MITRE's Response to the OMB RFI on Advancing the Domestic Manufacturing of Semiconductors in Commercial Information Technology

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About MITRE

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MITRE has a 40-year history of semiconductor design and security experience and has been pivotal in analyzing semiconductor supply chain vulnerabilities and fostering collaborative activities to advance the nation's semiconductor community. We also support federal agencies in related strategic planning, providing private sector and federal policy insights to help bolster U.S. manufacturing and innovation. MITRE is a founding member of the Northeast Microelectronics Hub, which works to advance the microelectronics needs of the U.S. Department of Defense (DoD) while spurring new jobs, workforce training opportunities, and investment in the region's advanced manufacturing and technology sectors. MITRE's state-of-the-art microelectronics security laboratories are available for use by all Hubs as part of a DoD Commons Core Capability.

Introduction and Overarching Recommendations

The semiconductor industry is pivotal to national security and economic stability, necessitating strategic investments in domestic capabilities. Our recommendations encompass several critical areas, including enhancing workforce development, bolstering research and development, addressing supply chain vulnerabilities, and fostering technological innovation. While the Request for Information (RFI) primarily seeks input on procurement strategies, we underscore here the significance of workforce and research as foundational elements that will drive sustainable growth and innovation in the semiconductor sector. These aspects, though not explicitly requested in the RFI, are integral to achieving a robust and resilient domestic semiconductor ecosystem and should be included in the Office of Management and Budget's strategy.

Workforce

A strong workforce is integral to the national strategy for enhancing U.S. semiconductor manufacturing capabilities. The sector demands expertise in fields such as materials science, electrical engineering, and physics. Ensuring a continuous supply of educated professionals through robust educational pipelines, including university programs and technical schools, is essential to meet industry needs. Attracting and retaining top talent is vital for maintaining competitiveness, especially against global leaders like Taiwan and South Korea, where the workforce is already highly developed. Workforce considerations also play into broader economic and security strategies, as semiconductors are crucial for national defense, technology innovation, and economic growth. With many current experts nearing retirement, urgent action is needed to train new workers for both traditional manufacturing roles and emerging technologies like automation and AI.

Strengthen educational pathways to ensure a continuous supply of skilled professionals in semiconductor manufacturing. A well-prepared workforce is essential not only for traditional manufacturing roles but also for managing new technologies like automation and AI, which are critical for advancing research and development in the semiconductor industry. A recent MITRE project underscores this need. We developed an interactive tool displaying 2022 award completion data from 149 academic programs across over 6,000 academic institutions, providing insights into postsecondary pathways leading to semiconductor jobs. The tool provides data on federally funded construction projects and enables users to explore information at various levels. In 2022, 521,603 credentials were awarded in relevant fields, identifying educational pathways that do not require a traditional four-year or advanced degree. This group of credential recipients, holding either a certificate or an associate degree, totals 148,449 and represents 28% of all postsecondary credentials awarded in fields relevant to the semiconductor industry. This underscores a significant opportunity for investment in non-advanced-degree pathways. The assessment further identified high-performing and underperforming programs, enabling our sponsor to start outreach, share best practices, and improve recruitment.

Research and Development

Research and development (R&D) is the backbone of maintaining and advancing the U.S. position in the global semiconductor industry. The relentless pace of technological change in this field necessitates continuous investment in cutting-edge technologies to ensure that the United States can compete with nations like Taiwan, South Korea, and China, which are rapidly advancing their own capabilities. Within this R&D framework, two critical areas require strategic focus.

Strategic investments in next-generation lithography technologies are needed to maintain a competitive edge in semiconductor manufacturing, particularly in High Numerical Aperture Extreme Ultraviolet (High-NA EUV) and emerging Hyper Numerical Aperture Extreme Ultraviolet (Hyper-NA EUV) systems. Advancements in lithography technology are a major limiting factor in the development of next-generation semiconductors. This technology is crucial for the continued scaling of transistors on chips over the next decade. The resolution of lithography processes, determined by the type of light source, optical system properties, and manufacturing process characteristics, is vital for advancing semiconductor capabilities. The EUV technology, primarily produced by ASML in the Netherlands, is essential for maintaining competitiveness against global adversaries heavily investing in these capabilities. By focusing on the development of light sources and next-generation photoresist materials, the United States can secure its position in the semiconductor industry.

Enhance capabilities in Advanced Packaging Equipment. As traditional Moore's law scaling slows down, today's AI and high-performance computing devices rely extensively

on the use of advanced packaging to integrate multiple chiplets such as CPUs, memory, power management, and analog components onto a single package. As 2.5D and 3D packaging evolve, advancements in lithography, deposition, etching, chemical mechanical planarization, metrology, and bonding equipment are essential to address challenges like warpage control, high aspect ratio gap fill, precise alignment, throughput, and cost efficiency. Advanced packaging is crucial for integrating complex chip architectures and fine pitch interconnects on non-planar surfaces, such as through silicon vias (TSVs) and multi-layer redistribution layers (RDLs). Innovations in photoresist materials, real-time error correction, and advancements in standard lithography for large panel applications are necessary to overcome these challenges.

Photolithography

Photolithography on large area panels is crucial for advanced packaging but is challenged by complex chip architectures, fine pitch interconnects on non-planar surfaces such as TSVs and multi-layer RDLs, and substrate warpage and stress. To address these issues, innovations in photoresist materials, real-time error correction, and advancements in standard lithography for large panel applications and in Direct Write Lithography with acceptable throughput are necessary.

Deposition

As feature sizes in 2.5D and 3D packaging technologies shrink and the aspect ratio increases, filling the gap in RDLs, TSVs, and other interconnects becomes more challenging and requires innovation in deposition techniques to enable uniform and void free deposition across wafers and large area panels. While plasma-enhanced chemical vapor deposition and plasma-enhanced atomic layer deposition techniques are widely used for gap fill deposition, there are still challenges such as low conformality for high aspect ratio structures, slow deposition rate, and precursor availability that need to be addressed.

Metrology

As device architectures grow increasingly complex with the advent of 2.5D/3D stacking and heterogeneous integration, metrology equipment faces challenges such as achieving precise measurements for high aspect ratio structures at high throughput, assessing buried structures, ensuring bonding overlay accuracy, managing wafer warpage, and handling material variations. As packaging technologies evolve, future investments should focus on developing non-destructive, high-resolution measurement techniques for silicon, organic, and glass substrates of various sizes, utilizing optical, X-ray, and acoustic technologies, to meet the growing demands of semiconductor innovation.

CMP (Chemical Mechanical Planarization)

As advanced packaging[1] involves heterogenous integration of different materials with varying hardness and removal rates, achieving uniform planarization without localized over-polishing, metal dishing, or dielectric erosion is a major challenge. Additionally, maintaining defect-free surfaces while achieving high removal rates necessitates advanced cleaning solutions and defect detection methods. Future investments should focus on developing innovative slurry chemistries

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[1] US Microelectronics Packaging Ecosystem: Challenges and Opportunities. 2023. arXiv, https://arxiv.org/pdf/2310.11651. Last accessed February 24, 2025.

to manage multi-material interactions and integrating metrology with AI-driven process control to enhance CMP performance and yield.

Bonding

Advanced packaging, such as 3D stacking, chiplets, and heterogeneous integration, requires precise bonding techniques to ensure performance and reliability. Among various techniques, hybrid bonding[2] is superior due to its high density and improved electrical performance, as it allows direct copper-to-copper bonding, enabling two dies with copper pads to be sealed at an ultra-fine pitch. To ensure manufacturability and cost efficiency, innovative solutions are needed to improve alignment accuracy at sub-micron and nano levels, surface preparation, cleanliness, and thermal budget management.

Dicing

Dicing is a process that involves the separation (or 'singulation') of individual dies from a semiconductor wafer. Various techniques are used based on packaging architectures and applications. Plasma dicing[3] is superior due to its design flexibility, suitability for fragile devices, elimination of particulate contamination, and increased die yield per wafer, as it doesn't require space for blade widths or laser spot sizes. However, it has a very narrow window of application and is therefore used in combination with other dicing techniques to achieve the final result. Innovative solutions are needed to address challenges like dicing through different materials including glass substrates, reducing process complexity, and improving cost efficiency.

Inputs Requested in RFI

6. What, if any, significant domestic supply chain vulnerabilities surrounding semiconductors are you aware of and what could be done to reduce or eliminate those vulnerabilities? Are there other vulnerabilities of which we should be aware?

The domestic supply chains for semiconductors include several risks:

Domestic Availability of Critical Materials and Chemicals. To mitigate supply chain vulnerabilities, we recommend investing in the domestic production and purification of critical materials and chemicals essential for semiconductor manufacturing. The availability of ultra-high-purity materials is crucial for maintaining the quality and reliability of semiconductor products. Current dependencies on adversary nations and unstable regions pose significant risks. By increasing domestic mining projects, streamlining permitting processes, and developing purification techniques, the United States can reduce these dependencies. Additionally, diversifying the supply chain through collaboration with allied nations and developing synthetic alternatives will bolster resilience. Establishing national reserves and stockpiling critical materials, with geographical diversification of stockpiles close to semiconductor hubs, can further safeguard against supply disruptions.

Regulations and Policies to Facilitate Production. We recommend establishing methods to streamline U.S. regulations and policies to decrease approval times for critical mineral mining

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[2] Hybrid Bonding. 2025. Applied Materials, https://www.appliedmaterials.com/us/en/semiconductor/markets-and-inflections/heterogeneous-integration/hybrid-bonding.html. Last accessed February 24, 2025.

[3] Plasma Dicing 101: The Basics. 2022. KLA, https://www.kla.com/advance/innovation/plasma-dicing-101-the-basics. Last accessed February 24, 2025.

and production. Strict regulations can hinder timely access to essential materials, impacting semiconductor manufacturing. By investing in environmentally safe mining projects and simplifying the permitting process, the United States can enhance its domestic supply chain capabilities. This approach will not only expedite production but also ensure compliance with environmental standards, supporting sustainable growth in the semiconductor industry.

Infrastructure for Power, Utilities, and Transportation. Investing in reliable power generation, water supply, and transportation infrastructure is essential to support semiconductor manufacturing. The high demand for utilities, such as high-purity water and waste treatment, requires efficient systems to ensure uninterrupted production. Enhancing power generation and backup systems, along with improving waste treatment efficiency, will address these needs. Additionally, investing in domestic manufacturing of chemical containers and developing track and trace capabilities for transportation will secure the supply chain against tampering and counterfeiting. Establishing alternative international routes for critical materials can further mitigate risks associated with geopolitical conflicts.

Fab Automation and Workforce Development. We recommend investing in smart manufacturing technologies, including digital twins and automation software security, to enhance fab automation. Automation is key to increasing efficiency and reducing human error in semiconductor production. By integrating advanced technologies, the United States can improve production capabilities and maintain competitiveness. Concurrently, workforce development is crucial to support these advancements. Training programs and educational initiatives should focus on equipping workers with the skills needed to manage and operate automated systems, ensuring a seamless transition to more advanced manufacturing processes.

Integrity and Confidentiality in Design and Fabrication. Ensuring the integrity and confidentiality of semiconductor design and fabrication processes is vital for national security. The Electronic Design Automation (EDA) industry, primarily led by U.S. companies, plays a critical role in designing semiconductors. Protecting these processes from malicious circuits and unauthorized access is essential. By maintaining trustworthy EDA companies and implementing robust IP protection mechanisms, the United States can prevent reverse engineering and safeguard its intellectual property. Additionally, engaging with major semiconductor companies and equipment manufacturers to increase participation in future initiatives will support secure and reliable production environments.

11. What raw materials used in semiconductor manufacturing are in limited or constrained supply and could prevent scale up of your domestic manufacturing operations?

Critical Minerals: Enhance Domestic Production and Diversification. The limited supply of critical minerals such as gallium (Ga), germanium (Ge), arsenic (As), tungsten (W), and fluorspar poses significant challenges to scaling up domestic semiconductor manufacturing. Gallium is essential for producing semiconductor compounds like gallium arsenide (GaAs), gallium nitride (GaN), and gallium phosphide (GaP), which are used in high-speed electronic devices and 5G communications. Germanium is known for its high electron- and hole-mobility, making it vital for advanced, high-speed semiconductor devices. Arsenic serves as a key component in compound semiconductors due to its high electron mobility. Tungsten's high conductivity and resistance to electromigration make it crucial for integrated circuits, while fluorspar is a primary source of fluorine for various chemicals used in semiconductor manufacturing.

Currently, the United States imports the majority of its gallium from countries like China, Japan, and Germany, and no arsenic has been produced domestically since 1985. This reliance increases supply chain vulnerabilities. By conducting geological surveys, investing in domestic mining projects, and streamlining permitting processes, the United States can reduce these dependencies. Additionally, diversifying the supply chain through collaboration with allied nations and developing synthetic alternatives will bolster resilience. Establishing national reserves and stockpiling critical materials, with geographical diversification of stockpiles close to semiconductor hubs, can further safeguard against supply disruptions.[4]

Photoresists: Strengthen Domestic Production and R&D. Photoresists are critical light-sensitive materials used in semiconductor fabrication, essential for transferring intricate designs onto substrates. Photoresists are available in various types based on their chemical composition and radiation sensitivity, such as positive-tone, negative-tone, i-Line (365 nm), g-Line (435 nm), DUV (248 nm), KrF (193-nm and 193-immersion), EUV (13.5 nm), and others. Currently, the production of novel photoresists is concentrated in Southeast Asia, posing risks to supply chain stability. These materials are produced and transported in small quantities, and have a limited shelf life, making them unsuitable for long-term storage. Despite their low consumption rates per wafer, they are indispensable for semiconductor fabrication.

We recommend collaborating with allied nations to incentivize onshoring and partner-shoring of photoresist production to ensure sufficient material availability. By incentivizing domestic research and development, the United States can enhance its capabilities in producing these vital and sophisticated materials, which have no substitutes and are crucial for maintaining semiconductor fabrication capabilities.

Wafers: Onshore Manufacturing and Establish Stockpiles. Silicon, polysilicon, and compound semiconductor wafers are fundamental to integrated circuit production. Silicon wafers, produced using processes like the Czochralski method, are essential for a wide range of electronic devices. Polysilicon, primarily used for solar cells, is refined through methods such as the Siemens process. Compound semiconductors like GaAs, GaN, InP, indium phosphide, and Silicon Carbide are used for high-speed, high-frequency, and high-power applications, making them suitable for 5G-6G networks and photonics.

China currently dominates the production of these materials, producing over 70% of the world's silicon in 2023.[5] We recommend onshoring the extraction and purification of silicon and polysilicon to electronic grade and establishing domestic manufacturing for these wafers. By domestically producing and stockpiling wafers, the United States can mitigate risks associated with supply chain disruptions and ensure a stable supply for domestic manufacturing operations.

Chemicals: Incentivize Domestic Production and Purification. Key chemicals such as anhydrous hydrogen chloride (AHCl), hydrofluoric acid (HF), nitrogen trifluoride (NF_3), and

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[4] Chipping in: Critical minerals for semiconductor manufacturing in the U.S. 2023. MIT Science Policy Review, https://sciencepolicyreview.org/wp-content/uploads/securepdfs/2023/08/MITSPR-v4-191618004005.pdf. Last accessed March 5, 2025.

[5] Silicon. 2024. United States Geological Survey, https://pubs.usgs.gov/periodicals/mcs2024/mcs2024-silicon.pdf. Last accessed March 5, 2025.

sulfuric acid (H_2SO_4) are critical for semiconductor manufacturing. AHCl is used for etching and cleaning, HF for oxide etching, NF_3 as a chamber cleaning gas, and H_2SO_4 for stripping photoresist and organic residues. While the United States has some domestic suppliers, the technology for achieving ultra-high purity levels is primarily owned by Southeast Asia, creating vulnerabilities in the supply chain. Additionally, the United States relies on imports for the key raw material, fluorspar, required to produce HF and NF_3.

We recommend working with allied nations to incentivize the onshoring of production for these chemicals to ensure sufficient domestic availability. By investing in domestic R&D for purification technology development, the United States can secure its supply of these essential chemicals.

Specialized Gases and Precursors: Onshore Production and Establish Stockpiles. Rare earth gases, such as helium, argon, neon, krypton, and xenon, are vital for semiconductor manufacturing due to their inert properties. They are used in plasma etching, film deposition, and photolithography. Helium is particularly important for equipment cooling and leak detection. High-purity precursors are crucial for depositing thin films with precise properties, using methods like atomic layer deposition and chemical vapor deposition. For example, tungsten hexafluoride is used for forming interconnects, and scandium forms scandium oxide gate dielectrics.

Russia and Ukraine are primary producers of these gases for the semiconductor industry, while China is a major producer of raw materials for some precursors. We recommend onshoring the production of essential minerals and incentivizing domestic precursor production. Establishing stockpiles of key precursors produced in non-allied countries will further mitigate risks. By focusing on the domestic production of electronic-grade rare earth gases, the United States can ensure a stable supply chain and scale up domestic manufacturing operations.

14. What types of innovations can help make the manufacturing market more efficient?

Digital Twins and Prototyping: Implement Advanced Simulation and Validation Models. The adoption of digital twins in the semiconductor industry can significantly enhance manufacturing efficiency. We recommend leveraging partnerships between foundries and EDA vendors to develop digital twin capabilities. These virtual models enable integrated device manufacturers to simulate and optimize processes, reducing the timeline for device qualification and market rollout. The success of digital twins relies on establishing common frameworks and standard interfaces, which can streamline operations and improve product quality. By implementing digital twins, manufacturers can anticipate potential issues, optimize resource use, and enhance overall production efficiency. Additionally, establishing prototyping and pathfinding validation facilities can further improve manufacturing efficiency by providing a controlled environment for testing new materials and processes. These facilities enable rapid prototyping and validation, accelerating innovation and reducing time-to-market for new semiconductor technologies.

AI-Driven EDA and Synthetic Materials: Accelerate Design and Expand Material Options. AI is transforming the landscape of integrated circuit design. We recommend investing in AI-driven EDA tools to accelerate design timelines and improve the quality of semiconductor products. Leading EDA companies like Synopsys, Cadence, and Siemens have already introduced AI-based solutions that enhance design productivity and optimize results. For Radio

Frequency Integrated Circuit design, programs like the Natcast Artificial Intelligence-Driven Radio Frequency Integrated Circuit Design Enablement are demonstrating the potential of AI to lower the experience barrier, increase productivity, and generate innovative designs. MITRE's role in supporting Natcast through independent verification and validation underscores the importance of AI in advancing semiconductor design. Additionally, the development of synthetic materials can address supply chain constraints and enhance manufacturing efficiency. By investing in research and development to create synthetic alternatives for critical materials, manufacturers can reduce dependencies on limited resources and explore new applications for semiconductor technologies, leading to more sustainable and cost-effective production processes.

Furthermore, we recommend that semiconductor design be considered a beneficial use case in the Office of Science and Technology Policy's in-development AI Action Plan. This inclusion would highlight the importance of AI in semiconductor design and provide a common objective for the national AI and semiconductor communities to organize around, fostering collaboration and innovation.