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Opinion

Can China achieve semiconductor self-sufficiency?

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Recently, Japan unveiled new export control measures for chipmaking equipment, encompassing twenty-three items across six categories, including lithography, etching, cleaning, deposition, and masking. While the specific targets of these measures were not explicitly mentioned, it is evident that China, being the largest importer of chipmaking equipment since 2020 and accounting for close to 40 percent of Japanese chipmaking equipment exports in 2021, is likely one of the intended targets.

The actions taken by Japan can be interpreted as a strategic alignment with the US-led 'Chip-4 Alliance,' aiming to curb China's semiconductor industry. An important question emerges: Will these measures effectively contain China, enabling the US-led chip alliances to maintain their strategic advantages, or will they trigger a new crisis for the chip industry by inadvertently providing China with an opportunity to accelerate its collective efforts toward achieving chip self-sufficiency?

Chips are pivotal to a nation's economic growth, societal advancement, and national security, acting as the 'brains' or controlling units of modern society. They are especially critical for emerging technologies such as artificial intelligence, quantum computing, and big data analytics, which are key determinants of a country's future technological competitiveness. Moreover, chips embody military-civil fusion technologies that can be employed in the development of advanced weaponry. Consequently, mastery over chipmaking supply chains has emerged as a central point of contention in the intense competition between the United States and China, two global powerhouses in a race for technological supremacy.

The US-led restrictions on China have prompted a shift in priorities within the semiconductor industry. National security is now taking precedence over economic efficiency, which was based on the global production network in chipmaking. These restrictions, which began under the Trump administration and have been reinforced by the Biden administration, include technological sanctions and export controls that prevent Chinese tech firms from acquiring advanced chips and restrict China's access to key technologies and personnel in chipmaking. Amid escalating economic nationalism and in response to the 2021 supply chain disruptions in the automotive industry, the US-led semiconductor alliances have enacted industrial policies to ensure the security of their chip supply chains. Such steps underscore the escalating concerns not just about safeguarding but fortifying national security as nations aim to preserve their sovereignty in an uncertain global landscape where trust and compliance with a rules-based order are on the decline. The fundamental premise here is that advanced technologies and equipment in chipmaking should not be supplied to countries that could potentially employ them to challenge the democratic world.

How far is China from self-sufficiency?

Following these restrictions, China is grappling with significant 'chokepoints' that are stymieing its advancement in the semiconductor industry. As a relative latecomer to the field, China is at risk of falling further behind, particularly in next-generation technologies, if these chokepoints stay in place. This 'chokepoint strategy' – akin to a kung fu master quickly executing a single sword move to sever their adversary's throat – can readily be employed in warfare or geopolitical disputes. Here, a country or organization can identify and exploit vital points or bottlenecks – like a critical resource, transport route, or technology – in the competitor's value chain. This metaphor vividly illustrates the risk of China being stifled or strangled, thereby hindering its ability to effectively compete and keep pace with the industry leaders in semiconductors.

The crux of the chokepoint strategy is that the party employing this strategy – in the case of semiconductors the United States and its allies – has monopolistic control over these chokepoints. By exercising this control, the United States and its allies can potentially disrupt the progress of China in chipmaking.

China has recognized the threat of chokepoints in its industrial capabilities. In 2018, the nation identified thirty-five technologies/products that could be subject to chokepoints. Advanced chipmaking tools and materials were included on this list. Fast forward five years, and with the United States and its allies having tightened their control over the chokepoints in China's chipmaking, how prepared is China for self-sufficiency?

A simple response is 'not much,' despite China having made certain strides in the domestic supply chain. Chinese start-ups span nearly all subsectors, from design software and databases to manufacturing equipment and semiconductor materials. However, regarding domestic substitution, the readiness is below 5 percent in most areas so far.

To upgrade its capacity for mature processing mode chipmaking, the Semiconductor Manufacturing International Corporation (SMIC) has invested in four additional foundries in Shanghai, Beijing, Tianjin, and Shenzhen since 2021. Although SMIC asserts that it can theoretically produce advanced 14nm chips using its existing DUV lithography systems, it is a considerable distance from reaching mass production. In the capital- and technology-intensive chipmaking industry, achieving mass production at a high yield rate is critical, as it can effectively lower the cost per chip. Transitioning to mass production and reaching a high yield rate requires significant time, manpower, and capital investment, provided the necessary equipment and tools are accessible.

The advanced lithography machine is a significant chokepoint in China's chipmaking capability. In this area, domestic substitution is currently less than 1 percent. ASML, based in the Netherlands, remains the sole supplier of EUV lithography machines, which are vital for advanced chipmaking. Immersion DUV lithography machines, produced by both ASML and Nikon from Japan, are likely to be added to the export restriction list, which could trigger a significant upheaval in China's chipmaking capability. Shanghai Microelectronics, a domestic competitor, can currently manufacture lithography machines that only support mass production of chips using a 90nm or larger processing mode.

China has made notable progress in the field of etching machines, achieving about 10 percent domestic substitution. China's Advanced Micro Fabrication Equipment Company is the first in the country to produce etching machines for advanced chipmaking. With the use of domestically produced lithography and etching machines, and through multiple exposures, it is feasible for China to manufacture chips with a 65nm processing mode or smaller at a large scale with high yield rates. These domestically produced machines can meet the production needs of most chips used in military applications, power management, LCDs, Wi-Fi, automobiles, and a wide array of consumer electronic systems.

Electronic Design Automation (EDA) tools represent another significant chokepoint in China's chipmaking endeavours. Under the influence of US sanctions, Huawei has found itself unable to update its EDA software, despite holding permanent EDA licenses. There have been reports of Huawei developing its own EDA tool, yet its efficacy and market acceptance remain uncertain.

Semiconductor materials could potentially become chokepoints if Japan implements export control measures. Out of the nineteen core semiconductor materials, Japanese companies command a market share of over 50 percent in fourteen. For instance, Japanese companies dominate the worldwide supply of photoresist used in lithography, holding over 85 percent of the market share. Amid the Japan-Korea trade dispute in 2019, Japan, by restricting the export of three types of materials to South Korea, instigated a disruption throughout the entire semiconductor value chain. China has progressed in low-end photoresist production, but still heavily depends on Japanese imports for almost all high-end photoresists. Due to these reasons, Japan's export control measures are interpreted as targeting China in a more systemic and precise fashion than the US-imposed sanctions.

A chaotic future?

While these restrictions may hinder China's progress in chipmaking, their long-term effectiveness remains uncertain. Chips are highly complex products that require deep technical expertise in both hardware and software, and they rely on a tightly woven global production network.

The sophistication of chipmaking is evident in the significant investment in research and development. In 2021 alone, the industry invested a total of $71 billion in research and development (R&D), which overshadowed the total investment by China's 'Big Fund' of $51 billion since 2014. The R&D investment has been fuelled by the global innovation ecosystem, where customer demand for high-performance chips has been a driving force behind advancements in chip design and manufacturing. Nvidia, as an example, initially focused on providing GPUs (graphics processing units) for the gaming industry but has expanded its applications to other areas. Its growth has been propelled by increasing user demand in graphics-intensive gaming, bitcoin mining data analytics, and AI training and inference tasks. The CEO of Nvidia, Jensen Huang, has expressed concerns that being unable to access the Chinese market would significantly limit their opportunities for growth as China remains its largest market in gaming and data centres.

The global production network in chipmaking is constantly evolving, with companies striving to enhance their positions by acquiring new capabilities and engaging in higher value-added activities. Throughout history, there have been three major shifts in the chipmaking industry, each involving the relocation of lower value-added segments of the value chain to emerging economies or regions. In the first shift, chip manufacturing was transferred from the United States to Japan, while the United States maintained its dominance in chip design and intellectual property. The second shift witnessed Japan retaining higher value-added segments in materials and equipment, while manufacturing and packaging were transferred to South Korea and Taiwan. In the third shift, South Korea solidified its position in memory and display semiconductors, Taiwan specialized in foundries, and China took on the lower value-added packaging and manufacturing of chips of mature process mode. Each of these shifts not only led to industry restructuring but also redefined the structure of the value chain, creating opportunities for latecomers to bridge the gap. However, it should be noted that each of these shifts was generously supported by their respective governments in terms of policy and capital.

China frequently comes under criticism for its use of industrial policy and subsidies to support its domestic technology sector. However, despite these measures, China has been unsuccessful in significantly enhancing its semiconductor sector using its industrial policy.

Reflecting on the situation, several factors have hindered China's progress in chipmaking. Apart from a deficiency in capital and talent within the industry, the largest barrier to China's advancement is the absence of effective synergy among its upstream and downstream players in the value chain. Chips function as intermediate goods in the production of electronic and electric devices, a sector where China has a significant global presence. To maintain their competitiveness, Chinese downstream manufacturers have favoured imported chips, which are cheaper, more powerful, and more energy-efficient than their domestically produced counterparts. Similarly, design tools struggle to secure orders from local chip designers; and domestic design software and IP, equipment, and materials face obstacles in being adopted by local foundries, as they often prefer superior imported alternatives. This lack of industry-level coordination stunts technological progress and results in disjointed industrial development.

The current structure of the semiconductor value chain is highly interdependent, though value distribution is uneven. The United States holds the largest market share (47 percent), primarily in chip design and core IP. It's followed by South Korea, Taiwan, Japan, and China (as of 2021). Specialized equipment manufacturers, who operate within a niche but highly protected market, can only survive within this global network. For instance, ASML has investments from several downstream companies within the network. Despite its monopoly, ASML only garnered about 6.5 billion euros in 2022, making up less than 2 percent of the total semiconductor industry revenue. This structure of the value chain presents formidable barriers to latecomers, such as China, who are seeking to gain a foothold in the market.

Now, technology sanctions and export controls have inadvertently opened a window of opportunity for Chinese firms to catch up. In response to the chokepoint strategy, the Chinese semiconductor industry is forced to strive for self-sufficiency by fostering interdependent relationships within the ecosystem. The timing also works in favour of Chinese enterprises. Had the sanctions been imposed a decade ago, Chinese companies would have had limited technological accumulation to enable catching up. Over the past ten years, however, China's investments in nearly every subsector of chipmaking have witnessed rapid generational upgrades within closed feedback loops, bolstered by collective investment from a wide array of players such as the government, tech companies, digital platforms, and downstream manufacturers. Thus, China is poised to stimulate a catch-up in chipmaking.

Reflections

Predicting a specific timeframe for China's catch-up in semiconductors is challenging. However, a complete stifling of progress is unlikely. Geopolitical disruptions, coupled with technological upheavals, have led to reduced stability and predictability. Indeed, the 'chokepoint strategy' carries its own set of challenges and risks. It may inhibit global cooperation and innovation and stall the overall growth of the semiconductor industry, potentially affecting Western participants. Moreover, it could provoke retaliatory actions from targeted adversaries, further destabilizing global supply chains, and potentially leading to escalating conflicts or even warfare.

For China, maintaining an open mindset in chipmaking is vital. The sector stands to benefit from the diverse inputs of all stakeholders. Furthermore, China needs to strike a delicate balance between competition and cooperation with its foreign competitors whenever possible. Regrettably, self-sufficiency often runs the risk of leading to self-isolation.

For Japan, the export control measures could potentially impact bilateral relations and may escalate trade tensions, especially considering the historical conflicts between Japan and China. Japan is a significant trading partner for China, and the Chinese market remains vital for Japanese manufacturers in semiconductors. In retaliation to Japan's alignment with the United States in curbing China's chipmaking, Beijing could consider restricting the export of critical minerals to Japan and Chinese consumers could potentially organize boycotts of Japanese products, as they have during previous bilateral conflicts.

Worst of all, an intensification of the chip wars could potentially lead to a complete decoupling in technology. Such technological decoupling entails not just the separation of supply chains, but also the establishment of different technological standards, innovation ecosystems, and markets by the disconnected parties. This could bear significant economic and social repercussions.

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