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Semiconductor Manufacturing Supply Chain
Attn: semiconductorstudy@bis.doc.gov, david.boylan@bis.doc.gov
Office of Technology Evaluation
Bureau of Industry and Security
U.S. Department of Commerce

Via Federal e-Rulemaking Portal: http://www.regulations.gov

Re: Request for Public Comment on Risks in the Semiconductor Manufacturing and Advanced Packaging Supply Chain; 86 Fed. Reg. 14308; Docket No: 210310-0052; RIN: 0694-XC07

The Center for Security and Emerging Technology (CSET) offers the following submission for BIS's consideration. BIS requested information and comments related to "the capabilities of the U.S. microelectronics industrial base to support the national defense, in light of the global nature and interdependence of the supply chain with respect to manufacture, design, and end use."

CSET's submission will expand on the following points:

- U.S.-headquartered firms are highly competitive suppliers of many, but not all, key items required to produce semiconductors.
- Many critical parts of the semiconductor supply chain are highly consolidated, often in a single or small number of suppliers or countries. Although most consolidated segments are concentrated in the United States or allied countries, other segments such as leading-edge logic chip manufacturing have consolidated in regions posing risks of disruption due to natural disasters, geopolitical events, or other business disruptions.
- We recommend fully funding the manufacturing grant program in the CHIPS for America Act, with a focus on leading-edge logic chip manufacturing.
- Investments in education and workforce programs are essential for long-term supply chain competitiveness. These programs should target a broad range of relevant fields and promote on-the-job training and public-private partnerships.
- Short-term semiconductor workforce needs can only be met through a combination of domestic investments and immigration reform.

1. SUPPLY CHAIN ASSESSMENT

With regard to (i) *"Critical and essential goods and materials underlying the semiconductor manufacturing and advanced packaging supply chain"; and* ***(ii)*** *"manufacturing and other capabilities necessary to produce semiconductors, including electronic design automation software and advanced integrated circuit packaging techniques and capabilities":*

U.S.-headquartered firms are highly competitive suppliers of many specialized goods, materials, tools, and software required for semiconductor manufacturing. Table 1 below, adapted from CSET's recent report on the semiconductor supply chain, shows U.S. competitiveness across many key inputs to manufacturing.[1] Further details on market shares, primary suppliers, and the relative importance of each input technology can be found in the original report.

Table 1. The United States' competitiveness across supply chain segments

R&D

DESIGN
- Logic chips
- CPUs (logic)
- GPUs (logic)
- FPGAs (logic)
- AI ASICs (logic)
- DRAM (memory)
- NAND (memory)
- Analog chips
- OSD

FAB
- Logic chips
- Logic foundry
- Logic IDM
- Advanced logic
- Memory chips
- Analog chips
- Optoelectronics
- Sensors
- Discretes

ATP

LITHOGRAPHY TOOLS
- EUV scanners
- ArF immersion scanners
- ArF dry scanners
- KrF steppers
- i-line steppers
- Mask aligners
- E-beam lithography
- Laser lithography
- Imprint lithography
- Imprint lithography
- Resist processing

DEPOSITION TOOLS
- Chemical vapor deposition
- Physical vapor deposition
- Rapid thermal processing
- Tube-based diffusion & dep.
- Spin coating
- Electrochemical deposition

ETCH & CLEAN TOOLS
- Dry etch and clean
- Atomic layer etch
- Wet etch and clean

ASSEMBLY & PACKAGING TOOLS
- Assembly inspection
- Dicing
- Bonding
- Packaging
- Integrated assembly

TESTING TOOLS
- Memory
- System-on-a-chip
- Burn-in
- Linear & discrete
- Handlers & probers

WAFER AND MASK TOOLS
- Wafer manufacturing
- Wafer & mask handling
- Wafer marking

PROCESS CONTROL TOOLS
- Wafer inspection
- Photomask inspection
- Wafer level pkg inspect.
- Process monitoring

CMP TOOLS

ION IMPLANTERS
- Low current
- High current
- High voltage
- Ultra high dose

EDA SOFTWARE

CORE IP

RAW MATERIALS

FAB MATERIALS
- Wafers
- Photoresists
- Photomasks
- CMP slurries & pads
- Deposition
- Electronic Gases
- Wet chemicals

PACKAGING MATERIALS

Note: *Green*: high capabilities (internationally competitive); *Yellow*: moderate capabilities; *Orange*: low capabilities; *Red*: minimal or no capabilities; *Bolded*: high-level category; Unbolded: items within and listed below high-level category. Ratings based on authors' analysis.

With regard to (v) *"the resilience and capacity of the semiconductor supply chain to support national and economic security and emergency preparedness, including…* ***(b)*** *exclusive or dominant supply of critical or essential goods and materials by or through nations that are, or may become, unfriendly or unstable":*

Although parts of the semiconductor supply chain have diverse suppliers, many critical segments are highly consolidated, presenting risks of disruption due to natural disasters, geopolitical events, or other business disruptions. Table 2 below lists a sample set of technologies required for producing semiconductors where suppliers are highly consolidated in a single country (excluding the United States). All of the countries in Table 2 are U.S. allies or partners; the consolidation of leading-edge logic chip manufacturing in Taiwan represents the greatest risk given heightened geopolitical tensions in the region. Japan also stands out, given the number of key technologies it dominates and its proximity to China. For a more comprehensive summary of supply chain segments consolidated in a single or small number of suppliers or countries, see CSET's report on the semiconductor supply chain.[2]

Table 2. Points of consolidation in the semiconductor supply chain

<table>
<tr><th>Supply chain segment</th><th>Critical technology</th><th>Country</th><th>Country's market share*</th><th>US share</th></tr>
<tr><td rowspan="2">Fabs</td><td>Leading-edge logic chips (<10 nm)</td><td>Taiwan</td><td>92%</td><td>0%</td></tr>
<tr><td>Memory chips</td><td>South Korea</td><td>41%</td><td>5%</td></tr>
<tr><td rowspan="4">Wafer manufacturing and handling tools</td><td>Crystal growing furnaces</td><td>Germany</td><td>100%</td><td>0%</td></tr>
<tr><td>Wafer bonders and aligners</td><td>Austria</td><td>83%</td><td>5%</td></tr>
<tr><td>Crystal machining tools</td><td rowspan="7">Japan</td><td>95%</td><td>0%</td></tr>
<tr><td>Wafer handling tools</td><td>88%</td><td>6%</td></tr>
<tr><td rowspan="2">Deposition tools</td><td>Spin coating tools</td><td>100%</td><td>0%</td></tr>
<tr><td>Tube diffusion and deposition tools</td><td>84%</td><td><1%</td></tr>
<tr><td>Assembly and packaging tools</td><td>Dicing tools</td><td>85%</td><td>2%</td></tr>
<tr><td rowspan="4">Lithography tools</td><td>Resist processing tools</td><td>96%</td><td><1%</td></tr>
<tr><td>EUV resists</td><td>>90%</td><td>0%</td></tr>
<tr><td>EUV photolithography tools</td><td>Netherlands</td><td>100%</td><td>0%</td></tr>
<tr><td>EUV laser amplifiers and mirrors</td><td>Germany</td><td>100%</td><td>0%</td></tr>
</table>

* Market shares come from Khan, Mann, and Peterson, "The Semiconductor Supply Chain."

2. SUPPLY CHAIN POLICY

With regard to (vii) *"policy recommendations or suggested executive, legislative, regulatory changes, or actions to ensure a resilient supply chain for semiconductors (e.g., reshoring, nearshoring, or developing domestic suppliers, cooperation with allies to identify or develop alternative supply chains, building redundancy into supply chains, ways to address risks due to vulnerabilities in digital products or climate change)."*

We recommend fully funding the manufacturing grant program in the CHIPS for America Act. Sufficient incentives would reverse the decades-long decline in the U.S. share of wafer capacity, which has been driven in part by large subsidies offered to chipmakers by Taiwan, South Korea, and China.[3]

Funding should especially target leading-edge logic fabs. Logic chip manufacturing capacity at 7nm and below is especially concentrated in Taiwan and will unlock novel applications important to economic competitiveness and national security.

3. WORKFORCE AND EDUCATION POLICY

With regard to (iii) *"the availability of the key skill sets and personnel necessary to sustain a competitive U.S. semiconductor ecosystem, including the domestic education and manufacturing workforce skills needed for semiconductor manufacturing; the skills gaps therein, and any opportunities to meet future workforce needs":*

Investments in education and workforce programs are essential for supply chain competitiveness. Technical progress in the semiconductor industry is highly labor-intensive; data suggests that innovation in semiconductor technology requires 18 times more R&D staff today than during the 1970s.[4] Growth in U.S. domestic semiconductor R&D and advanced manufacturing will lead to large increases in demand for high-skilled labor. If this demand surge is not matched by large increases in supply, reshoring initiatives will run a high risk of failing.

Education and workforce programs should target a broad range of semiconductor-relevant fields. Specific education and skill demands vary based on the semiconductor supply chain segment. A recent CSET report analyzed available data on educational backgrounds across different supply chain segments.[5] Electronic and computer engineering backgrounds are dominant in design-related roles, while manufacturing-related workers have a range of physical science and engineering backgrounds (e.g., materials science, chemistry, mechanical engineering). Skill needs will evolve as technology progresses; to ensure alignment between educational programs and industry needs, workforce policies should promote on-the-job training programs and public-private partnerships. The report also makes several other recommendations for strengthening the domestic U.S. semiconductor workforce.

Short-term semiconductor workforce needs can only be met through a combination of domestic investments and immigration reform. An estimated 40% of the high-end U.S. semiconductor workforce consists of foreign-born workers, and more than half of the graduate students in most semiconductor-related programs at U.S. universities are international students.[6] Today's domestic education investments will take many years to bear fruit; semiconductor companies therefore identify immigration reform as the "number one [workforce policy] change that would help the industry in the near term."[7] Several CSET reports offer specific immigration policy recommendations that would strengthen U.S. semiconductor supply chains.[8]

We thank BIS for the opportunity to comment, and we look forward to further supporting BIS and its partner agencies as they formulate policy to ensure U.S. supply chains are resilient, diverse, and secure.

Will Hunt
Research Analyst
Center for Security and Emerging Technology
wh461@georgetown.edu

Remco Zwetsloot
Research Fellow
Center for Security and Emerging Technology
rz140@georgetown.edu

[1] 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/research/the-semiconductor-supply-chain/.
[2] Khan, Mann, and Peterson, "The Semiconductor Supply Chain."
[3] For a breakdown of current wafer fab capacity across countries and types of semiconductors see Figure 10, p. 20 in Khan, Mann, and Peterson, "The Semiconductor Supply Chain."
[4] Nicholas Bloom et al., "Are Ideas Getting Harder to Find?", *American Economic Review* 110, no. 4 (2020): 1104–1144, https://doi.org/10.1257/aer.20180338.
[5] 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/research/the-chipmakers-u-s-strengths-and-priorities-for-the-high-end-semiconductor-workforce/
[6] Hunt and Zwetsloot, "The Chipmakers," Figure 1 and Table 2.
[7] Semiconductor Industry Association, "SIA Workforce Roundtable: Summary Report" (March 2018), p. 6, https://www.semiconductors.org/wpcontent/uploads/2018/06/Roundtable_Summary_Report_-_FINAL.pdf
[8] See, e.g., Hunt and Zwetsloot, "The Chipmakers," pp. 32-33; Zachary Arnold et al., "Immigration Policy and the U.S. AI Sector" (Center for Security and Emerging Technology, September 2019), https://cset.georgetown.edu/research/immigration-policy-and-the-u-s-ai-sector/