Ploughshares

When the chips are down: Can middle powers navigate the Great Powers' high-stakes semiconductor game?

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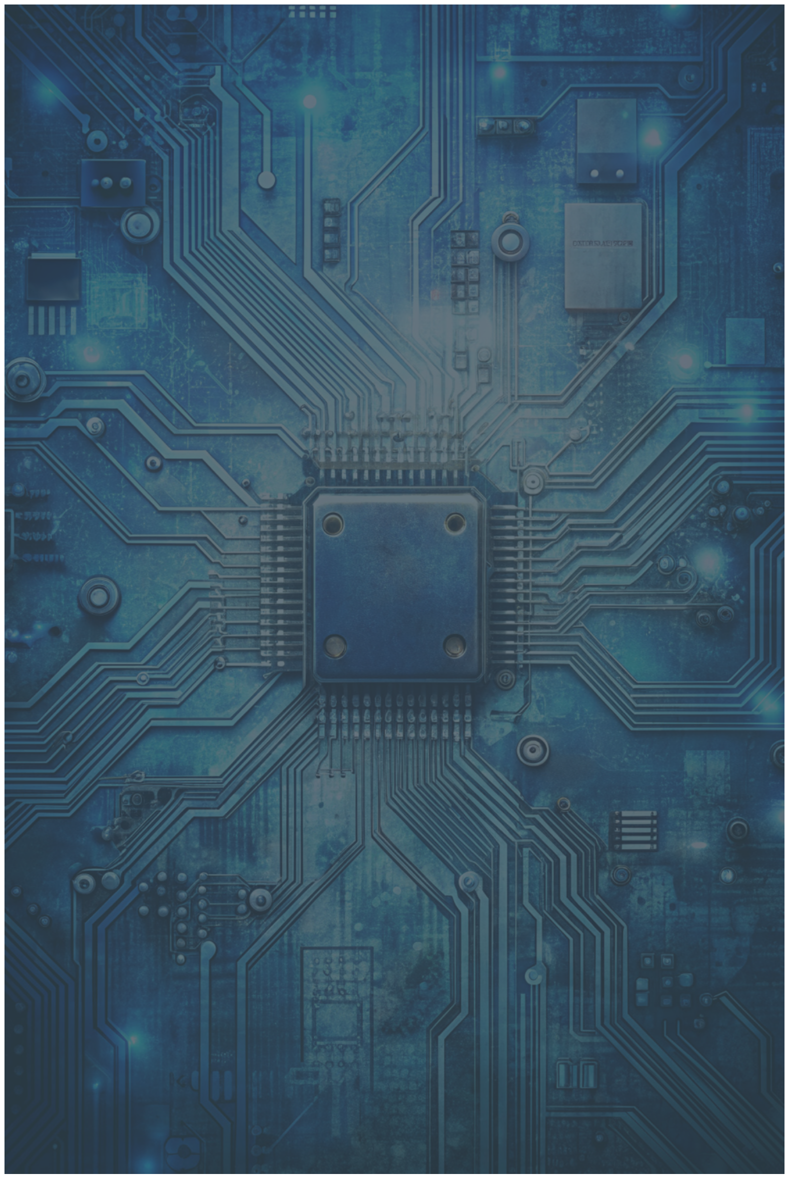

Overview

Semiconductors are central components of both major defence systems and platforms, and many ubiquitous civilian technologies. They are critical in advancing technologies such as artificial intelligence (AI) and quantum computing. The United States, in particular, defends its need for leadership and control over microelectronic production and exports that ensure that the American economy is well supplied, and U.S. military supremacy is maintained. While the United States is currently the dominant power in semiconductors, China is making major advances. In response, the U.S. government is taking measures against China and pressuring allies that are home to significant microelectronic companies to do likewise. The Netherlands has responded with export control policies that, while not explicitly singling out any country, are widely understood to be aimed at China. Canada and other U.S. allies could be next. Most states acknowledge that today's complex global supply chains make national sovereignty in semiconductor production infeasible for them. The new goal is greater stability among the key producers. While allies—particularly Canada—are likely to follow the U.S. lead, the continued competition between the Great Powers contributes to the further destabilizing of the global order and requires diplomatic responses.

Introduction

Speaking at the 2023 Aspen Security Forum, China's Ambassador to Washington, Xie Feng, warned that if the United States continued to threaten China's chip sector with escalating scrutiny and tighter restrictions on semiconductor exports, China would be forced to respond. Xie stated, "China, definitely … will make our response. But definitely it's not our hope to have a tit-for-tat. We don't want … a trade war, technological war, we want to say goodbye to the Iron Curtain as well as the Silicon Curtain."

A year later such sentiments appear to have fallen by the wayside as the struggle between the United States and China over key technologies intensifies. Meanwhile, U.S. strategists continue to call for expanded government intervention to ensure that the United States maintains a competitive position in the development and deployment of next-generation technologies. American national industrial policy currently employs leveraging subsidies, tax credits, and other tools to foster domestic production and mitigate the risk of overdependence on foreign technologies. For some experts, such as Evan Ellis, a research professor at the U.S. Army War College, the outcome of the United States–China tech competition raises an "ethno-civilisational question."

Other experts have also claimed that neutrality will not be possible and eventually countries will need to choose between Beijing and Washington. Thus, it is important for Canada and other middle powers to consider their positions and anticipate diplomatic solutions. Most states, even with greater investment in the semiconductor sector, remain beholden to the few states capable of producing the necessary chips and the even fewer states designing the means of manufacturing them. Thus, aligning with either side could negatively affect a particular country's continued access to relevant resources and knowledge.

U.S. allies will certainly support American actions to some extent, for both strategic and ideological reasons. Their challenge lies in balancing this support with their own technological development. Ultimately, it is in the interest of most states if U.S.-Chinese competition in semiconductors avoids further escalatory measures. Whether the middle powers are going to be able to navigate the technological divide, the impacts of which will be felt beyond military technologies and on civilian products, remains to be seen.

The Global Semiconductor Industry

Semiconductors or chips, also known as microchips or integrated circuits (ICs), are the foundation of our digitalized and electronic world, with both commercial and defence applications, and thus have received particular governance attention. Usually composed of silicon or gallium arsenide, they are fabricated as dies etched into a round wafer base. Each die consists of transistors that control the binary current of electricity. Following Moore's Law, every two years the quantity of transistors in an IC has roughly doubled while the associated costs have been halved. The more transistors an IC has, the greater its processing power; achieving more of this power is the main objective of the semiconductor industry.

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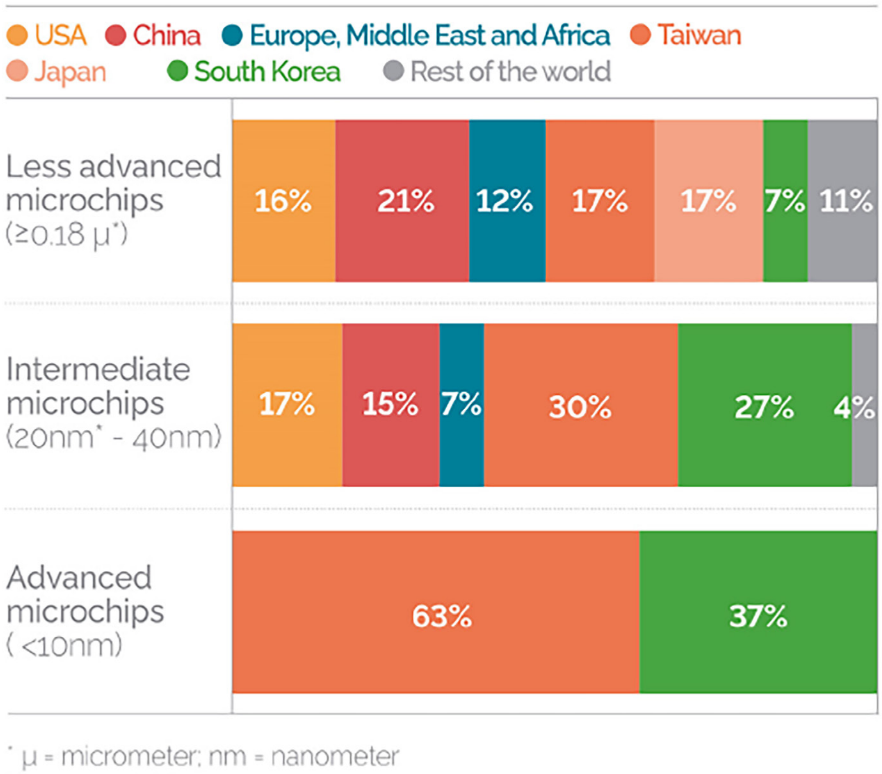
Because creating ICs requires expertise and is extremely capital-intensive, there are few competitors at the leading edge. Most chip technology is produced by only a handful of countries outside China and the United States: Taiwan, Japan, the Republic of Korea, and the Netherlands. The United States is now attempting to ensure that non-Chinese producers follow its lead. Interestingly, the most advanced chips are typically not manufactured in either the United States or China, even though they are often designed there. Consequently, the countries that manufacture these advanced chips are of great interest to both nations.

Despite a record distribution of 1.15 trillion semiconductor units worldwide, the global spread of COVID-19 caused a significant semiconductor shortage in 2021. Both national governments and industry recognized the need to develop more sustainable practices, including diversification of supply chains. Efforts to increase production seem to be working, with national policies aimed at the advanced "domestication" of chip manufacturing.

And, while global semiconductor revenue in 2023 was 11 per cent lower than in 2022, there is an expectation that, by 2030, chip-making companies in Asia, the United States, and Europe will have invested approximately a trillion dollars in new production facilities. Within the next decade, they could not only reshape the industry but also significantly redistribute the dynamics of global power.

Currently, Asian producers dominate semiconductor production. The United States and China are exploring various opportunities to increase their influence over top "chip-making tigers" Taiwan and the Republic of Korea, as well as lower-tier player Japan.

Figure 1: Chips: Asia leads the race



Source: Gili, Alessandro and Davide Tentori. "The Fight for Global Technology Leadership: A Matter of Geopolitics (and Industrial Policy Too)," p. 30 in The Comeback of Industrial Policy: The Next Geopolitical Great Game. Gili, Alessandro and Davide Tentori (Eds.) Milan: Ledizioni LediPublishing, 2024.

The chart demonstrates that Asia (including China, Japan, the Republic of Korea, and Taiwan) has a significant lead in production for all categories of microchip.

In addition to depicting significant imbalances in global chip production, the chart provides useful information about the context for chip consumption, providing data for an analysis of the economic and political confrontation between the United States and China as they attempt to bring other Asian producers of semiconductors under their umbrella. It is anticipated that, by 2030, China will consume more than double its production capacity, making it increasingly vulnerable and reliant on less advanced and intermediate chip producers. The United States and the European Union are also looking at gaps between production capacity and anticipated consumption. Meanwhile, Taiwan, with major production and minimal domestic consumption, will remain committed to its export market.

The COVID-19 pandemic starkly exposed the fragility of the semiconductor supply chain. As consumer demand for computers and smartphones surged due to stay-at-home orders, the industry faced immense pressure, resulting in widespread impacts. Automotive plants, unable to procure the necessary chips for their vehicles, were forced to furlough workers and shut down factories, highlighting the vulnerability of global production networks. The U.S. Department of Commerce estimated that the chip shortage cost the American economy $240 billion in 2021. The surge in demand is only one facet of the challenge elucidated during the pandemic; the bottlenecks in the supply chain constitute the other.

The specialization of the IC supply chain

The global IC supply chain is characterized by specialization and the division of labour. IC production consists of three main stages:

1. IC design and blueprinting;
2. fabrication of wafers and the dies on them by foundries; and
3. assembly and packaging.

Elements in each stage are controlled by a limited number of actors. American firms focus on designing ICs and the software needed to create them. Taiwan Semiconductor Manufacturing Co. Ltd. (TSMC) and Samsung (Republic of Korea) produce ICs with the smallest transistor sizes (gate length of 7 nanometres [nm] and less). Japanese companies produce the chemicals necessary for production and assembly. American and Japanese companies also produce semiconductor manufacturing equipment (SME); SME production represents a secondary choke point in the IC supply chain.

ASML's extreme ultraviolet (EUV) lithography technology is critical to the physical production of chips made from silicon wafers. EUV lithography is currently the most advanced form of photolithography, capable of etching dies using wavelengths of light measuring 13.5 nm; the shorter the wavelength, the more complex the chip that can be designed. ASML's EUV lithography technology is necessary to make transistors less than 7 nm in thickness, and is sought by any company—or country—aiming to establish themselves at the pinnacle of the AI space. ASML is currently the only company that makes EUV equipment, providing another chokehold.

Training AI on the most advanced chips is also capital-intensive. While accessing less advanced technology, such as chiplets, can be more affordable per unit and less restricted, overall expenses for training AI on chiplets can be even higher, as well as more time-intensive and less reliable.

China has its own strong assembly industry, but Chinese firms, such as SMIC, use technology that is several years out of date, resulting in their falling behind main competitors in the Republic of Korea and Taiwan.

The United States–China Competition

No country is currently near self-sufficiency or technological sovereignty in the production of ICs. Both China and the United States rely heavily on other nations for backend production. Indeed, suppliers in Asia have steadily replaced American companies that have offshored fabrication, while pursuing IC design and software. In 1990, American companies produced roughly 37 per cent of the world's semiconductors; today, they produce 12 per cent.

The United States is thus heavily reliant on foundries abroad to meet its demand for advanced semiconductor fabrication. In the absence of serious external supply shocks, U.S. policymakers have tolerated such specialization and division of labour and instead opted to consolidate American technological dominance in research and development, IC design, and semiconductor design software. For China, the dependency on the United States is also important. Some 80 per cent of SMIC equipment comes from the United States.

But this interdependency is now causing anxiety in Beijing, Washington, and other capitals.

The CHIPS and Science Act

On August 9, 2022, the Creating Helpful Incentives to Produce Semiconductors and Science Act (CHIPS Act) was signed into law by U.S. President Joe Biden. The act provides funds for programs and activities that enhance and secure American leadership in the semiconductor space while simultaneously blocking resources from, and partnerships with, tech companies in China and other "countries of concern."

The CHIPS Act is meant to provide

1. incentives and subsidies for the fabrication of semiconductors and semiconductor production equipment;
2. resources to support research and workforce training, most of which would be led by the Commerce Department;
3. minor additional funding for related security, collaborative, and supply-chain programs.

In total, $54.2 billion (U.S.)[1] was appropriated by the CHIPS Act, including $39 billion in subsidies for American semiconductor fabrication and $11 billion for a series of research and development programs. Other funds provide resources for Department of Defense semiconductor initiatives, allow the Department of State to coordinate and communicate with foreign partners, and support microelectronics workforce development and education. A report from the Center for Strategic & International Studies indicated that this Act and related actions "demonstrate an unprecedented degree of U.S. government intervention to not only preserve chokepoint control but also begin a new U.S. policy of actively strangling large segments of the Chinese technology industry."

The CHIPS Act also authorizes the Commerce Secretary to grant awards up to $3 billion (more with supplementary approval) to various public and private entities for the fabrication, assembly, testing, advanced packaging, and development of semiconductors. Notably, the Act provides few explicit resources for the design of semiconductors, ostensibly because American firms already have a strong market presence in design and design software.

It is also worth noting that as part of the Act, the U.S. Congress authorized a 25 per cent tax credit for the purchase, construction, or maintenance of equipment and property for advanced IC manufacturing. This provision was adopted from a previous proposal, the Facilitating American Built Semiconductors (FABS) Act. The Congressional Budget Office expects

1 Unless otherwise noted, all figures are in U.S. dollars.

roughly $24 billion in such tax credits to be granted through fiscal year 2031.

Several initiatives are expected to bolster American research and development:

- With $2 billion in funding for FY2022, the National Semiconductor Technology Center has been coordinating innovation, development, and resource mobilization for American advanced IC procurement in conjunction with other public institutions and private actors. This activity represents another attempt by the White House to combine public and private efforts in the Great Power competition, loosely mirroring Beijing's Military-Civil Fusion policy but in a specific domain.
- The National Advanced Packaging Manufacturing Program, which received $2.5 billion for FY2022, has focused on improving advanced packaging efforts, particularly chiplet, photonic, and heterogenous integration.
- The National Institute of Standards and Technology was granted $500 million in FY2022 to focus on microelectronics, materials science, and instrument breakthroughs.
- As many as three "Manufacturing USA" institutes (granted $500 million in FY2022) are to be created to promote advances in machinery and training in industry-relevant skills. As the United States attempts to drastically scale up fabrication and assembly capabilities, these institutes will promote the automation of machine maintenance and facilitate the creation of a pool of skilled workers.

China's response

The imposition of intellectual property sanctions and export controls by states aligned with the United States pushed the Chinese semiconductor industry to make large investments in chiplet technology years before their competitors. Powerful ICs were replaced with smaller, cheaper dies packaged together to increase computing power. While this "advanced packaging" of chips, also known as a multi-chip module (MCM) or a system in package (SiP), has been on the market since the 1980s, IC designers have thus far preferred to push the limits of transistor quantities on dies rather than rely on higher quantities of lower quality chips.

But now designers are finding it increasingly difficult to keep pace with Moore's law. It is now costing significantly more in money and expertise to make top-of-the-line transistors smaller. Moore himself predicted that it might become "more economical to build large systems out of smaller functions which are separately packaged and interconnected."

Chinese investment in chiplet assembly rose from $1.7 billion in 2018 to $3.3 billion in 2021. Meanwhile, Huawei applied for 900 chiplet-related patents in 2022, up substantially from 30 applications in 2017. More than 20 Chinese government policy documents highlight chiplet technology as important for China's capabilities in "key and cutting-edge tech." One such document, published by an outlet affiliated with the Ministry of Industry and Information Technology, urged Chinese tech firms to use "Chiplet technology to break through the United States' siege of [China's] advanced process chips."

Chiplet patents from a Silicon Valley startup sold to Chinese investors in 2021 reappeared in the portfolio of Chinese startup Chipuller just over a year later. Yang Meng, chairman of

Chipuller, has called chiplet tech the "core driving force for the development of the domestic semiconductor industry."

U.S. 2023 sanctions against China set the stage for further counteractions by Beijing. In July 2023, China announced new export licensing requirements for gallium and germanium, metals crucial in high-frequency and high-temperature semiconductor applications. This move was seen as retaliation, especially after TSMC announced plans to build fabrication facilities in Arizona. China controls approximately 98 per cent of the world's gallium and 68 per cent of the world's refined germanium production. By placing export restrictions on both metals, China has highlighted its strong position in the global semiconductor supply chain and messaged that its quest for technological sovereignty is seen in its control over resources.

ASML and the Middle Powers' Dilemma

As the home of ASML, one of the most important semiconductor companies in the world, the Netherlands is especially affected by the competition between the United States and China. ASML's monopoly on EUV lithography equipment seems likely to continue for some time. Both the development and application of EUV lithography are extremely capital intensive and require very specific expertise in multiple niche fields in electrical engineering. It is hard to believe that another company will soon successfully create a new version of EUV lithography or design technology that could surpass the tech produced by ASML. Thus, any company interested in producing the most advanced chips needs EUV lithography technology and must develop an ongoing direct or indirect relationship with ASML.

An EUV machine is a significant investment for a semiconductor production company (or foundry) like TSMC, Samsung, or Intel. Along with a multi-million-dollar price tag, buyers must pay for the services of multiple 747 aircraft to transport the components of the technology and permanent ASML staff to operate it. In December 2023, ASML sold its newest High NA EUV lithography machine to TSMC for 350 million euros ($380 million), making a 'standard' EUV machine a steal at only 200 million euros.

While a foundry may assert that sufficiently advanced chips are achievable even without the newest lithography technology, the market consensus maintains that the most direct route to the best chips begins with the technology that can most efficiently make the smallest transistors. EUV lithography continues to be produced, in most cases exclusively, by ASML.

U.S. pressure on ASML

In early 2018, the United States learned that the Dutch government had approved a licence for ASML to export an EUV machine to a customer in China. Over the next year and a half, the U.S. government tried to convince the Netherlands to impose export controls that would prevent Chinese access to EUV technology and so inhibit China's development and training of advanced AI programs. In late 2019, the Dutch government refused to renew ASML's export licence, effectively quashing the sale of the machine then valued at $150 million.

While the media looked for evidence that the Netherlands had bowed to American pressure, the Dutch government cited national security reasons for blocking the sale. Even with these restrictions, in place since 2019, ASML has been able to export to China lower-quality systems that do not use EUV lithography.

Dutch news media also reported on possible Chinese espionage at ASML in 2019. Four years earlier there had been a robbery at ASML; former employees working with Silicon Valley company XTAL "misappropriated" ASML intellectual property. ASML was awarded $223 million after XTAL was found guilty in 2018 by the Santa Clara Superior Court.

However, the nationalities of some of the guilty individuals, as well as XTAL funding sources, led the Dutch press to publish speculative reports about ASML's security as well as their business relationship with Chinese companies. ASML responded with press releases that challenged the characterization of the theft as evidence of espionage, claiming that "no evidence was found of any direct Chinese government involvement in this matter."

The CHIPS and Science Act in August 2022, combined with additional major export controls on the transfer of American AI and semiconductor technology to China the following October, signaled the U.S. objective to further restrict China's access to technology. In early 2023, the U.S. government asked the Netherlands to impose additional export restrictions on ASML products to China as a step to reaching the benchmark set by the U.S. export restrictions introduced in October 2022.

On June 30, 2023, the Dutch government announced additional restrictions on the "most advanced" technology related to semiconductor production. This expansion of 2019 restrictions includes previously permitted older generations of ASML's advanced photolithography technology. The new policy is described as "country-neutral" and Dutch Trade Minister Liesje Schreinemacher explained that the move was motivated by national security interests. China claimed that the restrictions were "completely unreasonable and untenable" and sales at ASML fell by 42 per cent from July to September of that year. However, China still accounted for approximately 46 per cent of ASML's total sales for the company's third-quarter, as customers anticipated restrictions coming into force on September 1.

Some analysts argue that China will commit more resources to developing its own chip-manufacturing technology. However, because of the enormous investment of capital and resources that would be required, the market seems to expect that ASML will retain its control over this narrow, yet vital, space of advanced chip manufacturing.

Implications for other U.S. allies

The case of ASML is unique and might not accurately reflect activity in the rest of the supply chain. But it is the case that other, smaller players in the semiconductor space have become involved in U.S. responses to China. Japan introduced export controls on 23 types of chipmaking gear in March 2023; while China was not named when the new restrictions were announced, Japan did note that manufacturers would need to request permits for exports to all regions.

Canada is generally seen to have fallen behind in the development of, and investment in, semiconductors. While it dedicated Can$36 million in 2023 to supplement the Can$250 million promised in 2022, these amounts are not sufficient to develop sophisticated chip technology. In 2024, Canada announced an additional Can$120 million over five years for a national chip network. Unable to match American efforts to protect their own semiconductor sector, Canada is focused on components that complement the U.S. chip sector, such as improved sensor technology. Canada has already expressed its interest in solidifying its role in the packaging and testing of semiconductors in North America. In March 2023, Prime Minister Justin Trudeau met with U.S. President Joe Biden and announced a cross-border semiconductor manufacturing corridor. A key part of this effort is the IBM Canada semiconductor advanced packaging facility in Bromont, Quebec. The facility is the largest manufacturing facility of its kind in North America. Canada is therefore keen to ensure its role in the semiconductor supply chain for North America.

Such a decision means that the competition between the United States and China, likely to include further export restrictions, will have an important effect on Canada's semiconductor sector. Canada's own diplomatic relationship with China remains fraught and so Canada will have few options as it develops its own emerging technologies sector. It is certainly possible that accessing certain raw materials and technologies will become increasingly difficult.

Canada and other U.S. allies might find that the net of the Great Power competition widens to include materials and technological components that they produce and which have nothing to do with semiconductors—even technologies that are currently in early research phases. Therefore, it is important to understand the ways in which other middle powers have survived in this high-stakes game.

Conclusion: When Giants Clash

Semiconductors play a key role in the modern global economy; it is in everyone's interest to ensure that the United States and China find ways to resolve disputes about chips without causing massive shocks to the global economy. Given China's expressed policy of military-civil fusion, it is likely that the United States will continue to use tools such as export controls to limit China's access to chips.

Middle powers, including Canada, could find themselves on shifting ground. While many share American concerns over China's diplomatic and military policies, they fear that continually providing U.S. companies with an edge in the sophisticated chip sector will negatively impact their own technological industry or that of other friendly countries. Allies will need to promote and encourage greater dialogue and diplomacy as further restrictions, however warranted, may not reflect actual security concerns.

The Great Power competition has also already affected certain regions. Reports indicate that the United States has slowed down exports of specific AI chips to the Middle East, citing concerns over potential diversion to China. Nonetheless, these export restrictions are likely to impact the region's industry.

The current dynamic goes far beyond a race between the United States and China to control the semiconductor market. At its heart is the desire of key and secondary chip players to establish new benchmarks for national security, economic stability, and technological advancement. Semiconductors are at the heart of this effort. In such a challenging landscape, the need for forward thinking, collaborative problem-solving, and strategies that balance domestic and international goals is undeniable.

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