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Testimony before the Strategic Technologies and Advanced Research (STAR) Subcommittee, United States House Permanent Select Committee on Intelligence "Microelectronics: Levers for Promoting Security and Innovation"

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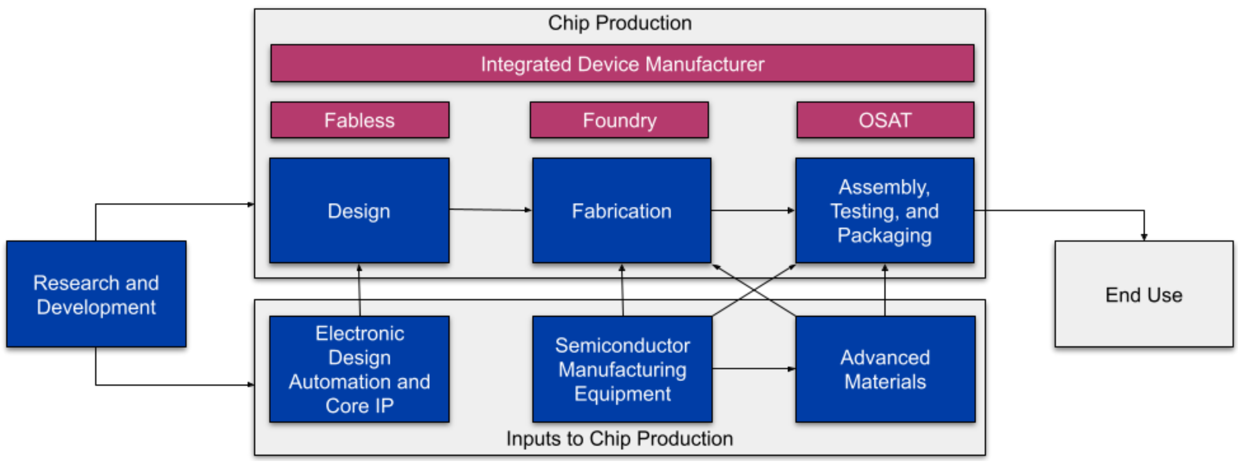
Chairwoman Speier, Ranking Member Stewart, members of the subcommittee: Good morning, and thank you for the opportunity to speak today. I am a research analyst specializing in semiconductor policy at the Center for Security and Emerging Technology (CSET), a nonpartisan think tank at Georgetown University that studies the security implications of new technologies.

I will address three topics. First, I will offer an abbreviated history of the semiconductor industry in the United States, and the incumbency advantages that we still have today as a result. Second, I will discuss policy levers that can help to promote U.S. advantages throughout the semiconductor supply chain. I will argue that while funding the CHIPS for America Act is an important step, long-term success in microelectronics depends equally on leveraging our strengths through investments in emerging microelectronics research, workforce development, and high-skilled immigration. Third, I'll identify ways Congress can protect the fruits of these efforts through export controls and research security, supported by robust open-source intelligence.

The United States enjoys an incumbency advantage in the semiconductor supply chain. In 1947, Bell Labs researchers William Shockley, John Bardeen, and Walter Brattain created the first transistor — a device that could switch or amplify electronic signals, which remains the basic building block of all modern electronics. Researchers trained by Shockley went on to found a string of new semiconductor firms in the Mountain View area. These companies, including names such as Intel and AMD, began cramming more and more transistors onto wafers of silicon, to serve a growing global market for electronics. The area in which they proliferated became known as Silicon Valley.

Since 1947, semiconductor manufacturing has evolved into a global industry worth more than $400 billion, powering everything from computers to smartphones to U.S. weapons systems. The industry is supported by one of the most complex supply chains in existence.[1] The process starts with pre-commercial research and development conducted in both universities and government- and corporate-funded labs. These insights are incorporated throughout the production process, which can be broken into three stages: design; manufacturing; and assembly, testing, and packaging (ATP). Firms called Integrated Device Manufacturers handle all three of these stages themselves. But many firms focus on just one stage, with fabless firms — that is, those that don't have fabrication capabilities — focusing on design, foundries focusing on fabrication, and Outsourced Semiconductor Assembly and Test firms focusing on assembly, testing, and packaging. Firms at all stages of chip production rely on a range of often-sophisticated inputs to manufacturing, including tools (referred to as semiconductor manufacturing equipment, or "SME"), materials (including "wafers" formed into chips), design software ("electronic design automation," or EDA, software), and intellectual property related to chip designs ("core IP").

Figure 1. The Semiconductor Supply Chain



Source[2]

Today, the United States remains dominant in research and development and retains a strong presence in virtually all high-value parts of the semiconductor industry — in particular, design, manufacturing, manufacturing equipment, EDA, and core IP.[3] However, the United States is weaker in certain key subsectors, especially photolithography tools (the most expensive and complex form of manufacturing equipment) and the most advanced chip factories (especially "foundries," which manufacture chips for third parties).[4]

Fortunately, U.S. allies also have strengths across the supply chain that complement our own. The Netherlands and Japan lead the world in photolithography equipment, while South Korea and Taiwan lead in advanced chip manufacturing. Europe (especially the Netherlands, the United Kingdom, and Germany) also specializes in other manufacturing equipment, advanced materials, and core IP.[5] Meanwhile, in addition to their strengths in manufacturing, South Korea is strong in materials and certain manufacturing tools,[6] while Taiwan is dominant in assembly, packaging, and test, and produces some materials.[7] Finally, Japan specializes in SME and materials, and it produces many legacy generations of semiconductors.[8]

China is a relative latecomer to the semiconductor industry. It has invested heavily in achieving semiconductor independence from the United States and its allies, but for now its strengths lie in the least-sophisticated parts of the supply chain: assembly, test, and packaging; tools for assembly and packaging; and raw materials.[9] China is also progressing in design and has considerable low-end manufacturing capacity (but no leading-edge capacity).[10] But China struggles especially in the most advanced production inputs, relying heavily on the United States and its allies for manufacturing equipment, electronic design automation software, core IP, and certain critical manufacturing materials.[11]

What can the United States and its allies do to promote their continued leadership in the semiconductor supply chain? An immediate priority for promoting U.S. semiconductor competitiveness is funding the CHIPS for America Act signed into law during the 116th Congress. Consistent, often extensive support from East Asian governments has contributed to the concentration of global semiconductor manufacturing capacity in South Korea, Japan, Taiwan, and China.[12] In particular, Taiwan currently manufactures almost all of the world's most advanced (sub-10nm) logic chips (the chips used for processing — as opposed to storing — data).[13] A disruption in Taiwan's chipmaking could have devastating economic consequences both in the United States and globally.[14] Funding for the CHIPS Act is only a first step toward addressing the fragility of the semiconductor supply chain, but it is a step worth taking given the real risks of natural or political disruptions in East Asia. An important subsequent step will be attempting to negotiate with China on limits on future subsidies, so that we do not wind up in a zero-sum race to the bottom.

Looking further ahead, we must double down on our strengths in microelectronics innovation by continuing to fund R&D. The CHIPS Act provides some funding for this purpose, but there are many areas in computing hardware that CHIPS Act funding will not address. I will offer two illustrative examples here. First, we are beginning to reach the limits of the current hardware paradigm that brought us the last several decades of progress in computing.[15] One especially important challenge is the growing amount of energy consumed by computing, which accounts for an increasing share of global electricity consumption.[16] This is a concern, for example, for the intelligence community, which relies on energy-intensive high-performance computers to perform encryption and other tasks.[17] Investing across a portfolio of novel, energy-efficient hardware paradigms should therefore be a priority for the United States over the next decade. IARPA's recent Cryogenic Computing Complexity program is a good example of the type of long-term research that could pave the way for commercialization of post-CMOS technologies a decade or more from now.[18]

Second, advanced chips specialized for particular tasks such as high speed machine learning lack some of the security features of general purpose computing chips.[19] To address this issue, which concerns the intelligence community, government in general, and many parts of the private sector, the U.S. government should invest in developing secure enclaves or other security guarantees for specialized AI accelerators.[20]

Of course, research funding will have little impact without the technical semiconductor talent needed to translate dollars into research. Strengthening the U.S. semiconductor workforce is therefore a critical priority. CSET research shows that approximately 40 percent of semiconductor workers in the United States are foreign-born[21]. This reflects a strength: as a hub of semiconductor innovation, the U.S. attracts more global semiconductor talent than any other country by far.[22] But it also reflects a stagnant pool of domestic talent. The number of American-born students in semiconductor-relevant graduate programs has flatlined since 1990, while the number of foreign-born students in these programs has more than doubled.[23] Foreign-born students now make up almost two-thirds of all graduates from U.S. semiconductor-related graduate programs.[24] To close the gap, the U.S. government must invest in workforce development, such as fellowships supporting American students to attend graduate school in electrical engineering and related disciplines.

While workforce development is critical to the long-term health of the industry, high-skilled immigration is the appropriate tool for addressing talent gaps in the near term.[25] To ensure the success of CHIPS for America funding, the United States should offer a capped number of visas with pathways to citizenship — perhaps 1,000 per year — to high-skilled Taiwanese and South Korean individuals with prior experience in the semiconductor industry. This would help meet the considerable specialized workforce demand that will be generated by new fabs established through the CHIPS for America Act.[26]

Policies to promote U.S. semiconductor innovation are vital, but equally important are policies to protect the fruits of that innovation. For example, the United States' ability to attract high-skilled global talent is a key advantage, but it also raises the possibility of rare but damaging cases of research espionage. The Chinese government has a vast infrastructure devoted to transferring S&T knowledge from the United States and other countries to Chinese researchers and firms.[27] A critical element of these technology transfer efforts is the Chinese diaspora, which the CCP mobilizes with a range of tools including talent recruitment programs and statesponsored technology "cooperation societies" located around the world.[28] With 120,000 Chinese students in U.S. STEM programs today and thousands of Chinese nationals working at U.S. semiconductor firms, the potential for technology transfer is real.[29] Transfers could range from IP theft or reverse engineering to the extralegal exploitation of open source information.[30]

To meet the scale of China's efforts, the United States must invest more resources in two priority areas relevant to research security. First, visa screening must be supported by robust open-source intelligence. This will require investment, but preventing theft through high-quality OSINT is far less expensive than attempting to repair the damage after theft has occurred. Second, much of the current U.S. effort to improve research security currently focuses on enforcing conditions for federally funded research related to transparency and conflicts of interest.[31] This effort, while important, is insufficient for an industry where the vast majority of research is privately- rather than federally-funded. The United States should establish a public-private partnership which would provide researchers on the frontlines, and their funders and managers, with open source information, security-related education and training, decision support resources, and a non-punitive interface with federal partners (when needed).[32] The institution would aim to empower scientists and technologists to ensure the security of their own work. Such an institution would also facilitate much-needed communication about research security among researchers, their institutions, and the public sector.[33]

Finally, China's heavy investments in semiconductor independence, including both subsidies and espionage, must be countered with export controls and investment controls targeting critical chokepoints without which China will be unable to manufacture leading-edge chips. The United States and its allies should control, with presumptive denial of licenses, advanced SME (especially extreme ultraviolet (EUV) photolithography and argon fluoride (ArF) immersion photolithography tools), advanced materials (photomasks and photoresists), and software necessary for China to build and use advanced chip factories.[34] Additionally, to ensure that U.S. export control policies remain effective and up-to-date, mapping and monitoring of the supply chain — especially inputs such as semiconductor manufacturing equipment — as well as vectors of technology transfer, should be prioritized in the National Intelligence Priorities Framework (NIPF).[35]

In summary, the United States and its allies have considerable advantages across the semiconductor industry. It is possible to sustain those advantages into the future. Investments in our semiconductor industry, such as those in the CHIPS Act, are key, but only a first step toward that end. Further steps must be taken to **promote** continued U.S. advantages as a global hub of semiconductor talent and innovation, while **protecting** those advantages with research security measures and export controls supported by robust open-source intelligence.

I thank the Committee for the opportunity to speak today and look forward to your questions.

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[1] For a detailed breakdown of national competitiveness across each part of the supply chain, see Saif M. Khan, Alexander Mann, and Dahlia Peterson, "The Semiconductor Supply Chain: Assessing National Competitiveness" (Center for Security and Emerging Technology, January 2021), https://cset.georgetown.edu/wp-content/uploads/The-Semiconductor-SupplyChain-Issue-Brief.pdf.
[2] Ibid
[3] Ibid.
[4] Ibid.
[5] Ibid.
[6] Ibid.
[7] Ibid.
[8] Ibid.
[9] Ibid.
[10] Ibid.
[11] Ibid.
[12] Antonio Varas, Raj Varadarajan, Jimmy Goodrich, and Falan Yinug, "Government Incentives and US Competitiveness in Semiconductor Manufacturing," Semiconductor Industry Association and Boston Consulting Group (2020), https://www.semiconductors.org/wp-content/uploads/2020/09/Government-Incentives-and-US-Competitiveness-in-Semiconductor-Manufacturing-Sep-2020.pdf.
[13] CSET analysis of World Fab Forecast data.
[14] Forthcoming CSET research.
[15] Note that the end of so-called CMOS scaling does not mean that computing progress will necessarily slow — there are many possible CMOS successor technologies, as outlined in the 2020 International Roadmap for Devices and Systems (https://irds.ieee.org/images/files/pdf/2020/2020IRDS_BC.pdf). But developing a new computing paradigm to the point where it can compete with latest-generation CMOS technology will be a serious challenge.
[16] Google, for example, now consumes more electricity than Zambia or Sri Lanka. Robert Bryce, "How Google Powers Its 'Monopoly' With Enough Electricity For Entire Countries," *Fortune*, October 21, 2020, https://www.forbes.com/sites/robertbryce/2020/10/21/googles-dominance-is-fueled-by-zambia-size-amounts-of-electricity/?sh=4ae774bb68c9.
[17] Bill Harrod, "Cryogenic Computing Complexity," https://www.iarpa.gov/index.php/research-programs/c3.
[18] Forthcoming CSET research shows that IARPA funding may have played a key role in galvanizing US cryogenic computing research productivity since 2016.
[19] Miles Brundage et al. "Toward Trustworthy AI Development: Mechanisms for Supporting Verifiable Claims," arXiv, April 15, 2020, https://arxiv.org/abs/2004.07213.
[20] Ibid.
[21] Will Hunt and Remco Zwetsloot, "The Chipmakers: U.S. Strengths and Priorities for the High-End Semiconductor Workforce." (Center for Security and Emerging Technology, September 2020), https://cset.georgetown.edu/publication/the-chipmakers-u-s-strengths-and-priorities-for-the-high-end-semiconductor-workforce/

[22] Ibid.
[23] Ibid.
[24] Ibid.
[25] Remco Zwetsloot and Will Hunt, "America's Supply Chain Needs High-Skilled Migrants," *Wall Street Journal*, May 28, 2020, https://www.wsj.com/articles/americas-supply-chain-needs-high-skilled-migrants-11590706977.
[26] Forthcoming CSET research.
[27] Remco Zwetsloot and Zachary Arnold, "Chinese Students Are Not a Fifth Column," *Foreign Affairs*, April 23, 2021, https://www.foreignaffairs.com/articles/united-states/2021-04-23/chinese-students-are-not-fifth-column.
[28] Ryan Fedasiuk and Emily Weinstein, "Overseas Professionals and Technology Transfer to China," (Center for Security and Emerging Technology, July 2020), https://cset.georgetown.edu/wp-content/uploads/CSET-Overseas-Professionals-and-Technology-Transfer-to-China.pdf
[29] Zwetsloot and Arnold, "Chinese Students Are Not a Fifth Column," and Hunt and Zwetsloot, "The Chipmakers."
[30] William C. Hannas and Didi Kirsten Tatlow, *China's Quest for Foreign Technology: Beyond Espionage* (Abingdon: Routledge, 2020), https://www.routledge.com/Chinas-Quest-for-Foreign-Technology-Beyond-Espionage/Hannas-Tatlow/p/book/9780367473570.
[31] "A New Institutional Approach to Research Security in the United States," Melissa Flagg and Zachary Arnold," (Center for Security and Emerging Technology, January 2021), https://cset.georgetown.edu/publication/a-new-institutional-approach-to-research-security-in-the-united-states/.
[32] Ibid.
[33] Ibid.
[34] Saif M. Khan, "Securing Semiconductor Supply Chains," (Center for Security and Emerging Technology, January 2021), https://cset.georgetown.edu/publication/securing-semiconductor-supply-chains/.
[35] Will Hunt, Saif M. Khan, and Dahlia Peterson, "China's Progress in Semiconductor Manufacturing Equipment" (Center for Security and Emerging Technology, March 2021), https://gtacexperts.com/wp-content/uploads/2021/04/CSET-Chinas-Progress-in-Semiconductor-Manufacturing-Equipment.pdf.