U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
HEARING CHARTER

Ensuring American Leadership in Microelectronics

Thursday, December 2, 2021
10:00 am – 12:00 pm
Zoom

PURPOSE

On Thursday, December 2, 2021, the Committee on Science, Space, and Technology will hold a hearing to examine the status of U.S. leadership in advanced semiconductor development and manufacturing; to discuss how new investments and partnership models can support continued U.S. leadership; and to explore the role of the federal government in supporting domestic semiconductor innovation and manufacturing throughout the supply chain.

WITNESSES

- **Dr. Ann Kelleher,** Executive Vice President and General Manager of Technology Development, Intel Corporation
- **Mr. Manish Bhatia**, Executive Vice President, Global Operations, Micron Technology, Inc.
- **Dr. Michael Witherell**, Director, Lawrence Berkeley National Laboratory
- **Dr. Mung Chiang**, Executive Vice President and John A. Edwardson Dean, College of Engineering, Purdue University

OVERARCHING QUESTIONS

- What is the state of U.S. leadership in advanced microelectronics R&D and manufacturing in the United States?
- Why is it important for the United States to maintain leading capabilities in both R&D and manufacturing of advanced microelectronics? What are the consequences of a loss of leadership?
- What is the appropriate role of the Federal government in supporting microelectronics research, innovation, and domestic manufacturing? How can the Federal government most effectively partner with the private sector and the research community?
- To what extent does the *CHIPS for America Act* address what is needed to maintain U.S. leadership in microelectronics innovation? Are any updates to CHIPS or additional legislation necessary to ensure a coordinated, transparent and effective Federal partnership with the private sector, universities, and National Labs to advance U.S. microelectronics innovation and manufacturing?

MICROELECTRONICS OVERVIEW

Advanced microelectronics are a primary driver of economic growth and scientific advancement. Microelectronics is a term describing all aspects of the miniaturization of electronic circuits and components, from fundamental research to design to manufacturing. Semiconductors are a subset of microelectronics. Most modern semiconductors are integrated circuits, also called “chips”, which are sets of miniaturized electronic circuits composed of active discrete devices (e.g., transistors), passive devices (e.g., capacitors), and their interconnections, all of which are layered on a thin wafer of semiconductor material (e.g., silicon). These chips enable nearly everything in our modern lives —from smartphones and cars to nuclear weaponry.

Semiconductors can be classified into three major product groups based on function:[1]

- Microprocessors and Logic Devices are the integrated circuits functioning on binary codes (0 and 1) that are used for the interchange and manipulation of data in computing.
- Memory Devices are used to store information. This segment includes dynamic random-access memory (DRAM), a common type of memory used to store the data or program code needed by a computer processor to function.
- Discrete, Analog, and Other (DAO) semiconductors transmit, receive, and transform information dealing with continuous parameters, such as temperature. For example, analog devices are used to translate analog signals, such as light, touch, and voice, into digital signals. Discretes, such as transistors and diodes, perform a single electrical function on each chip.

MICROELECTRONICS INNOVATION IN THE UNITED STATES

The United States has a long history of innovation in microelectronics. U.S. government investments in research helped lead to the invention of early computers and transistors in the 1940s, as well as the first integrated circuit in the 1950s.[2] In the 1980s, the rapid rise of Japan’s semiconductor industry led the federal government to establish a research consortium to support U.S. competitiveness in semiconductor technology, also known as SEMATECH. From 1988 through 1996, Congress provided approximately $870 million to SEMATECH through the Defense Advanced Research Projects Agency (DARPA), which was generally matched by industry contributions.[3] While the Government Accountability Office found that SEMATECH had a significant impact on U.S. semiconductor manufacturing and R&D performance,[4] the SEMATECH board of directors ultimately declined additional federal funding in 1996 and the consortium was later absorbed into the New York Polytechnic Institute in 2015.

[1] Antonio Varas et al., “Strengthening the Global Semiconductor Supply Chain in an Uncertain Era,” Semiconductor Industry Association, April 2021.
[2] Michaela Platzer et al., “Semiconductors: U.S. Industry, Global Competition, and Federal Policy,” Congressional Research Service, October 26, 2020.
[3] Ibid.
[4] “Federal Research: Lessons Learned from SEMATECH,” U.S. General Accounting Office, September 28, 1992.

The Federal Government continues to invest in semiconductor research across many different agencies and mission areas. The U.S. semiconductor industry has continued to lead the world in R&D spending, investing nearly one-fifth of its annual revenue in R&D each year.[5] In 2020, the U.S. semiconductor industry investment in R&D totaled $44.0 billion.[6]

"Moore's Law"

The semiconductor industry has a rapid internal product development cycle. This was first described by Gordon Moore, then R&D Manager for Fairchild Semiconductor, in 1965.[7] Moore's law, as his observation later became known, states that the number of transistors that can be cost-effectively included on an integrated circuit will double every 18 months to two years, making chips smaller, faster, and cheaper. This observation held for decades, in part because of the industry's high level of research and investment spending. However, this two-dimensional scaling of the chip is reaching its physical limits as chip complexity has increased due to new applications such as artificial intelligence, 5G, and the internet of things. The industry can no longer rely solely on this process to make the necessary generational improvements that will enable future chip iterations, including breakthroughs in energy efficiency, new materials, are more.[8] Long term grown will require fundamental breakthroughs in microelectronics technology.

THE GLOBAL SEMICONDUCTOR LANDSCAPE

Semiconductor production includes three segments: (1) design, (2) manufacturing/fabrication, and (3) assembly, testing, and packaging (ATP). In some cases, these steps are all performed by a single company, called an integrated device manufacturer (IDM). Major U.S. headquartered IDMs include Texas Instruments, Intel, and Micron. Other semiconductor companies, called fabless firms, only do design in-house. Fabless firms purchase fabrication services from a semiconductor factory and ATP services from an outsourced semiconductor assemble and test company. Semiconductor factories, also referred to as fabs or foundries, are often characterized by the size of the wafer that chips are printed on and the size of the transistor gate length printed on each chip.[9] Only a small number of fabs—none of which reside in the United States—produce the most state-of-the-art semiconductors. Additionally, the semiconductor production process requires several types of inputs, including materials, manufacturing equipment, software, and intellectual property, some of which is produced only outside of the United States.

While the Unites States is the current global leader is semiconductor sales and R&D, the competitive landscape for semiconductor development is shifting. In 2020, the U.S.

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[5] "2021 State of the U.S. Semiconductor Industry," Semiconductor Industry Association, June 2021.
[6] Ibid.
[7] Gordon E. Moore, "Cramming More Components Onto Integrated Circuits," *Electronics Magazine*, Vol. 28, No. 8, April 19, 1965, accessed through Georgia Tech.
[8] "The Decadal Plan for Semiconductors" Semiconductor Research Corporation, January 2021.
[9] Platzer et al., "Semiconductors: U.S. Industry, Global Competition, and Federal Policy."

semiconductor industry accounted for 47 percent of global semiconductor sales.[10] Furthermore, the United States leads in many parts of the semiconductor market, including manufacturing equipment and semiconductor design.[11] However, over the last few decades, much of the U.S. manufacturing capacity has been offshored. The U.S. share of global semiconductor manufacturing decreased from 37 percent in 1990 to just 12 percent today.[12] Much of this capacity has moved to Taiwan, South Korea, and Japan, and China.[13] For example, Taiwan accounts for 47 percent of the global capacity to manufacture advanced logic semiconductors, such as those used in smart phones or data centers.[14]

China, which accounts for roughly 25 percent of global consumption of semiconductors (roughly equal to that of the United States), is also heavily investing in domestic semiconductor capacity.[15] China is investing $150 billion with the stated goal of gaining 40 percent of the world's new manufacturing capacity by 2030.[16] While the country remains two to three generations behind in advanced semiconductor manufacturing capacity,[17] China has demonstrated the ability to rapidly close technology gaps.

Supply Chains, Disruptions, and Shortages

Demand for semiconductor output has grown consistently over the last two decades, with the Semiconductor Industry Association (SIA) predicting a 19.7 percent increase in global sales in 2021 and a subsequent 8.8 percent increase in 2022.[18]

From design to final sale, a single chip can progress through more than 1,000 production steps and cross 70 international borders.[19] When businesses started to close due to the COVID-19 pandemic in 2020, there was an abrupt and cascading global shortage of semiconductors. This shortage was primarily caused by significant swings in demand throughout the pandemic. Chip manufactures first slowed production due to lockdowns and a reduction in demand from their customers, who canceled their chip orders assuming a lengthy economic downturn. However,

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[10] "2021 State of the U.S. Semiconductor Industry."
[11] Antonio Varas et al., "Government Incentives and U.S. Competitiveness in Semiconductor Manufacturing," Semiconductor Industry Association, September 2020.
[12] Ibid.
[13] South Korea specializes in all production steps, while Taiwan is dominant in most advanced manufacturing and ATP. Japan specializes in manufacturing equipment. European nations, especially the Netherlands, the United Kingdom, and Germany, specialize in manufacturing equipment, materials, and core IP. Currently, China is the leader in ATP and raw materials.
[14] Varas et al., "Government Incentives and U.S. Competitiveness in Semiconductor Manufacturing."
[15] Varas et al., "Strengthening the Global Semiconductor Supply Chain in an Uncertain Era."
[16] Stephen Ezell, "Moore's Law Under Attack: The Impact of China's Policies on Global Semiconductor Innovation," the Information Technology and Innovation Foundation, February 18, 20201.
[17] Debbie Wu et al., "Why the World Is Short of Computer Chips, and Why It Matters," *Washington Post*, April 21, 2021.
[18] "Global Semiconductor Sales Increase 1.9% Month-to-Month in April; Annual Sales Projected to Increase 19.7% in 2021, 8.8% in 2022," *Semiconductor Industry Association,* press release, June 9, 2021.
[19] Saif Khan, "The Semiconductor Supply Chain Assessing National Competitiveness," the Georgetown Center for Security and Emerging Technologies, January 2021.

chipmakers soon saw surging demand in other sectors as new activities become more commonplace, such as remote healthcare, work-at-home, and virtual learning. When economic forecasts proved wrong, the original customers re-ordered chips, creating a significant backlog.

Several other events spurred the shortage. Stockpiling by certain companies and industries before the pandemic—especially Chinese companies seeking to weather U.S. trade restrictions—further tightened supply. Natural disasters also impacted chip manufacturing. For example, a Renesas plant in Japan, which primarily serves car manufacturers, had its production significantly delayed due to a fire.[20] Finally, truck shortages and global shipping backups have significantly stalled inputs that go into the manufacturing of semiconductors and their delivery to the customer.

The shortage affected many downstream sectors, such as car manufacturing and consumer electronics. For example, a General Motors plant in Kansas City was closed from February to September due to a lack of chips.[21] Notably, many semiconductor firms are no longer manufacturing the types of legacy chips that are used in vehicles and home appliances, instead focusing capacity on cutting-edge designs. This trend has further exacerbated shortages. Some analysts believe that the most problematic chip shortages will begin to ease in the third or fourth quarter of 2021, but it could take through 2022 for shortages to end.[22]

THE CHIPS FOR AMERICA ACT

To re-shore chip manufacturing and to advance U.S. competitiveness in microelectronics, in December 2020 Congress enacted the *Creating Helpful Incentives to Produce Semiconductors for America Act, or the CHIPS for America Act*.[23] The *CHIPS for America Act* establishes a grant program at the Department of Commerce that would incentivize new domestic semiconductor manufacturing facilities and workforce development. It also creates a multilateral semiconductors security fund to support development of measurably secure supply chains, as well as a Department of Commerce study to analyze the capabilities of the U.S. industrial base to support the national defense in the light of significant global supply chain interdependencies.

The law also supports several research and development related activities. First, it establishes an interagency working group, advised by an industrial advisory committee, to develop a national strategy for semiconductor research and development. The Act directs the Department of Commerce to support semiconductor R&D through multiple mechanisms, including a National Semiconductor Technology Center (NSTC) to conduct research and prototyping of advanced

[20] "Japanese carmakers assess impact of fire at Renesas chip plant," Reuters, March 21, 2021.
[21] Carlos Moreno, "Workers Return To GM's Fairfax Plant On Monday, Months After Mass Layoffs," *NPR*, September 20, 2021.
[22] Samuel Moore, "How and When the Chip Shortage Will End, in 4 Charts," IEEE, June 21, 2021.
[23] Creating Helpful Incentives to Produce Semiconductors for America Act (CHIPS for America Act), Title XCIV, The William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021, H.R. 6395, 116th Congress.

chips, a Manufacturing USA Institute for domestic semiconductor manufacturing, and a center on advanced semiconductor packaging. The Act directs the National Institute of Standards and Technology (NIST) specifically to conduct metrology research to accelerate the development of next generation semiconductors. Finally, the Act requires the Department of Defense to establish a national network for microelectronics research and development to support prototyping new semiconductor technologies for commercialization—commonly referred to as the "microelectronics commons."

Funding for the CHIPS Act, a total of $52 billion over five years, has been passed by the Senate as part of the *U.S. Innovation and Competition Act* (USICA). The House has passed several pieces of legislation within scope of USICA. House and Senate Leadership have called for a formal conference on the package of competitiveness bills.

The Department of Commerce has expressed its intent to delegate authority for the grant programs authorized in CHIPS to NIST. NIST has significant technical expertise to build on but will need additional expertise and administrative capabilities and staffing to implement the programs. The agency has actively engaged with the private sector and other stakeholders for months, in anticipation of the CHIPS funding being enacted.

CONTINUING CHALLENGES TO U.S. LEADERSHIP IN MICROELECTRONICS RESEARCH AND MANUFACTURING

Driving Transformational Advancements

The coming end of Moore's Law, as previously stated, presents major technological challenges and opportunities for progress in microelectronics. Future progress and innovation will require an approach that advances relevant materials science; device technologies; processing and packaging technologies; manufacturing technologies; circuit, chip, and system architecture; and software system and algorithm development in a co-design fashion.

The Department of Energy (DOE) has a decades-long history of working directly with industry and academia to drive scientific advancements in the areas mentioned above. DOE's microelectronics research is underpinned by its National Laboratory complex, as illustrated by the Department's recent decision to provide $54 million to support National Laboratory-based projects to advance research in microelectronics.[24] These activities are part of a longer term, crosscutting microelectronics initiative that, as articulated by a 2018 report from the DOE Office of Science, exemplifies a "fundamental rethinking" in what is needed to advance "the science behind the materials, synthesis and placement technologies, architectures, and algorithms."[25] Key to the Department's justification for its ambitions in microelectronics are its scientific user

[24] "DOE Announces $54 Million to Increase Energy Efficiency in Microelectronics Technologies," U.S. Department of Energy, August 25, 2021.
[25] "Basic Research Needs for Microelectronics: Report of the Office of Science Workshop on Basic Research Needs for Microelectronics, October 23-25, 2018," U.S. Department of Energy.

facilities, which both rely on and help drive advancements in microelectronics. These facilities, which are utilized annually by thousands of academic and industry researchers, include particle detectors, microscopes, X-ray and neutron sources, data centers, networks, and high-performance computers.

Bridging the "Lab-to-Fab" Gap

There is a general concern that the United States has underinvested in maturing breakthrough ideas for semiconductor technology to the point of manufacturing them domestically. This "lab to fab" innovation gap, known generally as the "valley of death" for technological innovation, is the phase between developing a concept or a product and scaling it into a profitable innovation that the market adopts. This phase often leads to early-stage technologies being shelved indefinitely or prematurely abandoned.[26] Importantly, funding is not the only challenge in bridging the valley of death. Companies need access to facilities, tools, and personnel suitable for demonstrating the ability to produce an innovation at commercial scale. Even well-funded startups struggle to secure time at fabs and foundries to test their products, as they compete with larger companies for access.[27]

There is an earlier valley of death from fundamental research to prototyping. Many different government agencies and other groups support early-stage semiconductor research, from the National Science Foundation to the Semiconductor Research Corporation. However, many of these funding sources stop short of supporting prototyping. Only a few U.S.-headquartered companies have the resources, infrastructure, and expertise to translate basic research into commercial production. Venture capital firms have also drastically reduced their funding to hardware companies in recent years in favor of software-driven companies with fast time-to-market and low capital expenditures.[28] The DOD led microelectronics commons was conceived to address this earlier gap.

Maintaining Competitiveness in Advanced Packaging

In addition to manufacturing, the United States has lost market share in advanced packaging. This process, called assembly, testing, and packaging (ATP), involves cutting a finished wafer into individual chips. Each chip is mounted on a frame with wires that connect the chip to external devices and enclosed in a protective casing. Traditionally, ATP was shipped overseas to countries with comparatively low wages because it is the most labor-intensive part of the manufacturing process. As a result, U.S. industry currently only has 2 percent of the global market share in ATP services.[29] R&D in advanced packaging in the United States has also lagged as relatively few research institutions focus on the topic as a priority.

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[26] "Nanomanufacturing--Emergence and Implications for U.S. Competitiveness, the Environment, and Human Health," U.S. Government Accountability Office, May 19, 2014.
[27] "American Innovation, American Growth: A Vision for the National Semiconductor Technology Center (NSTC)."
[28] Dr. Walden Rhines, "Predicting Semiconductor Business Trends After Moore's Law," SemiWiki.com, 2019.
[29] "2021 State of the U.S. Semiconductor Industry."

Many observers now believe breakthroughs in packaging will be key to improving chip efficiency beyond Moore's law because the packaging provides an alternative avenue for innovation in density and size of products. Other countries are heavily investing to get an advantage in next generation packaging. For example, the Taiwan Semiconductor Manufacturing Company (TSMC) announced in June 2021 that it would partner with 20 Japanese companies to establish an R&D center dedicated to advanced packaging design.[30]

Building a Workforce

While federal investments to grow domestic semiconductor manufacturing capacity will likely increase the number of semiconductor-related jobs in the United States,[31] concerns remain about the U.S. capacity to fill those jobs. As of 2018, there were over 4,000 open technical positions in the United States among prominent semiconductor firms.[32] The pandemic has only worsened the industry's supply of high skilled workers. In comments to NIST on strengthening the semiconductor workforce, the Semiconductor Industry Association (SIA) listed the following workforce-related challenges: a lack of supply of U.S. workers with advanced education, a lack of academic programs supporting emerging technologies, high competition among tech industries for high skilled workers, low awareness of the semiconductor industry among graduate students in STEM, a lack of hands-on training to prepare graduates for work on the manufacturing floor, a lack of diversity in STEM, and retention issues due to cultural differences between young workers and the older workforce.[33]

While the *CHIPS for America Act* addresses some of these issues through its incentive program for workforce training and through its newly established R&D programs, targeted workforce programs may be necessary to establish a lasting microelectronics workforce.

Accessing Material Inputs

Increased production of semiconductors in the United States would require increased domestic production of materials (including critical materials), chemicals, and gases. Regarding critical materials, it is often a difficult and lengthy process to establish domestic critical mineral production. A June 2021 report from the White House found that a reasonable estimate for this process is "not less than ten years."[34] Domestic production of other materials, chemicals, and gases used in semiconductor manufacturing is also somewhat limited. Both the U.S. Geological

[30] Scott Foster, "TSMC eyes 3D chip packaging edge in Japan," *Asia Times*, June 21, 2021.
[31] "The Positive Impact Of The Semiconductor Industry On The American Workforce And How Federal Industry Incentives Will Increase Domestic Jobs," Semiconductor Industry Association, webinar, May 2021.
[32] "Challenges and Opportunities Facing Semiconductor Workforce," Semiconductor Industry Association, May 30, 2018.
[33] "Current and Future Workforce Needs to Support a Strong Domestic Semiconductor Industry," Semiconductor Industry Association, comments to National Institute of Standards and Technology, August 15, 2018.
[34] "Building Resilient Supply Chains, Revitalizing American Manufacturing, And Fostering Broad-Based Growth," the White House, 100-Day Reviews under Executive Order 14017, June 2021.

Survey and NIST maintain lists of materials and gases used in semiconductor production.[35] With the exception of a few of these materials, such as Helium and Silicon, most of these materials are not produced or refined in the United States.[36] A lack of domestic access to these materials has further exacerbated supply chain delays.

Overcoming Environmental Challenges

The semiconductor industry faces significant environmental challenges. It both contributes to and is affected by climate change. It takes a significant amount of energy to produce semiconductors. Companies need to take raw silicon then melt and purify it—a process that produces a significant amount of carbon. For example, TSMC, the current largest chip producer in the world, was responsible for 15 million tons of carbon in 2020.[37] The Semiconductor Research Corporation, a nonprofit organization that funds semiconductor R&D, has committed to funding research to produce sustainable, energy efficient chip architectures.[38] In addition, Intel has said 82 percent of its energy in 2020 came from green sources such as solar and geothermal.[39]

Climate change has also harmed semiconductor production around the globe, adding to supply chain delays. For example, in February 2020, a cold snap in Texas created power outages that severely impacted semiconductor manufacturing in the state, leading to a months-long backup in production.[40] Producing chips also requires a lot of water, and severe drought in Taiwan has added to production delays.[41]

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[35] "Mineral Commodity Summaries 2020," U.S. Geological Survey, January 2020; "Index of Semiconductor Process Gases," National Institute of Standards and Technology, accessed November 2021.
[36] John VerWey, "No Permits, No Fabs: The Importance of Regulatory Reform for Semiconductor Manufacturing," Georgetown Center for Security and Emerging Technologies, October 2021.
[37] Alex Crawford et al., "The Chip Industry Has a Problem With Its Giant Carbon Footprint," *Bloomberg*, April 2021.
[38] "Energy Efficient Computing: from Devices to Architecture," Semiconductor Research Corporation, 2021.
[39] Sam Shead, "The global chip industry has a colossal problem with carbon emissions," *CNBC*, November 3, 2021.
[40] Wu et al., "Why the World Is Short of Computer Chips, and Why It Matters."
[41] Emanuela Barbiroglio, "No Water No Microchips: What Is Happening In Taiwan?" *Forbes*, May 31, 2021.