SEMICONDUCTORS

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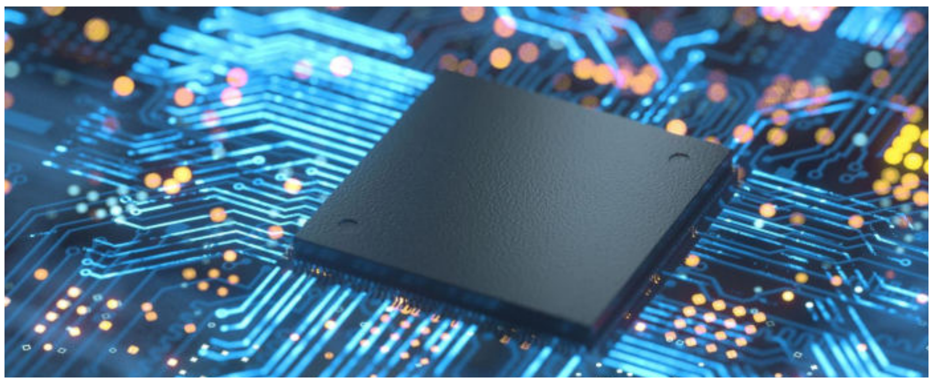
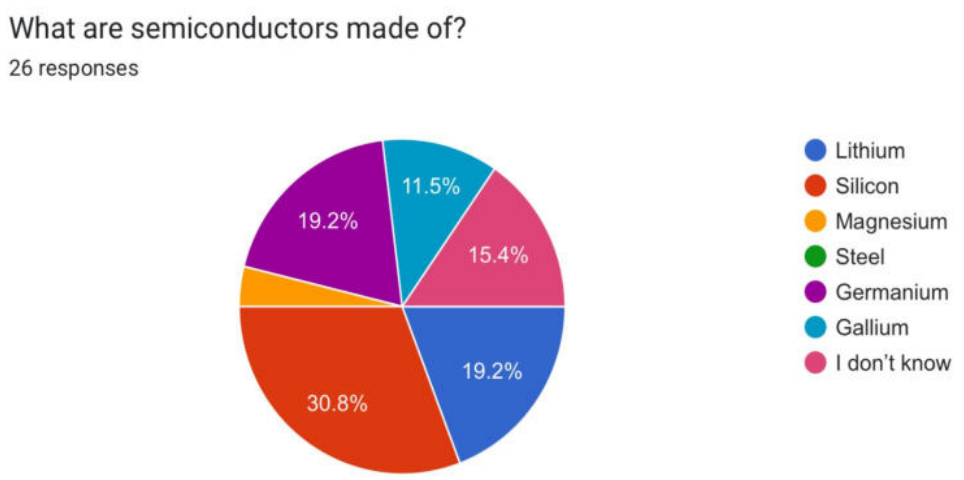
Semiconductors is a topic that occupies minds of many when it comes to innovation, politics and development. The role played by those tiny electronic masterpieces is not to be underestimated. Even though the knowledge on them possessed by the society seems to be, quite often, lacking. We – a group of students – decided then to investigate this topic deeper and shortly describe the backstage of this invention. Starting with a small scale survey among the academic society, let's discover something more.

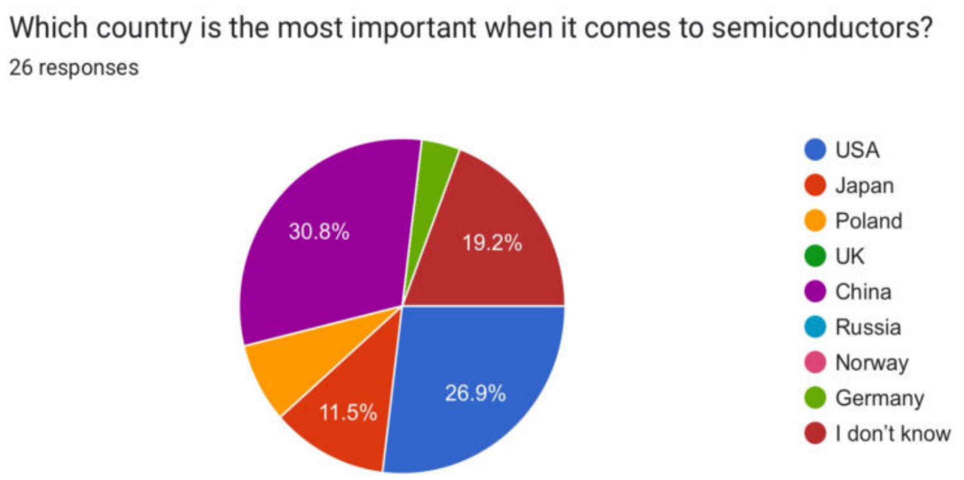


Conducting research

The survey that has been conducted in order to investigate the overall knowledge of the society on semiconductors and topics connected with them. The responses have been gathered mainly in the academic environment and the majority of respondents were students. It contained four parts: collocations, construction of semiconductors, geopolitical knowledge and personal opinions.

The first part intended to research the collocations that are assigned to the word 'semiconductor'. The responses were mainly following e.g.: current, electricity, transistor. As it is possible to be observed 'semiconductors' are correctly assigned to electronics.



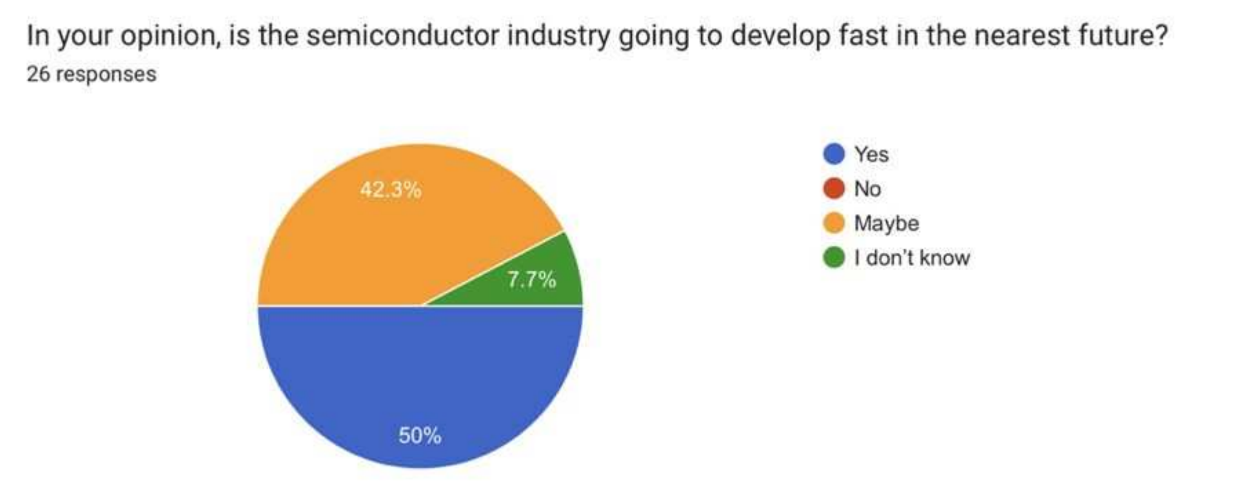


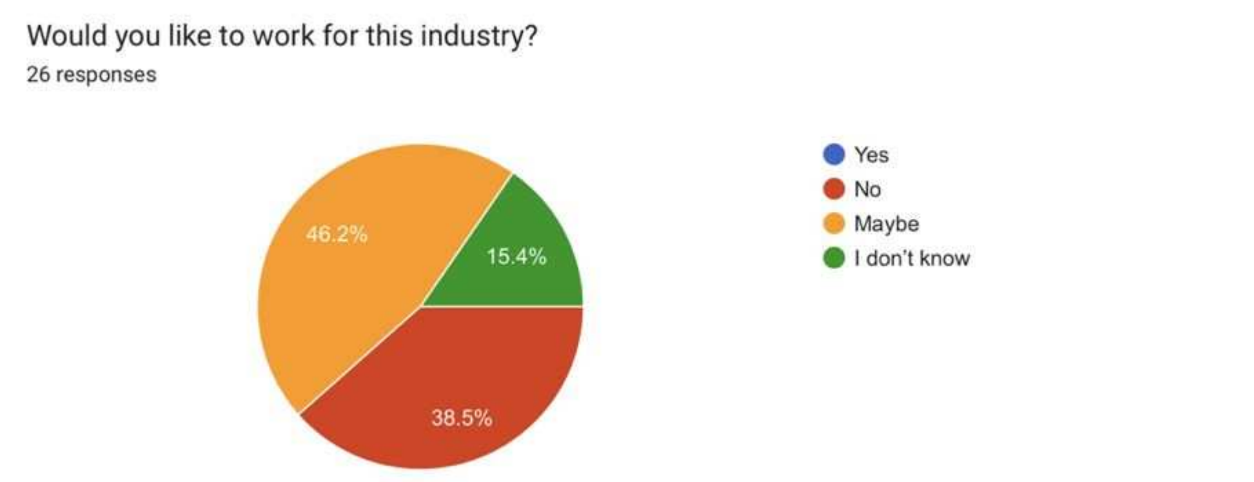
Some responses were more precise and descriptive. Only few indicated the lack of knowledge on this branch of electronics.

The next part delved deeper into the construction and ingredients of semiconductors. There were, as well, many correct answers.

The third part, in which some geopolitical knowledge has been researched, presents itself slightly less positive. Even though the knowledge on leading countries and companies, when it comes to semiconductors, was quite good, most respondents did not seem aware of the future of this branch.

The personal opinion section seems to be the most interesting one, as even though the respondents claimed that the semiconductor industry is going to develop quickly in the nearest future, they were not at all interested in working for this industry. Most of respondents also evaluated their knowledge as 'poor' or slightly higher.





Historical Evolution of Semiconductors

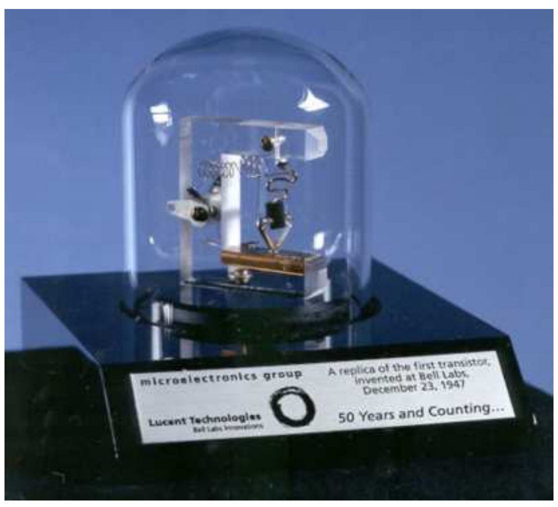
The story of semiconductors is a fascinating journey through the annals of scientific discovery and technological innovation. From their humble beginnings in the early 20th century to their pivotal role in shaping the modern world, semiconductors have undergone a remarkable evolution. Let's delve into the historical background of semiconductors, tracing their development and transformation over the years.

Early Beginnings:

The roots of semiconductor technology can be traced back to the late 19th and early 20th centuries when scientists began to explore the electrical properties of various materials. In 1874, the phenomenon of semiconductivity was first observed by the German physicist Karl Braun, who noticed that certain materials exhibited intermediate conductivity between conductors and insulators.

Invention of the Transistor:

The true breakthrough in semiconductor technology came in 1947 with the invention of the transistor by John Bardeen, Walter Brattain, and William Shockley at Bell Labs. The transistor, a small electronic device capable of amplifying and switching electrical signals, revolutionized the field of electronics. Unlike vacuum tubes, which were bulky and unreliable, transistors were compact, durable, and energy-efficient, paving the way for the miniaturization of electronic devices.



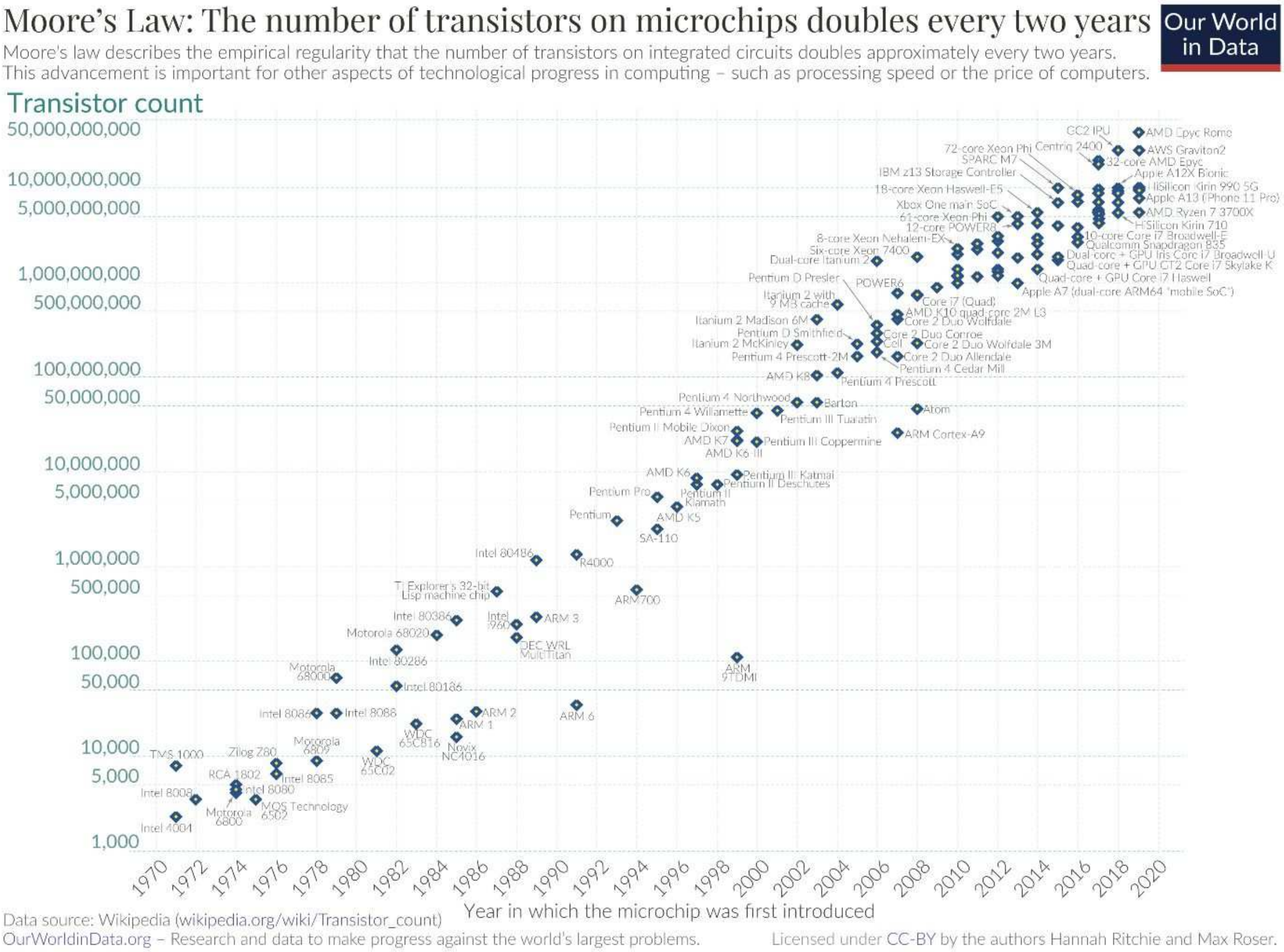
Semiconductor Materials:

In the early days of semiconductor technology, germanium was the primary material used to fabricate transistors and diodes. However, researchers soon discovered that silicon offered several advantages over germanium, including greater abundance, higher operating temperatures, and improved stability. By the late 1950s, silicon had become the dominant material in semiconductor manufacturing and remains so to this day.

Integrated Circuits and Moore's Law

The 1960s witnessed another milestone in semiconductor technology with the invention of the integrated circuit (IC) by Jack Kilby at Texas Instruments and Robert Noyce at Fairchild Semiconductor. Integrated circuits combined multiple transistors, resistors, and capacitors onto a single semiconductor chip, leading to further reductions in size, cost, and power consumption.

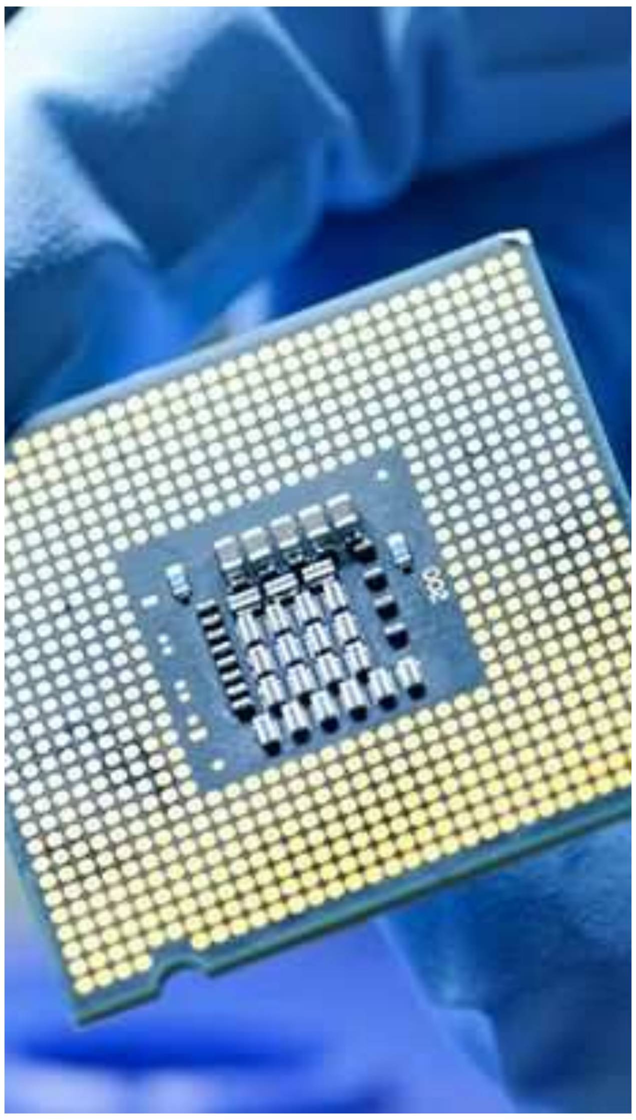
Moore's Law, formulated by Intel co-founder Gordon Moore in 1965, predicted that the number of transistors on a semiconductor chip would double approximately every two years, leading to exponential growth in computing power. This prediction has held true for several decades, driving continuous advancements in semiconductor manufacturing processes and enabling the development of increasingly powerful and complex electronic devices.



Evolution of Semiconductor Technologies

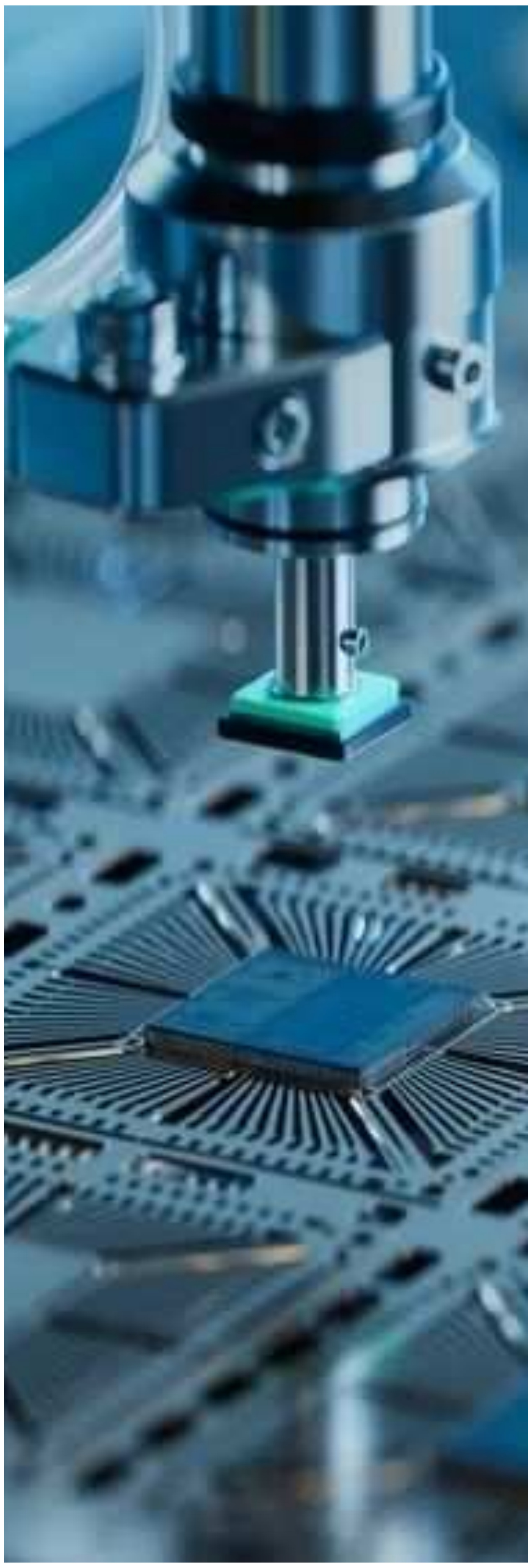
Over the years, semiconductor technology has continued to evolve, driven by innovations in materials science, device physics, and manufacturing techniques. Key developments include the introduction of complementary metal-oxide-semiconductor (CMOS) technology, which revolutionized digital integrated circuits by enabling low-power operation and high-speed performance.

Advances in lithography, the process of patterning semiconductor chips, have allowed manufacturers to shrink transistor dimensions and increase chip densities, leading to higher performance and greater functionality in electronic devices.



Manufacturing and use

In the vast landscape of modern technology, few components are as crucial and ubiquitous as semiconductors. These tiny wonders are the hearts of the devices that have become integral to our daily lives, from smartphones to computers, and from medical equipment to transportation systems. Let's delve into the intricate world of semiconductors, exploring their ingredients, production processes, and wide-ranging applications.



Ingredients of Semiconductors

Semiconductors are typically made from materials known as semiconducting elements. The most common of these are silicon and germanium. These elements possess unique electrical properties that make them ideal for semiconductor manufacturing.

Silicon (Si): Silicon is the cornerstone of semiconductor production. It's abundant in nature and possesses excellent semiconductor properties. The silicon used in semiconductor manufacturing is typically purified to extremely high levels to ensure the desired electrical properties.

Germanium (Ge): Although less commonly used than silicon, germanium also exhibits semiconductor properties. It was widely used in the early days of semiconductor technology and still finds niche applications today.

Production Process

The production of semiconductors involves highly sophisticated processes that require precision and control at the atomic level. Here's a simplified overview of the key steps involved:

Crystal Growth: The process begins with the production of a single crystal ingot of high-purity silicon through methods like the Czochralski process or the float-zone method. This ingot is then sliced into thin wafers.

Wafer Preparation: The silicon wafers undergo extensive cleaning and polishing to ensure a pristine surface free from contaminants.

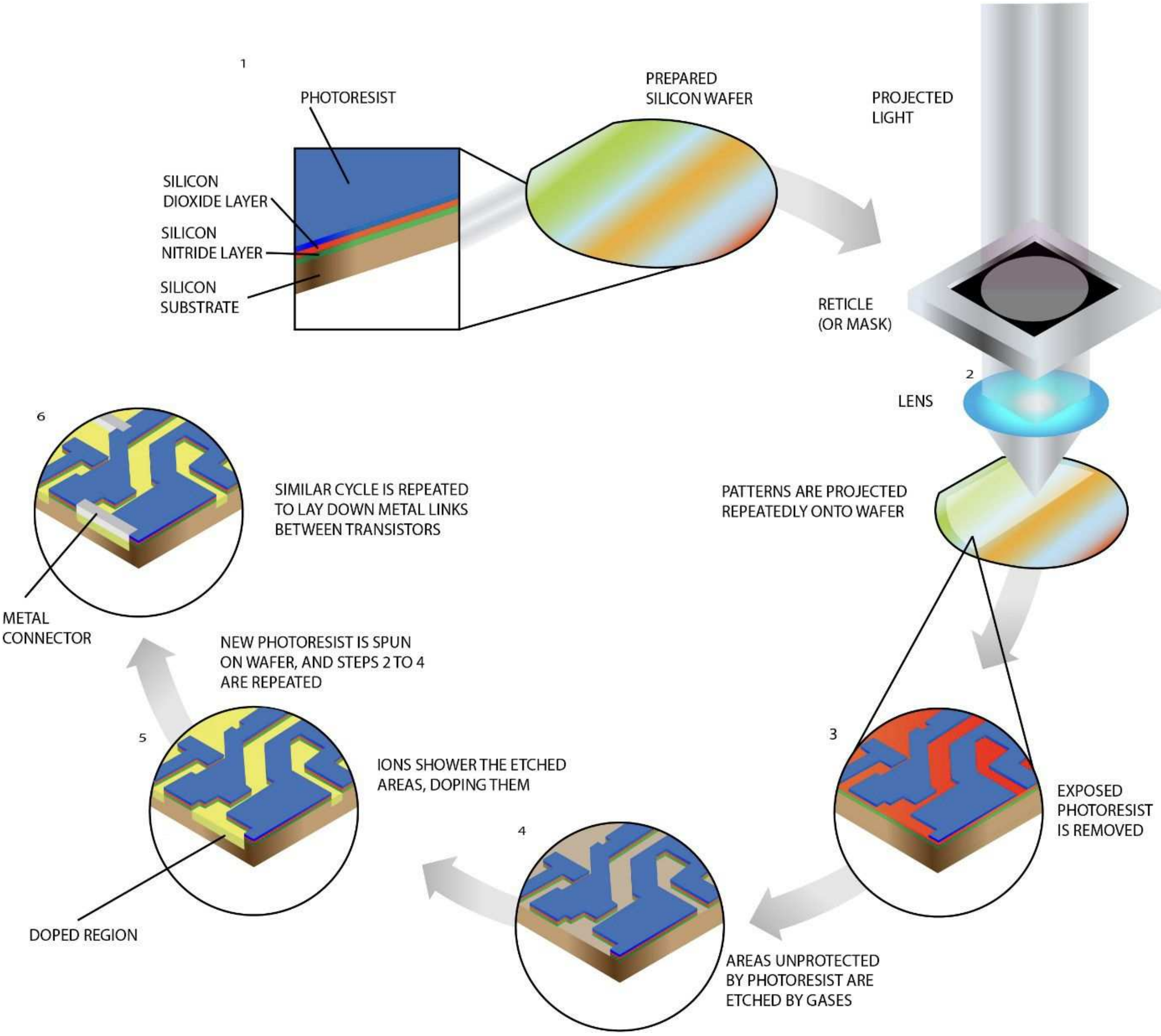
Doping: Doping is the process of intentionally introducing impurities into the silicon crystal to alter its electrical properties. This is achieved by diffusing specific dopant atoms, such as phosphorus or boron, into the crystal lattice.

Photolithography: This is a crucial step in defining the intricate patterns of the semiconductor components. A light-sensitive photoresist is applied to the wafer surface, exposed to ultraviolet light through a mask, and then developed to selectively remove portions of the resist.

Etching: Etching is used to remove material from the wafer according to the pattern defined by the photoresist. This can be done through chemical etching or plasma etching processes.

Deposition: Various thin films of materials such as metals, oxides, and nitrides are deposited onto the wafer surface using techniques like chemical vapor deposition (CVD) or physical vapor deposition (PVD).

Annealing: This step involves heating the wafer to activate dopants and repair any damage caused during previous processing steps.



Packaging:
Once the semiconductor devices are fabricated on the wafer, they are separated and packaged into individual components, ready for integration into electronic circuits.

Applications of semiconductors

Semiconductors are the building blocks of modern electronics, enabling a vast array of devices and systems. Some key areas where semiconductors are applied include:

Consumer Electronics:
From smartphones and laptops to televisions and digital cameras, semiconductors power the devices that have become indispensable in our daily lives.

Information Technology:
Data centers, servers, and networking equipment rely heavily on semiconductors for processing, storage, and communication.

Renewable Energy:
Semiconductors are integral to solar photovoltaic cells, which convert sunlight into electricity, as well as to power management systems in wind turbines and battery storage.

Industrial Automation:
Semiconductors enable the automation and control systems used in manufacturing, robotics, and process control.

Telecommunications:
From smartphones to network infrastructure, semiconductors form the backbone of modern telecommunications systems, facilitating wireless communication and high-speed data transfer.

Automotive:
Semiconductors play a crucial role in automotive technology, powering advanced driver-assistance systems (ADAS), infotainment systems, and electric vehicle (EV) components.

Industry and geopolitical situation

Due to their importance in almost every aspect of the modern world, the manufacturing of semiconductors became a crucial factor in global politics. The United States and China have become central players in the global semiconductor landscape, with both countries vying for dominance in critical technologies such as artificial intelligence, 5G telecommunications, and advanced manufacturing. The U.S.-China semiconductor rivalry has led to increased scrutiny of technology exports, investment flows, and intellectual property rights, raising concerns about economic decoupling and technological fragmentation. Geopolitical tensions, trade tensions, and cybersecurity concerns have further complicated the relationship between the world's two largest economies, shaping the trajectory of international relations and global governance.

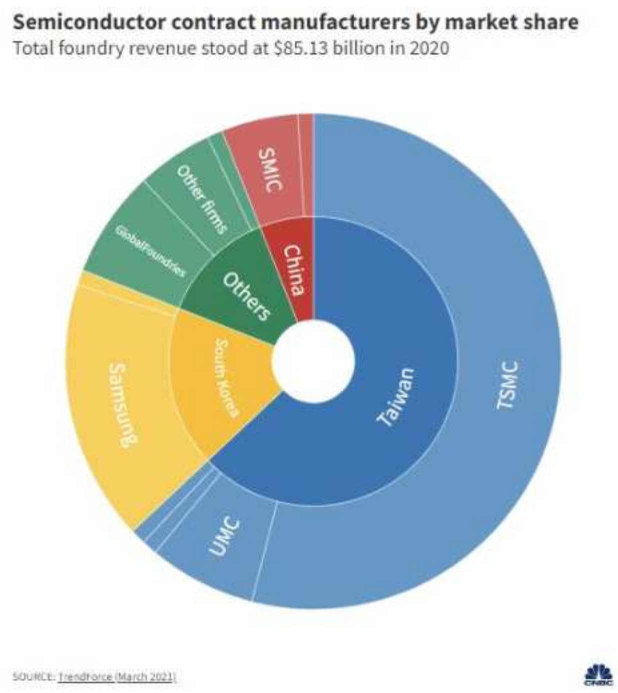
China and America are locked in a high stakes battle for dominance in semiconductor technology, recognizing its strategic importance for national security, economic competitiveness, and technological leadership. Both countries are investing heavily in semiconductor research, development, and manufacturing capabilities to gain a competitive edge in critical technologies such as artificial intelligence, 5G telecommunications, and advanced manufacturing.

The centre of this rivalry lies in Taiwan, as about 90%[2] of the most technologically advanced chips are produced there. The island nation is renowned for its advanced semiconductor industry, which is centered around companies like TSMC (Taiwan Semiconductor Manufacturing Company), MediaTek, and UMC (United Microelectronics Corporation).

For instance, TSMC, the world's largest semiconductor foundry, leads the pack in Taiwan's semiconductor industry. It is known for its cutting-edge fabrication facilities, which produce chips for a wide range of applications, from smartphones to advanced computing systems.
Importantly, Taiwan's government has been supportive of the semiconductor industry, implementing policies to promote its growth and competitiveness. This includes providing incentives for investment in semiconductor manufacturing facilities and fostering collaboration between academia, industry, and government research institutions.

However, Taiwan's semiconductor industry also faces challenges, particularly in the form of geopolitical tensions. Taiwan's relationship with both China and the United States regarding semiconductors is complex and multi-faceted, often influenced by geopolitical tensions, economic interests, and technological competition. The island's relationship with mainland China adds a layer of complexity and uncertainty, as China considers Taiwan a renegade province and has expressed ambitions to reunify it with the mainland[3]. This geopolitical situation can impact Taiwan's semiconductor industry, as it relies on international trade and cooperation. At the same time China is the largest consumer of Taiwanese chips, as well as being one of the main sources of resources used to produce them.

On the other hand, the United States has a strong interest in Taiwan's semiconductor industry, as Taiwan is a critical supplier of advanced semiconductors to U.S. companies, critical for their national security. The U.S. government has recognized the importance of securing the semiconductor supply chain and maintaining technological leadership in this sector. Trade tensions between China and America have escalated in recent years, with



semiconductors emerging as a focal point of contention. The Trump administration imposed export controls and sanctions targeting Chinese semiconductor companies, such as Huawei and SMIC[1], citing national security concerns and allegations of intellectual property theft. These measures have disrupted global semiconductor supply chains and prompted retaliatory actions from China, exacerbating tensions between the two economic superpowers.

The Biden administration has maintained a tough stance on China's semiconductor ambitions, emphasizing the need to protect America's technological leadership and address unfair trade practices. The U.S. government has advocated for greater international cooperation on semiconductor standards, intellectual property protection, and export controls to safeguard global supply chains and prevent the proliferation of sensitive technologies to adversarial regimes. However, efforts to strike a balance between economic interests, national security imperatives, and international cooperation remain a complex and ongoing challenge for policymakers. The semiconductor rivalry between China and America underscores the need for nuanced strategies and multilateral engagement to address the complex interplay of economic, technological, and geopolitical factors shaping the future of the semiconductor industry.

Poland, Ukraine, and superconductors

Importance of semiconductors is recognized in our region as well. For instance, both countries have a growing market of startups related to superconductors, as well as significant cooperation with academia and research institutions. Some of the key players, such as Intel, are actively expanding in the region. Intel intents to build a large factory around Wrocław[5], which would cut wafers into individual chips, assemble, and test them before they're shipped off to customers. It will work closely with Intel's state-of-the-art microchips production site in Magdeburg, Germany, which is also scheduled to become operational in similar period around 2027.

Up to the war Ukraine was producing about half the world's supply of neon, one of the key ingredients for making chips. Most of the neon which is critical for the lasers used to make chips, came from two Ukrainian companies, Ingas and Cryoin. However, due to Russian aggression both had to shutter their operations. Ukraine also hosts large deposits of rare earth metals, critical for the production of advanced semiconductors and technologies[6].

This paints a prospect for a fully European semiconductor production chain, where Poland and Ukraine both would be key players[4], providing both resources and production of semiconductors. This would mean an opportunity to increase the security of European supply chains in the semiconductor industry and thus the economic security of the continent – at the same time representing an opportunity for the reconstruction and development of the Ukrainian economy and opening a new chapter in the history of an independent Ukraine.

Emerging technologies

As the semiconductor industry continues to evolve at a rapid pace, numerous emerging trends and technologies are sure to reshape the landscape of electronics and computing.

Miniaturization: Chips are getting smaller and smaller. This trend, known as Moore's Law, has been ongoing for decades. However, as we approach the physical limits of miniaturization, new techniques like EUV lithography and novel materials are being developed to keep the trend alive.

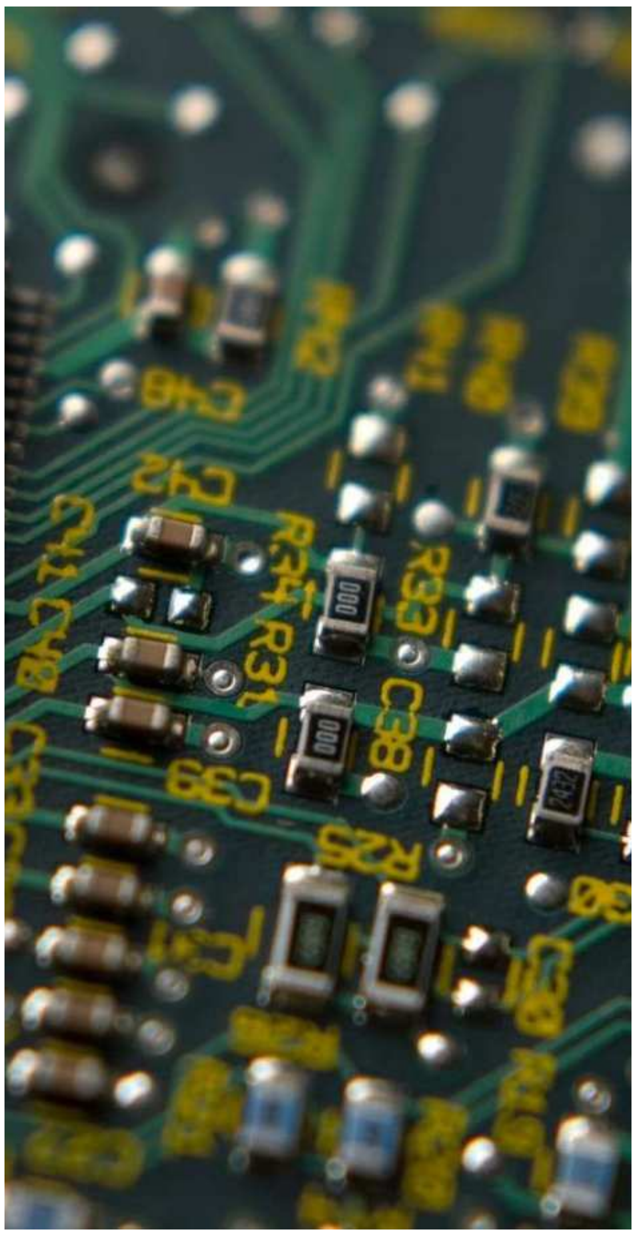
Quantum Computing: Quantum computing represents a massive shift in computing power, promising exponential speed up over classical computers for certain tasks. Semiconductors play a crucial role in the development of quantum computing hardware, including qubits, control electronics, and quantum memory. Major semiconductor companies and research institutions are investing in quantum computing research to unlock its potential for applications in cryptography, optimization, medical discoveries, and materials science[7].

AI Chips: The proliferation of artificial intelligence (AI) and machine learning (ML) applications is driving demand for specialized AI chips optimized for neural network inference and training. These AI accelerators leverage semiconductor technology, in order to deliver high-performance computing for AI workloads. AI chips enable advancements in autonomous vehicles, robotics, natural language processing, and computer vision, revolutionizing industries and driving innovation in AI-driven solutions.

Edge Computing: With the rise of Internet of Things devices and autonomous systems, there is a growing need for processing power at the edge of networks. This trend is driving the development of low-power, high-performance chips suitable for edge computing applications[7].

5G and Beyond: The rollout of 5G wireless networks is fueling demand for semiconductor components, such as RF transceivers, baseband processors, and power amplifiers, to support high-speed connectivity and low-latency communications. Beyond 5G, other emerging technologies like millimeter-wave communications, massive MIMO (massive multiple-input multiple-output), and network slicing are driving the development of next-generation semiconductor solutions for 6G and beyond. These advancements hold the promise of transformative applications, including smart cities, augmented reality, telemedicine, and industrial automation.

Overall, the future of semiconductors is one of continued innovation, with modern technologies driving advances in performance, efficiency, and capabilities. [10]



Global Influence of Semiconductors

Semiconductors have not only revolutionized technology but have also had a profound impact on the global economy, international trade, and geopolitical dynamics. Here's a detailed exploration of their global influence:

1. Transformation of the Global Economy:
Semiconductors have become a cornerstone of the global economy, powering industries and driving productivity and innovation. Their pervasive influence extends across sectors such as telecommunications, healthcare, transportation, manufacturing, and entertainment. The semiconductor industry itself is a significant contributor to global GDP, generating billions of dollars in revenue annually and creating millions of jobs worldwide. The relentless pace of technological advancement and the increasing integration of semiconductors into everyday products continue to fuel economic growth and competitiveness on a global scale.

2. Impact on International Trade and Supply Chains:
Semiconductor manufacturing has become a highly globalized industry, with complex supply chains spanning multiple countries and regions. The production of semiconductor chips involves a series of intricate processes, from semiconductor wafer fabrication to assembly and testing, each requiring specialized expertise and resources. As a result, semiconductor companies often rely on a network of suppliers and partners located around the world to ensure a steady supply of materials, equipment, and components. This interconnected supply chain has made semiconductor manufacturing susceptible to disruptions, such as natural disasters, geopolitical tensions, and trade disputes, highlighting the importance of resilience and diversification in supply chain management.

Furthermore, semiconductors are a critical component of international trade, with countries vying for leadership in semiconductor manufacturing and technology development. The global semiconductor market is characterized by intense competition, with major players like the United States, China, South Korea, Taiwan, and Japan jockeying for market share and technological supremacy. Trade policies, tariffs, export controls, and intellectual property rights play a significant role in shaping the dynamics of semiconductor trade and investment, impacting the competitiveness of nations and the balance of power in the global economy.

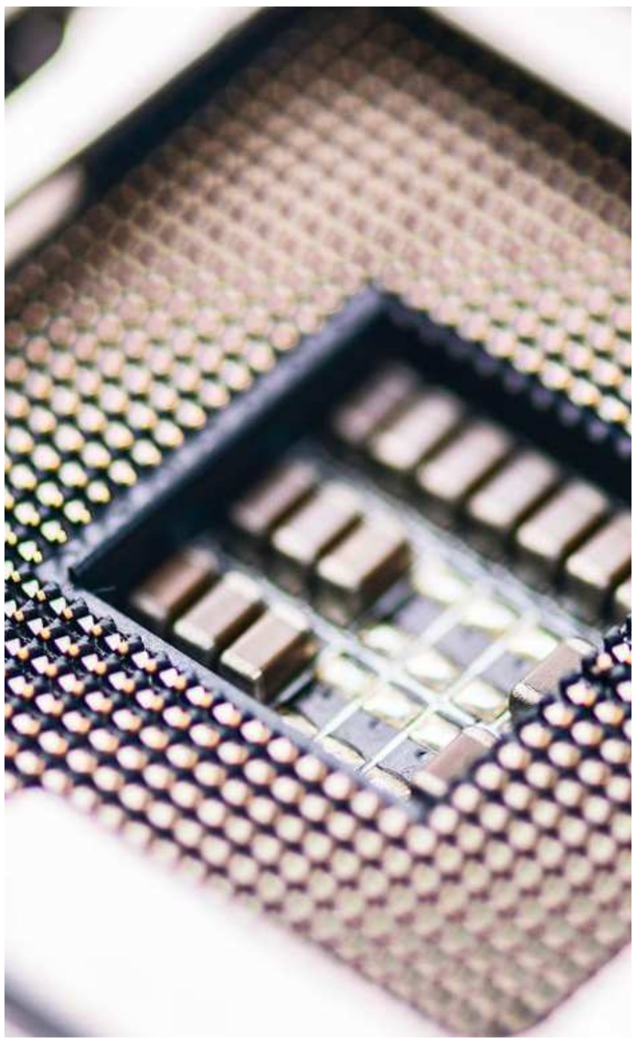
3. Role in Shaping International Relations and Geopolitics:
Semiconductors have emerged as strategic assets in the geopolitical arena, with countries recognizing their importance for national security, economic competitiveness, and technological leadership. The race to develop advanced semiconductor capabilities has intensified in recent years, driven by concerns over supply chain vulnerabilities, technological dependencies, and geopolitical rivalries. Nations are investing heavily in semiconductor research, development, and manufacturing infrastructure to strengthen their domestic capabilities and reduce reliance on foreign suppliers.

The United States and China, in particular, have become central players in the global semiconductor landscape, with both countries vying for dominance in critical technologies such as artificial intelligence, 5G telecommunications, and advanced manufacturing.

The U.S.-China semiconductor rivalry has led to increased scrutiny of technology exports, investment flows, and intellectual property rights, raising concerns about economic decoupling and technological fragmentation. Geopolitical tensions, trade tensions, and cybersecurity concerns have further complicated the relationship between the world's two largest economies, shaping the trajectory of international relations and global governance.

Moreover, semiconductors have geopolitical implications beyond bilateral relations, influencing alliances, partnerships, and security arrangements among nations. Strategic alliances and collaborative initiatives in semiconductor research, standardization, and regulation have emerged as tools for promoting interoperability, resilience, and trust in global supply chains. At the same time, geopolitical rivalries and security concerns have prompted calls for greater autonomy, sovereignty, and strategic autonomy in semiconductor manufacturing and technology development.

In summary, semiconductors have become a linchpin of the global economy, reshaping international trade, supply chains, and geopolitical dynamics. As countries navigate the complexities of the semiconductor landscape, they must strike a balance between economic competitiveness, technological innovation, and national security interests to thrive in an increasingly interconnected and competitive world. [9]



Political Dynamics: China vs. America

The semiconductor industry has emerged as a focal point of geopolitical competition between China and America, with both nations vying for supremacy in this critical technology sector. Here's an in-depth examination of the political dynamics driving the semiconductor rivalry between these two global powerhouses:

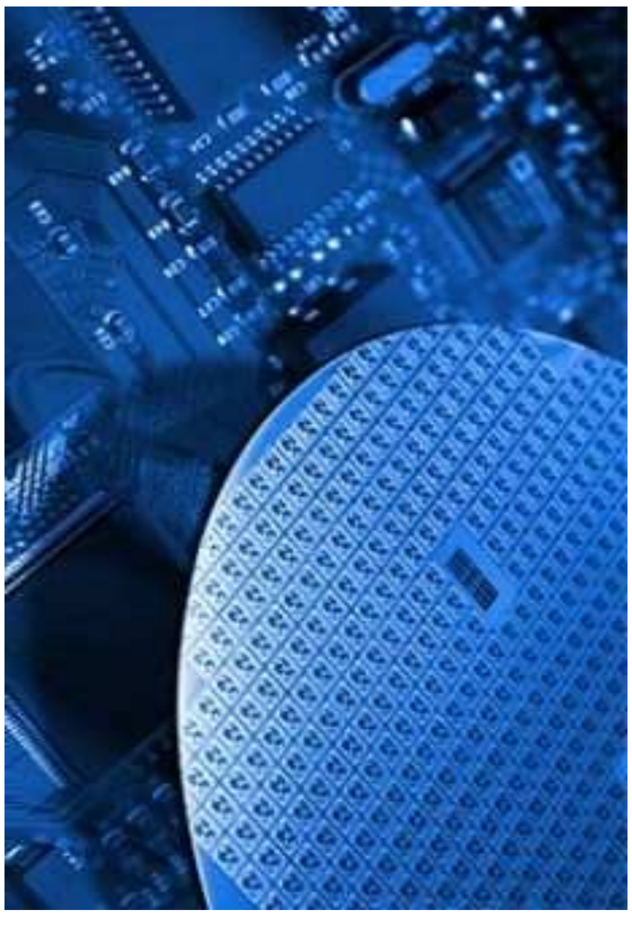
1. China's Semiconductor Ambitions:
China has set ambitious goals to become self-sufficient in semiconductor manufacturing and reduce its reliance on foreign suppliers, particularly in the wake of escalating trade tensions with the United States. The Chinese government has launched several initiatives, such as the "Made in China 2025" program and the National Integrated Circuit Industry Investment Fund, aimed at accelerating the development of the domestic semiconductor industry.
China has made significant investments in semiconductor fabs, research facilities, and talent recruitment to bolster its capabilities in chip design, fabrication, and packaging.

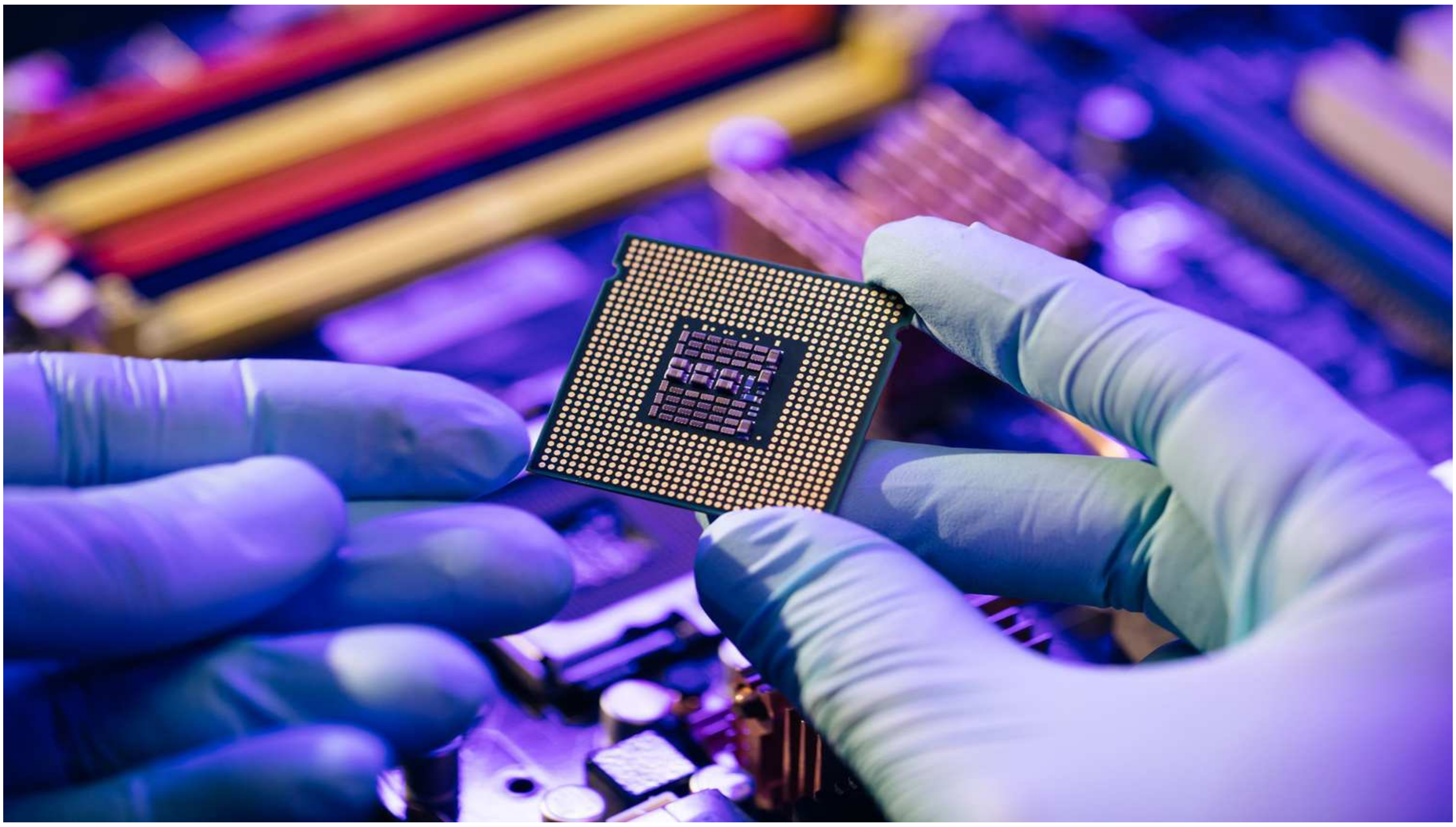
However, China faces numerous challenges in achieving semiconductor self-sufficiency, including technological bottlenecks, intellectual property barriers, and supply chain dependencies. The country's efforts to acquire foreign semiconductor companies and technology through mergers, acquisitions, and partnerships have faced scrutiny and opposition from foreign governments, citing concerns about national security, intellectual property theft, and unfair trade practices.

2. America's Dominance in Semiconductor Technology:
The United States has long been a global leader in semiconductor technology, home to some of the world's most innovative and influential semiconductor companies, including Intel, Qualcomm, NVIDIA, and AMD. American firms dominate key segments of the semiconductor market, such as microprocessors, memory chips, and advanced semiconductor equipment.

The U.S. government has historically supported the semiconductor industry through funding for research and development, investment incentives, and export controls aimed at protecting sensitive technologies.

Despite America's technological prowess, the country faces challenges in maintaining its leadership in semiconductor manufacturing and innovation.





The rise of formidable competitors, such as China and South Korea, coupled with increasing regulatory scrutiny and trade tensions, has raised concerns about the erosion of America's competitive advantage in critical technologies. The Biden administration has emphasized the importance of semiconductor manufacturing and supply chain resilience, proposing initiatives such as the CHIPS Act to invest in domestic semiconductor production and strengthen U.S. competitiveness in semiconductor technology.

3. Trade Tensions and Policies

Trade tensions between China and America have escalated in recent years, with semiconductors emerging as a focal point of contention. The Trump administration imposed export controls and sanctions targeting Chinese semiconductor companies, such as Huawei and SMIC, citing national security concerns and allegations of intellectual property theft. These measures have disrupted global semiconductor supply chains and prompted retaliatory actions from China, exacerbating tensions between the two economic superpowers.

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In conclusion, the semiconductor rivalry between China and America reflects the broader geopolitical tensions and strategic competition unfolding in the 21st century. As both countries vie for dominance in semiconductor technology, the stakes are high, with profound implications for global trade, innovation, and security. Navigating these political dynamics will require a delicate balancing act between competition and cooperation, as nations seek to harness the transformative potential of semiconductor technology while safeguarding their strategic interests and values.

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