, FiconTEC, AIXEMTEC GmbH, Aifotec AG , Bay Photonics, Etteplan	Imec, IHP, CEA-Leti, VTT, CNM-IMB, AMO GmbH, Cornerstone – University of Southampton	Alcyon Photonics, VLC Photonics – Hitachi Group, Bright Photonics, Epiphany Design	Luceda Photonics, Bright Photonics, VPIPhotonics, Photon Design
The US	AIM Photonics,	GlobalFoundries, Tower Semi.	Intel	Jabil, PI, FormFactor Inc., Keysight, IBM, Chiral Photonics	AIMPhotonics,	SYNOPSYS, Spark Photonics	SYNOPSYS, CADENCE, ANSYS
China	CUMEC				NOEIC, IMECAS		
Japan	PETRA			Hitachi High-Tech			
Taiwan			TSMC	SURUGA SEIKI CO, MPI, ASE Group			
Singapore	A-Star		AMF		NTNU		
South Korea		Samsung			KAIST		
India					IISc Bangalore		

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