OVERCOMING SEMICONDUCTOR
Processing Challenges

PRESCOUTER

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By leveraging deep analytics and enhanced communication technologies on the supply chain side, and the adoption of new processes and materials on the technical side, the semiconductor industry can retain the large growth opportunity currently available.

The semiconductor industry is facing a critical time in its evolution, with supply chain shortages caused by COVID and large demands from different customers across different industries exacerbated by processing challenges.

The supply-demand mismatch is creating complexity for the semiconductor industry. Increased demand from IoT devices, chipsets for electric vehicles, and smartphones led to an all-time sales record in 2021, but companies are hampered by issues with raw materials provisioning and supply chain bottlenecks that have been exacerbated by disruptions caused by the COVID-19 pandemic.

Moving forward, the semiconductor industry can leverage advanced technologies to mitigate problems with the supply chain and overcome technical challenges associated with moving to higher resolution components through the adoption of new processes (deposition and etching technologies) and materials (such as SiC and GaN).

This will be a key area of focus for the semiconductor industry over the next decade.

Contents

The strategies and information provided in this report are an example of the insights clients rely on PreScouter for.

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SEMICONDUCTOR

State of Industry

Semiconductor usage has increased radically in recent years due to the demand for more advanced memory chips that can process extensive data more rapidly.

Wireless IoT connected devices are creating great demand across the globe, with companies offering high-capacity memory and multi-chip packages powered with artificial intelligence for use in embedded, mobile cloud, and edge applications.

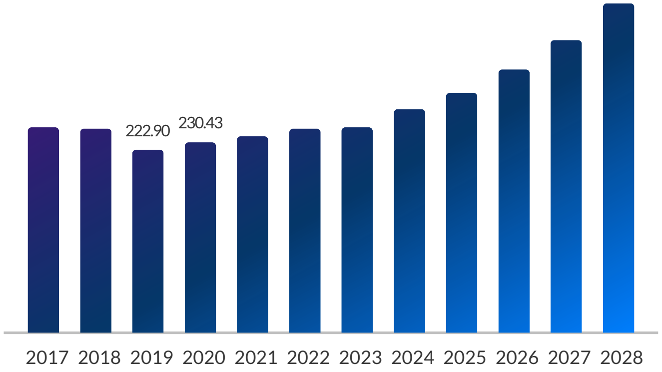


Figure 1. *Asia Pacific semiconductor market size, 2017-2028.*
Source: Fortune Business Insights.

Global semiconductor market share by application in 2020

- ✓ Networking and communications
- ✓ Data processing
- ✓ Industrial
- ✓ Consumer electronics
- ✓ Automotive
- ✓ Government

Semiconductor market growth is also being driven by chip makers.

South Korea's Samsung Electronics, the leading memory chip manufacturer, and Taiwan's TSMC, the top producer of chips up to 10 nm, together manufacture over 70% of the semiconductors on the market, while the US company Intel is the dominant manufacturer of laptop and desktop CPUs. Major US chip designers include AMD, Qualcomm, Broadcom, and Nvidia, with the majority of the world's wafers being manufactured in South Korea and Japan.

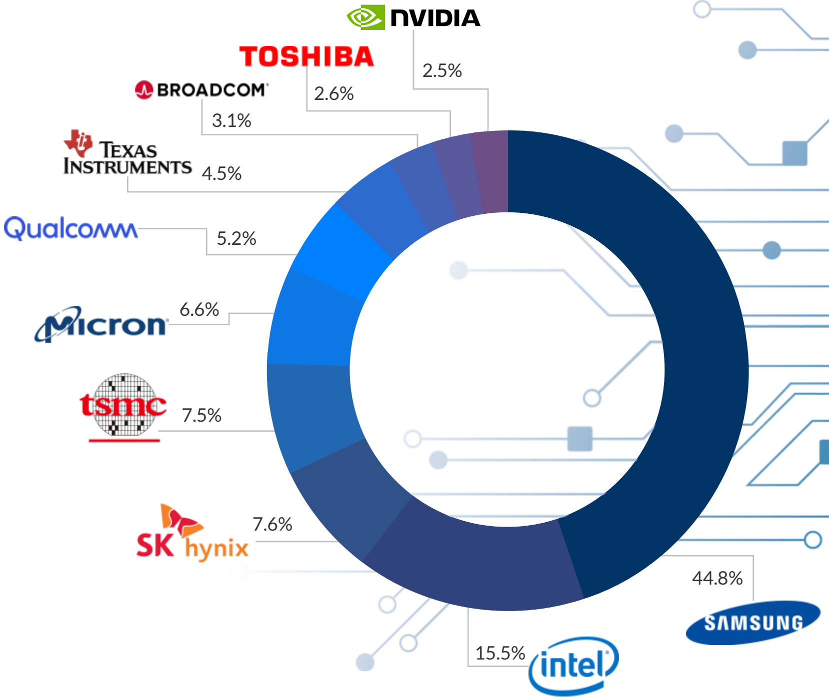


Figure 2. *Largest semiconductor companies by revenue, USD billions. Source: Financial Express.*

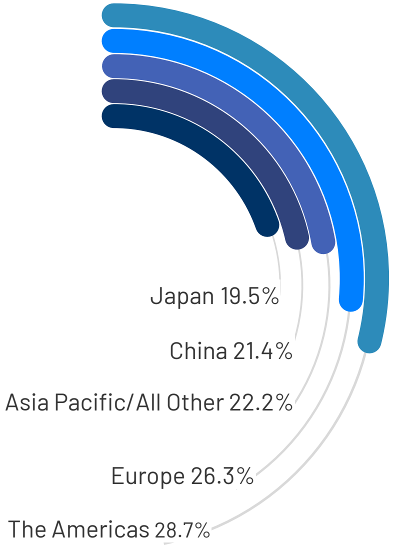
Growth is being further driven by 5G smartphones and the rise of SiC chipsets in electric vehicles

1.05 trillion cumulative annual total of semiconductors sold through November 2021

$49.7 billion global semiconductor industry sales in November 2021

23.5% increase over the November 2020 total

1.5% increase over the October 2021 total



Year-to-year increase in semiconductor sales

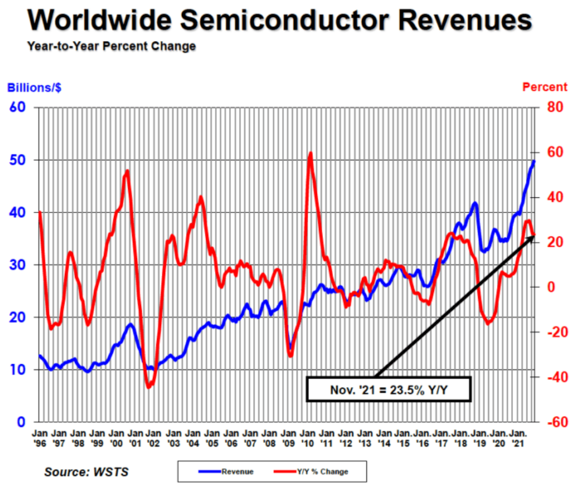


Figure 3. Worldwide semiconductor revenues. Source: Semiconductor Industry Association.

Global semiconductor sales increased 23.5% from November 2020 to November 2021, establishing an industry record for the highest-ever annual total.

The three big DRAM semiconductor manufacturers — Samsung, Micron, and SK Hynix — are gradually kicking off mass production of next-gen DDR5 products. Simultaneously, they continue to increase the penetration rate of LPDDR5 for the smartphone market in response to demand for 5G smartphones.

The growing selection of SiC chipsets for automotive applications has reached the tipping point where most chip manufacturers now consider it a comparatively safe risk, setting off a scramble to stake a claim and push this wide-bandgap technology into the mainstream.

SiC has a lot of potential in the automobile industry, especially for battery electric vehicles. When compared to silicon, it can increase driving range per charge, decrease charging time, and add to overall efficiency by delivering the same range with lesser battery capacity and weight. The current challenge is to lower the cost of producing these devices, which is why SiC fabs are switching from 6-inch (150mm) to 8-inch (200mm) wafers.

Supply chains haven't been able to keep up with demand due to supply issues with raw materials and challenges with logistics.

The global semiconductor supply chain is complex, with parts for one device being manufactured in different locations. Because of this complexity, there are three different techniques to measure the origin of semiconductor demand:

Location of the electronic equipment manufacturers' headquarters

These companies are chip companies' customers, and they buy the semiconductors that go into their gadgets. Electronic device manufacturers, also known as original equipment manufacturers (OEMs), create their products and choose which vendors to utilize for their components. The chips that go into a smartphone designed by a business located in the United States, for example, would be tallied as US demand under this technique, even if the device was physically made in another country.

Location of where the device is manufactured/assembled

OEMs frequently do not manufacture their devices in the same nation as their headquarters or the engineering team that designed it. Instead, the gadgets are usually constructed in a manufacturing plant in another country or several countries by companies known as original device manufacturers (ODMs) or electronic manufacturing services (EMS). This is the site to which the completed semiconductors must be physically delivered. For example, chips used in a smartphone designed by a US corporation but manufactured by a Taiwanese contractor in a plant in mainland China would be counted as Chinese demand under this method.

Location of the end users that purchase the electronic devices

Because semiconductors are components, sales of electronic devices to end users, including consumers and corporations fuel semiconductor demand. The value of the chips in smartphones created in the United States but built in China, for example, would be distributed across all nations where these handsets are sold to customers.

Demand and manufacturing needs vary from region to region, with some regions being net exporters and others being net importers.

Figure 4 depicts the geographic split of worldwide semiconductor demand using these three different lenses. The proportions of nations or regions vary greatly depending on the criteria. However, none of the three possible ways is seen as the "right" one; rather, they reflect the many roles that countries and regions play in the broader electronics sector. China has the biggest share of semiconductor manufacturing, while the headquarters of these semiconductor manufacturers are mostly located in the United States.

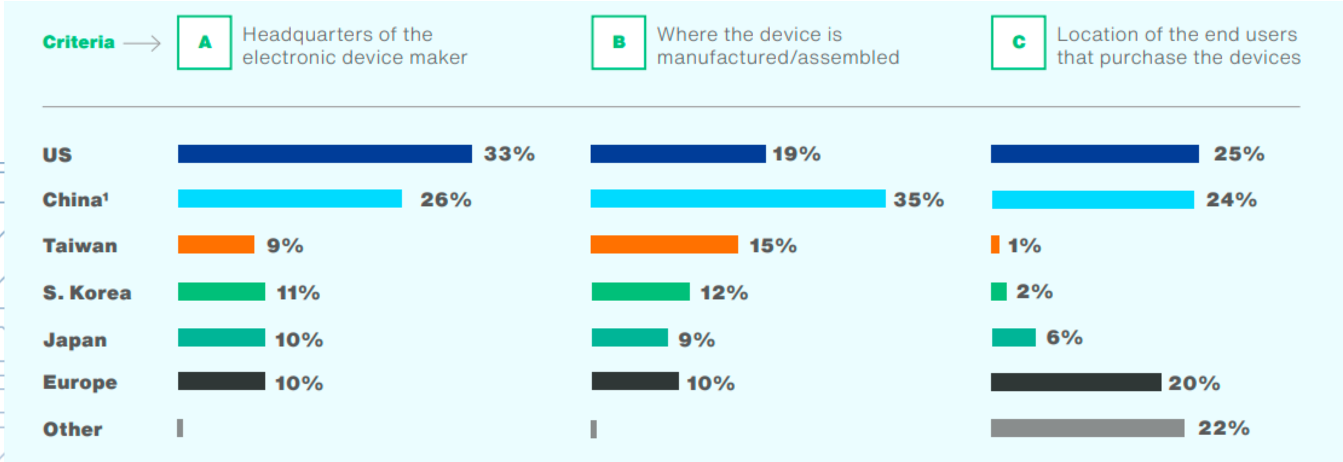


Figure 4. Worldwide semiconductor revenues. Source: BCG x SIA.

The global semiconductor shortage, exacerbated by the COVID-19 pandemic, has deeply affected the automotive industry, information communications, consumer electronics, and similar industries.

The **automobile** sector was not comforted by the roughly 26 billion chips shipped last year. The sharp drop in vehicle sales and the closure of manufacturing plants frightened automakers, prompting them to cut output and reduce or cancel orders for parts, including large quantities of computer chips, at the start of the lockdowns because of the effects of supply chain issues on semiconductor production.

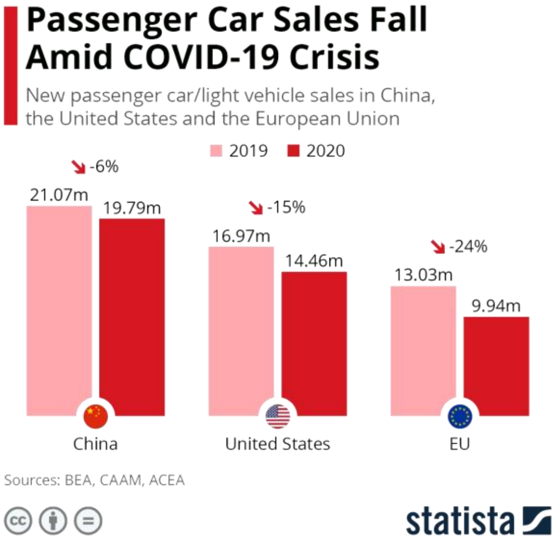


Figure 5. *Passenger car sales amid the COVID-19 crisis*
Source: Statista.

IDENTIFYING

Manufacturing Challenges

The ongoing COVID-19 pandemic brought on unprecedented challenges for chip manufacturers.

SUPPLY CHAIN PROBLEMS

- ✓ Production plans were thrown off by late deliveries
- ✓ Due to a scarcity of resources, firms were forced to move production lines
- ✓ Diversification of suppliers was required to avoid order fulfillment difficulties

MORE COMPETITIVE MARKET

- ✓ The emphasis switched from offline to online, increasing the pressure on delivery time
- ✓ Just in Time (JIT) strategies had to be improved by manufacturers
- ✓ As part of the JIT strategy, a reactive demand-driven methodology was deployed
- ✓ The more competitive the internet market becomes, the more product configurations are required

INTERNAL PROBLEMS

- ✓ Due to illness and quarantine procedures, there is a shortage of personnel
- ✓ Production capacity has been hampered by supply chain constraints and fluctuating demand
- ✓ Hygiene processes that were improved have a direct impact on production efficiency

But even when the pandemic ends, manufacturers will still face the “usual” manufacturing challenges.

- ✓ Companies face a basic challenge in that they are unable to simply identify the causes of downtime.
- ✓ Production planning is a difficulty for businesses.
- ✓ Communication with suppliers is a challenge for businesses.
- ✓ A situation similar to this exists in B2B customer interactions.
- ✓ Workers lack the skills required to adjust machinery.
- ✓ Processing times are slowed by manual operations and administrative effort.

BUILDING

Supply Chain Resilience

Companies can take some precautions to help ensure supply chain resilience in the face of the negative effects of the pandemic.

- ✓ Transport available inventory to locations outside of quarantine zones and close to ports where it can be shipped.
- ✓ Secure Tier 2 and Tier 3 supplier capacity and delivery status, as well as allocated supply and overtime assembly capacity where possible.
- ✓ Purchase inventory and raw materials that will be in limited supply in afflicted areas in advance.
- ✓ Secure the future air transportation when supply and capacity become available, reducing lead times that would otherwise rely on ocean freight.
- ✓ In situations where the primary supplier is disrupted but a secondary source is not, activate pre-approved parts and raw material substitutions.
- ✓ Where dependable second sources of parts or raw materials are not already available, activate product redesigns and material certification resources.
- ✓ Inform customers of delays and adjust customer allocations to maximize profits on near-term income or to meet contractual obligations.
- ✓ Shape demand by, for instance, offering a discount on available inventory in circumstances when availability is likely to be limited for late winter fulfillment, and maximize near-term profitability.
- ✓ Introduce new products to other plants that were previously earmarked for China.

Looking forward, companies can begin to address the more significant consequences to their supply networks as manufacturing facilities in affected countries gradually reopen and knowledge gaps close.

- ✓ Quantify the virus' impact on supply and demand disruptions as well as market performance in the future.
- ✓ Conduct an operational risk assessment on key business functions.
- ✓ To accurately analyze the potential impact, address important supply chain data from all layers.
- ✓ Prepare to implement a temporary inventory recovery and review process and pursue alternate sourcing alternatives, if necessary.
- ✓ Communicate with key supply chain stakeholders about supply volume and changes in demand volume.
- ✓ Conduct scenario planning exercises to better understand the financial and non-financial repercussions of various scenarios.

Global semiconductor sales increased 23.5% from November 2020 to November 2021, establishing an industry record for the highest-ever annual total.

Many global semiconductor **supply chains** pass through the affected areas. Corporations are concerned that they will not be able to meet contractual commitments on time due to a lack of complex data. Concerns over depletion (or idle) stock are growing. And companies are also concerned that partners will not be able to meet contractual obligations on time due to a lack of hard data.

Understanding how semiconductor manufacturers deal with supply chain interruptions can aid all businesses in planning their own reactions.

Impacts in a wide range of businesses and industries appear to be unavoidable. In the short term, the cost of supplies from China (because they have the biggest share of semiconductor manufacturing) may rise due to overtime and expedited freight charges, as well as premiums paid to purchase up supplies and maintain capacity. Alternative sourcing tactics are also being considered by businesses. Identifying alternate supply scenarios and evaluating what they represent for operations will be crucial, for example, as outbreaks of viral transmission occur in different countries.

OVERCOMING TECHNICAL CHALLENGES

New Transistor Architectures

Moore's law stipulates that the number of transistors in an integrated circuit doubles every 2 years, but this interval has risen. Also, due to quantum effects, the dimensions of transistors are limited.

The chip market has traced two paths for the near future:

- ✓ Development of new transistor architectures that assist the development of the next nodes
- ✓ Development of new materials to produce more energy-efficient transistors

The next technological node, the 3 nm, is about to be announced by the chip manufacturers; but as the necessity for high-performance computing creates the demand for even faster devices, the next nodes, 2.5 nm, and 1.5 nm, are already being planned.

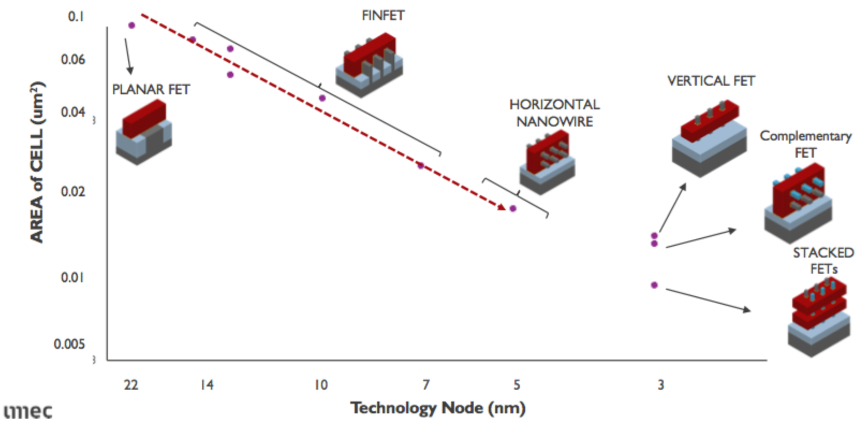


Figure 6. Next-gen transistor architectures. Source: Semiconductor Engineering.

Technological bottlenecks for producing the next nodes involve lithography, selective processes, and space concerns.

Technological breakthroughs necessary for achieving the next nodes:

NEW LITHOGRAPHY

Extreme ultraviolet (EUV) lithography is required for 7nm/5nm. Beyond 3nm, though, there may be need for a next-generation EUV technology called "high-numerical-aperture" EUV.

SELECTIVE PROCESSES

Chipmakers also need a broader array of selective deposition and etch technologies enabling producers to deposit and remove materials more precisely.

NEW INTERCONNECTS MATERIALS

The wiring schemes in chips are too congested, requiring new materials in the arena.

FinFET architecture has been widely employed in the semiconductor industry since 2011.

TSMC and Intel are working to present their newest 3 nm node transistors using finFET architecture. Intel introduced the finFET infrastructure with its 2011 Ivy Bridge processor, a 22 nm node transistor. It presents significant performance, overcoming several problems related to its planar counterpart. However, it is complex to produce.

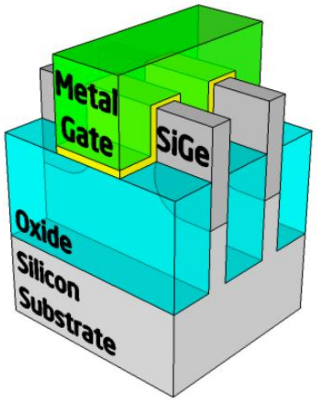


Figure 7. Intel's high-speed, low-power 22 nm finFET design. Source: Intel.

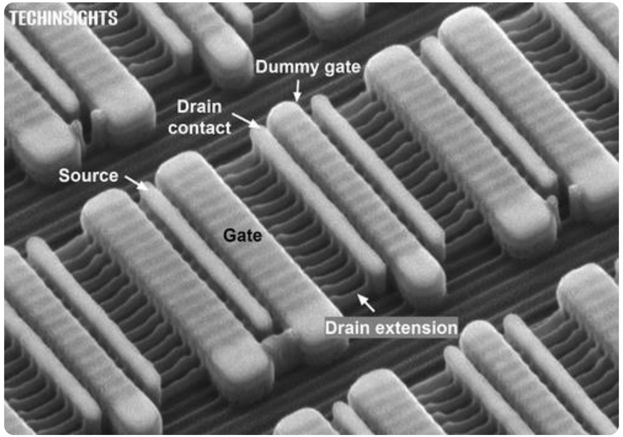


Figure 8. Tilt View Image of TSMC 16 nm finFET I/O transistors. Source: TechInsights.

Multi-bridge channel field-effect transistor (MBCFET) is a variation of a gate-all-around field-effect transistor (GAAFET).

Samsung is planning its 3 nm node devices using the new MBCFET architecture. TSMC and Intel are also working on the development of their GAAFET transistors for 2 nm node devices.

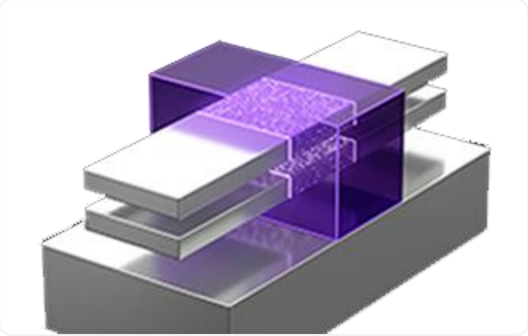


Figure 9. *Samsung's MBCFET architecture. Source: Samsung Foundry.*

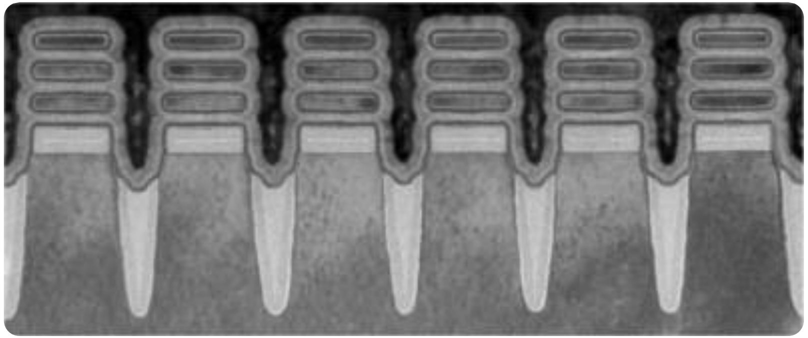


Figure 10. *Row of 2 nm nanosheet devices. Souce: IBM.*

OVERCOMING TECHNICAL CHALLENGES

New Semiconductor Materials

Silicon, the traditional material employed in the semiconductor industry, is reaching its limits.

The silicon technology is mature and robust, and all the industrial apparatus are designed for this material. However, silicon transistors are facing their limits, as further reduction in their dimensions can be harmful to the devices due to quantum effects.

In addition, silicon demands huge amounts of energy to manufacture, as most of the purification steps occur at high temperatures.

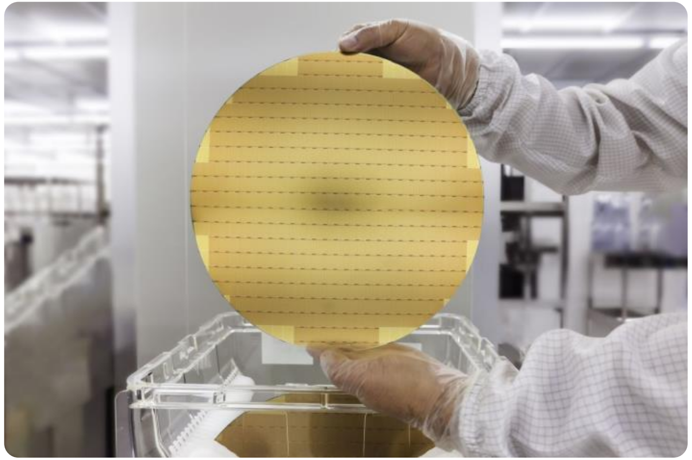


Figure 11. *Silicon wafers prepared for chip production (stock image).*

Hence, chip manufacturers must seek alternatives to silicon.

Silicon Carbide (SiC) and Gallium Nitride (GaN) are two materials that are being introduced as alternatives to silicon.

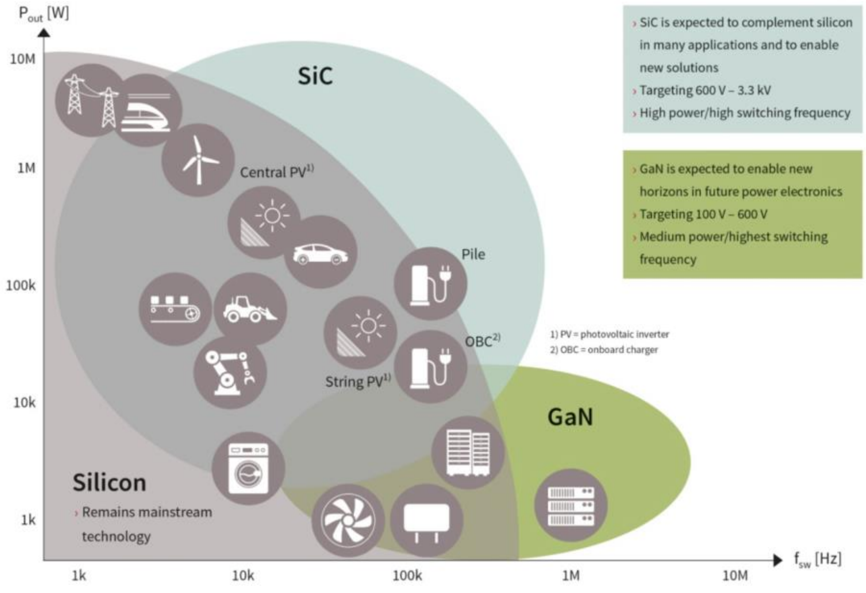


Figure 12. GaN offers higher efficiency at higher switching frequencies than conventional silicon or silicon carbide for specific applications. Source: Infineon.

Silicon Carbide (SiC): An attractive option for car makers

SiC semiconductors are now attracting the attention of the electric car industry. Automakers like Tesla (USA), GM (USA), NIO (China), Yutong (China), Hyundai (South Korea), Toyota (Japan), and Renault (France) implemented or are planning to implement SiC chips.

Third-generation semiconductors are planned to enter the market complementing the traditional silicon semiconductors. They are suitable for making high-temperature, high-frequency, radiation-resistant, and high-power devices.

In the electric car industry, these new components can reduce thermal power loss.

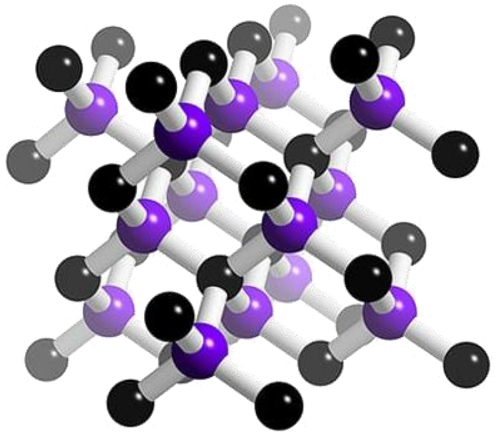


Figure 13. *Silicon carbide model.*
Source: Nick Greeves and OUP - CC BY-NC-ND 4.0.

Silicon Carbide (SiC): An attractive option for car makers

These materials, however, are much more expensive when compared to the cost of silicon. For example, a 6-inch wafer of silicon costs $20, while a 6-inch wafer of SiC costs $1500. The production of cost of SiC must drop to around $750 before the SiC MOSFET becomes practical.

TSMC is making progress in the fabrication of third-generation semiconductor wafers of 8 inches. This effort aims to reduce productions costs. Other manufacturing industries are following the same steps. The popularization of SiC semiconductors is expected in about 2025.

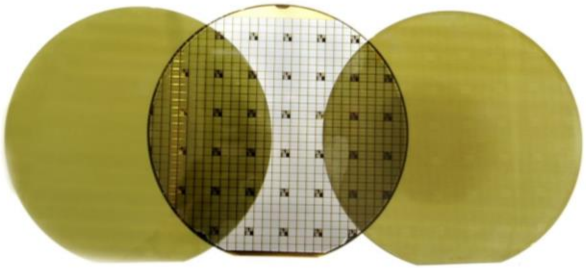


Figure 14. *Silicon carbide wafers.*
Source: STMicroelectronics Blog.

Gallium Nitride (GaN): Offers speed, optimal for communication applications

GaN is a material that can deal efficiently with very high power due to its reduced resistance compared to silicon. It also presents superior thermal efficiency, as well as very high switching speeds, which is important for use cases like communications.

GaN presents superior properties when compared with silicon for some applications. However, its cost is even higher than that of SiC. It is expected that the development of the SiC industry will lead to a reduction in GaN manufacture.

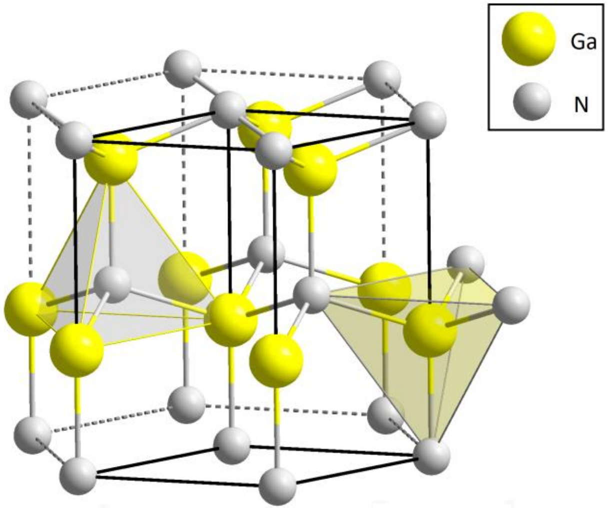


Figure 15. *Gallium nitride model.*
Source: Wikimedia Commons - CC-BY-SA-4.0.

Gallium Nitride (GaN): Offers speed, optimal for communication applications

To reduce costs and take advantage of its superior properties, GaN is been deposited over silicon.

GaN-based chips are highly expected in power management chips, which manage the conversion and distribution of electricity in devices such as phone and laptop chargers. This leads to more compact devices with better power efficiency. For a data center, for example, this is a considerable reduction in energy consumption.

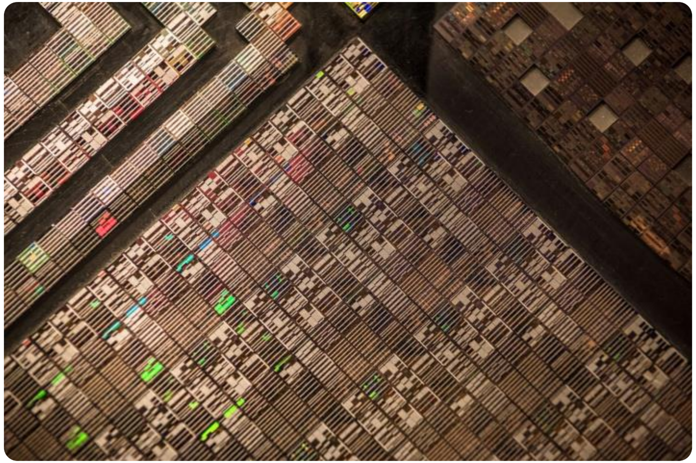


Figure 16. *Closeup of a semiconductor wafer (stock image).*

ROADMAP TO

Overcoming Current Challenges

Timeline for effective mitigation of the current semiconductor challenges

2022-2025

- ✓ 3nm transistor node using FinFET and GAAFET

2025-2028

- ✓ 2.5 nm node using GAAFET
- ✓ Popularization of SiC semiconductors

2028-2030

- ✓ 1.5 nm node
- ✓ Popularization of GaN semiconductors

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Sofiane leads the high-tech, aerospace & defense, and automotive & logistics practices at PreScouter. For nearly a decade, he has worked with hundreds of F500 and G1000 clients across multiple industries, through which he has developed an expertise in key emerging technologies (such as 5G, IoT, AI/ML, blockchain, energy storage and generation, quantum sensing, and others) and a strong understanding of the associated business ecosystem and drivers pushing these sectors forward (e.g., key players and trends, roadblocks to commercialization, etc). Sofiane's strategic insights have ranged from technical due diligence for acquisition targets to identifying relevant markets for newly developed products based on emerging technologies and assessing market penetration strategies. Sofiane holds a PhD in Materials Science and Engineering from the Georgia Institute of Technology, where his research focused on nanotechnology and energy storage.

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Matheus, born in 1988, is currently a postdoctoral researcher in Physics Institute at the University of São Paulo. He obtained his Bachelor’s (2012) and Master’s (2014) degrees in chemistry from the University of Brasilia, working on the synthesis of material for application on photocatalysis, and his Ph.D. in Chemistry from the University of Campinas (2020), focusing on the in-situ formation of 2D structures with bulk perovskites. His research focuses in the formation and stability layered perovskites films and application in perovskites solar cells.

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