House Committee on Science, Space, and Technology,
Subcommittee on Research and Technology

"Strengthening the U.S. Microelectronics Workforce"

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Chairwoman Stevens, Ranking Member Feenstra, and members of the Subcommittee, thank you very much for inviting me to testify about microelectronics workforce development, and to share my perspective about new federal investment and university-industry partnerships to strengthen the U.S. microelectronics workforce.

I am a Distinguished Professor of Electrical Engineering and Computer Sciences (EECS) and Dean of the College of Engineering at the University of California, Berkeley. Since the early 1960s, when the university was the first to establish a lab for prototyping of integrated circuits,[1] Berkeley EECS faculty and students have made pioneering contributions to semiconductor devices and manufacturing processes, including innovations in integrated circuit "chip" design methodology and software tools.

As one of the top three schools of engineering in the country,[2] Berkeley Engineering has also played an integral role in training the microelectronics workforce. Concurrent with advances in research, our faculty have continually led the development of courses to educate and train students in the rapidly evolving field of microelectronics. Many of the standard textbooks used to teach microelectronics at universities around the world were written by Berkeley EECS faculty. Our graduates include many trailblazing entrepreneurs, co-founders and leaders of technology companies such as Apple, Google, Intel, and Texas Instruments.[3] This is all to say that we have a keen interest in re-establishing U.S. leadership in microelectronics, and that I am here to talk about how universities can help achieve this goal in partnership with industry and government.

[1] https://www2.eecs.berkeley.edu/Pubs/TechRpts/2013/EECS-2013-158.pdf
[2] https://www.usnews.com/best-graduate-schools/top-engineering-schools/eng-rankings
[3] https://eecs.berkeley.edu/people/alumni/cs-distinguished-alumni, https://eecs.berkeley.edu/people/alumni/ee-distinguished-alumni

Executive Summary

By now you've heard the dire statistics: the U.S. share of semiconductor manufacturing capacity, which was 37% back in 1990, has dropped to 12%.[4] Collaborative new approaches are needed to attract and train a much larger and more diverse workforce necessary for the U.S. microelectronics industry to grow, leveraging regional capacities at universities and community colleges, at national laboratories, and at companies across the microelectronics supply chain. Universities and community colleges offer degree-oriented educational programs, while the national labs and companies offer complementary experiential learning opportunities and practical hands-on skills training.

I chair the executive committee for the American Semiconductor Academy (ASA) Initiative,[5] which brings together four-year universities and community colleges to collaborate with each other and to collectively partner with industry to revitalize the semiconductor microelectronics curriculum and to coordinate hands-on training experiences for students at a local (regional) university, national lab and/or company R&D facility. This initiative is driven by faculty across the U.S. who are engaged in semiconductor research and education at more than 50 universities, plus their community college partners.

SEMI,[6] an industry association representing more than 2,500 member companies across the microelectronics design and manufacturing supply chain, is partnering with the ASA Initiative to bolster workforce education and training programs to grow and diversify the talent pool for the U.S. microelectronics industry. This partnership will leverage and complement existing successful federally funded programs such as the National Science Foundation (NSF) Advanced Technological Education (ATE) program,[7] the NSF National GEM Consortium,[8] the Department of Energy (DOE) Minority-Serving Institution Partnership Program (MSIPP),[9] and the Department of Defense (DOD) Scalable Asymmetric Lifecycle Engagement (SCALE) program,[10] to name just a few.

The ASA is proposed to be an inclusive national microelectronics education and training network, open to all U.S. universities and colleges to participate, and to industry and government stakeholders to partner with. This initiative has been endorsed by over 30 companies, including each of the leading U.S. semiconductor manufacturing companies.

Federal funding to establish the ASA would grow the pool of talent for the programs authorized by the 2020 CHIPS for America Act[11] and, more importantly, the broader U.S. microelectronics ecosystem with the greatest possible speed, scale and impact.

[4] https://www.bcg.com/publications/2020/incentives-and-competitiveness-in-semiconductor-manufacturing
[5] https://www.semi.org/en/workforce-development/ASA
[6] https://semi.org/en
[7] https://beta.nsf.gov/funding/opportunities/advanced-technological-education-ate
[8] https://www.gemfellowship.org/
[9] https://www.energy.gov/nnsa/nnsa-minority-serving-institution-partnership-program-msipp
[10] https://www.purdue.edu/discoverypark/scale/
[11] https://www.congress.gov/bill/116th-congress/senate-bill/3933/text

Background

Advances in information and communication technologies – powered by microelectronics – are continually transforming every aspect of life in modern society. Today we see the growth of cloud computing and the emergence of the Internet of Everyhing, which together with advancements in machine learning are giving rise to artificially intelligent systems. In the not-too-distant future, such systems will manage critical infrastructure for smart cities, offer personalized health care and medicine for smart hospitals, automate vehicles and optimize traffic flow for smart highways, and maximize manufacturing efficiency for smart factories. Artificially intelligent systems require real-time processing of large quantities of data, which is possible today because the capabilities of information-processing devices (for computing, communications and data storage) have steadily improved at an exponential pace over the past several decades.

Such rapid improvement in performance has been driven by Moore's Law, which dictates that the number of transistors (used as electronic switches in digital circuits and as amplifiers in analog circuits) on the most advanced microprocessor chip doubles every two years: (i) advances in integrated circuit (IC) chip manufacturing technology enable smaller transistors to be fabricated, so that (ii) more transistors can be integrated on a single silicon die for more functionality at lower manufacturing cost; (iii) this improvement enables new microelectronics products with greater information processing capability and/or more affordable prices, resulting in (iv) substantial market growth and profits leading to reinvestment to (cycle back to step i) further advance chip manufacturing technology.

This virtuous cycle of semiconductor technology advancement and market growth has made it possible for modern ICs to contain over 50 billion transistors on a chip[12] contacted and interconnected with a crisscross of conductive wires formed from more than a dozen layers of metallic material to achieve the desired chip functionality. The most advanced chips today comprise semiconducting, insulating, and conducting material layers with feature sizes that are one thousand times smaller than the width of a human hair. They are cut from thin silicon wafers 300 mm in diameter and less than one millimeter in thickness, that have been processed through more than one thousand fabrication steps to simultaneously form billions of transistors and interconnects one layer at a time. The fabrication steps used to form each material layer have stringent process requirements – parts-per-billion composition control and atomic-scale patterning precision across the entire wafer – and each step must be completed within one minute. The most advanced chip manufacturing processes today involve an integrated process sequence of more than one thousand steps (taking up to four months to complete), and the leading semiconductor foundries ("fabs") process more than 100,000 wafers per month.[13]

The semiconductor manufacturing industry's ability to manipulate materials at an atomic level on an industrial scale is truly impressive:[14]

- The total length of nanoscale copper wiring in a half-inch square chip is over 20 miles.
- The width-to-height aspect ratio of nanoscale vertical structures is greater than 40, whereas the aspect ratio of the world's tallest skyscrapers is less than 10.
- The level of precision is equivalent to spotting a single ant from outer space, and then identifying its species in less than one second.

[12] https://en.wikipedia.org/wiki/Transistor_count
[13] https://en.wikipedia.org/wiki/List_of_semiconductor_fabrication_plants
[14] Omkaram Nalamasu, SEMI International Trade Partners Conference (Oahu, HI USA), November 3, 2021.

An Urgent and Growing Workforce Development Need

The unparalleled complexity and sophistication of IC design (which involves electronic design automation software tools to develop new billion-component chip products in a timely fashion) and semiconductor manufacturing (which involves highly specialized facilities, equipment and processes optimized with the aid of technology computer aided design software tools) require a highly trained microelectronics workforce with knowledge and skills spanning a wide range of STEM disciplines and educational levels. In 2017 a survey conducted by Deloitte and SEMI[15] found that 82% of semiconductor industry executives reported a shortage of qualified job candidates. The challenge of finding qualified workers has increased since then, and it is now acute at all skill and education levels – from technicians to doctoral-level engineers. Looking forward, the U.S. microelectronics workforce development need is expected to more than double as CHIPS Act manufacturing incentives likely will create tens of thousands of new jobs,[16] concentrated in high-skilled engineering roles, within the next few years.

Today the majority of students enrolled in U.S. universities and colleges do not have sufficient work experience to take on technical/engineering positions in semiconductor fabs.[17] Therefore, there is an urgent need to provide students with more hands-on training opportunities such as apprenticeships and internships. Also, updating of educational curricula and of university research and training facilities is needed since the forefront of chip design and manufacturing technology continues to advance at a rapid pace with new microprocessor architectures for specific applications, heterogeneous integration of a diversity of devices for enhanced system functionality, and multiple-chip packaging for optimal performance-power-cost tradeoff, *etc*.

Growing the Microelectronics Industry Talent Pool with Speed and Scale

To meet this urgent and growing U.S. microelectronics workforce development (WFD) need, professors across the U.S. are advocating for the establishment of a collaborative nationwide network of universities and community colleges – referred to herein as the American Semiconductor Academy (ASA) – to increase access to education and training for technical careers in the microelectronics industry, particularly in semiconductor manufacturing.

The ASA Initiative is aimed to dramatically increase the supply of talent and innovation needed to grow the U.S. microelectronics industry, by broadly engaging and empowering faculty and by incentivizing students enrolled at U.S. universities and colleges to pursue careers in the microelectronics industry. Specifically:

1. An up-to-date and comprehensive curriculum in integrated circuits and systems, semiconductor materials and devices, and micro-/nano-fabrication technology will be developed in partnership with the industry and shared across the ASA network, to facilitate education of a broad diversity of undergraduate and graduate students, in order to prepare them well to enter the U.S. microelectronics workforce;
2. Hands-on training (apprenticeships) in semiconductors and integrated circuits, microfabrication, and wafer processing tools will occur at ASA-networked universities that are equipped and staffed to support this training. These facilities will be accessible to all students who have completed prerequisite courses through the ASA network. Students who complete these courses and training will be well prepared for industrial internship opportunities leading to careers.

[15] Chris Richard, Karthik Ramachandran, and Ivan Pandoy. Deloitte and SEMI. 2017 SEMI-Deloitte Workforce Study. (2017).
[16] https://www.semiconductors.org/wp-content/uploads/2021/05/SIA-Impact_May2021-FINAL-May-19-2021_2.pdf
[17] https://cset.georgetown.edu/wp-content/uploads/CSET-Reshoring-Chipmaking-Capacity-Requires-High-Skilled-Foreign-Talent.pdf

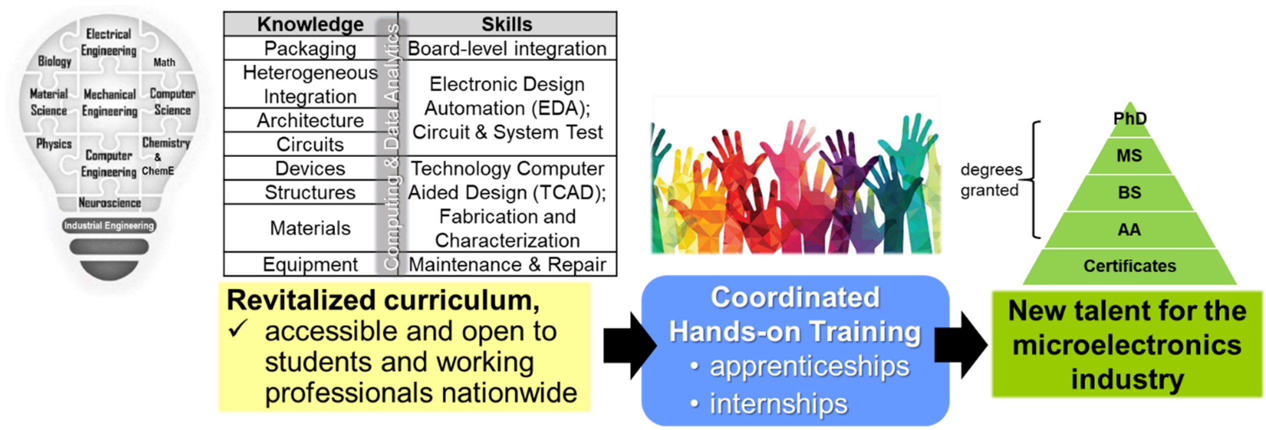

Figure 1: Paving a broad and diverse WFD pathway for the U.S microelectronics industry

A novel aspect of the ASA initiative is that promotes nationwide collaboration between universities and community colleges working collectively with companies across the microelectronics ecosystem to educate and train a broad diversity of students and to give them hands-on learning experiences. Such a large-scale effort is made possible through another novel aspect of this initiative: a partnership with SEMI, the global industry association representing more than 2,500 member companies across the electronics design and manufacturing supply chain. SEMI offers experiential learning and training programs that complement the degree-oriented education programs offered by universities and colleges, and also gives students greater visibility into rewarding professional careers in the industry. The ASA-SEMI partnership aims to connect over 200 universities and community colleges (depending on the level of funding) to more than 1,500 SEMI member companies with U.S. operations. In addition to revitalizing a comprehensive curriculum that spans multiple disciplines and credential levels, these institutions and organizations will coordinate hands-on training and apprenticeships for students, paving a broad pathway for WFD to meet the microelectronics industry's talent needs (Figure 1).

This partnership will leverage and complement other WFD programs such as the National Science Foundation (NSF) Advanced Technological Education (ATE) program that prepares community college students for technician jobs in high-technology fields; the NSF National GEM Consortium that provides graduate fellowships to students from underrepresented groups (African Americans, Native Americans, and Hispanic/Latinx Americans); the Department of Energy (DOE) Minority-Serving Institution Partnership Program (MSIPP) that enhances research-oriented education capacity at MSIs; and the Department of Defense (DOD) Scalable Asymmetric Lifecycle Engagement (SCALE) program that addresses the WFD needs of the defense industry, to name just a few examples.

A cornerstone of the ASA and SEMI partnership is a commitment to foster equity and inclusion and to enrich the diversity of the talent pool by including minority-serving institutions and community colleges nationwide, sharing resources and best practices, and offering hands-on learning, research experiences, and internship opportunities for their students and trainees.

Also, to ensure a robust microelectronics workforce in the coming decades, it is critical to build a pipeline of students at the primary and secondary level who are interested STEM. (High-profile scientific and technical challenges like the Space Race and the Human Genome Project inspired generations of young students to learn about space and biology and ultimately to pursue careers in aerospace and biotechnology.) Therefore we also aim to collaborate in K-12 outreach to increase awareness of the importance of microelectronics in modern society and to inspire future generations of talent for the industry.

The ASA-SEMI partnership objectives are to:

- broadly engage, enable, and empower university faculty for excellence in microelectronics education and training;
- align courses and competencies with present and future industry needs;
- increase awareness of career opportunities and create excitement among students for microelectronics-related fields;
- develop knowledgeable and skilled graduates, from technician to Ph.D. level;
- develop a diverse talent pathway from K-12 to re-skilling/up-skilling workers.

To achieve these objectives, new government funding is needed to support microelectronics curriculum revitalization and dissemination; to incentivize universities to hire new faculty (to increase the capacity of microelectronics-related educational programs); to upgrade existing educational/research laboratory facilities and equipment critical for student hands-on training; to cover the operational costs of hands-on training at ASA universities and colleges; and to provide student incentives (*e.g.*, scholarships, fellowships, paid apprenticeships).

It should be noted that careers in microelectronics research and development – critical for maintaining our country's technological leadership – often require graduate-level training, whereas careers in software engineering generally require a bachelor's degree or less and offer higher starting salaries, *i.e.*, student incentives are necessary to attract students to careers in hardware engineering. This is why sufficient government funding is critical to grow the domestic pipeline of students in microelectronics-related graduate programs.

The Semiconductor Industry Association has estimated that $50B invested by the federal government will result in 42,000 new jobs in semiconductor manufacturing over 5 years, leading to a total of 280,000 new jobs in the U.S. economy.[18] The U.S. should invest now to grow the domestic pipeline of students in order to be able to fill these new positions. Only a broad, inclusive and collaborative network of universities and colleges – the ASA – can sustainably meet this growing workforce development need with the necessary speed, scale and impact.

Thank you for holding this important stakeholder hearing. I look forward to answering your questions and working with you to strengthen the U.S. microelectronics workforce.

[18] https://www.semiconductors.org/wp-content/uploads/2021/05/SIA-Impact_May2021-FINAL-May-19-2021_2.pdf