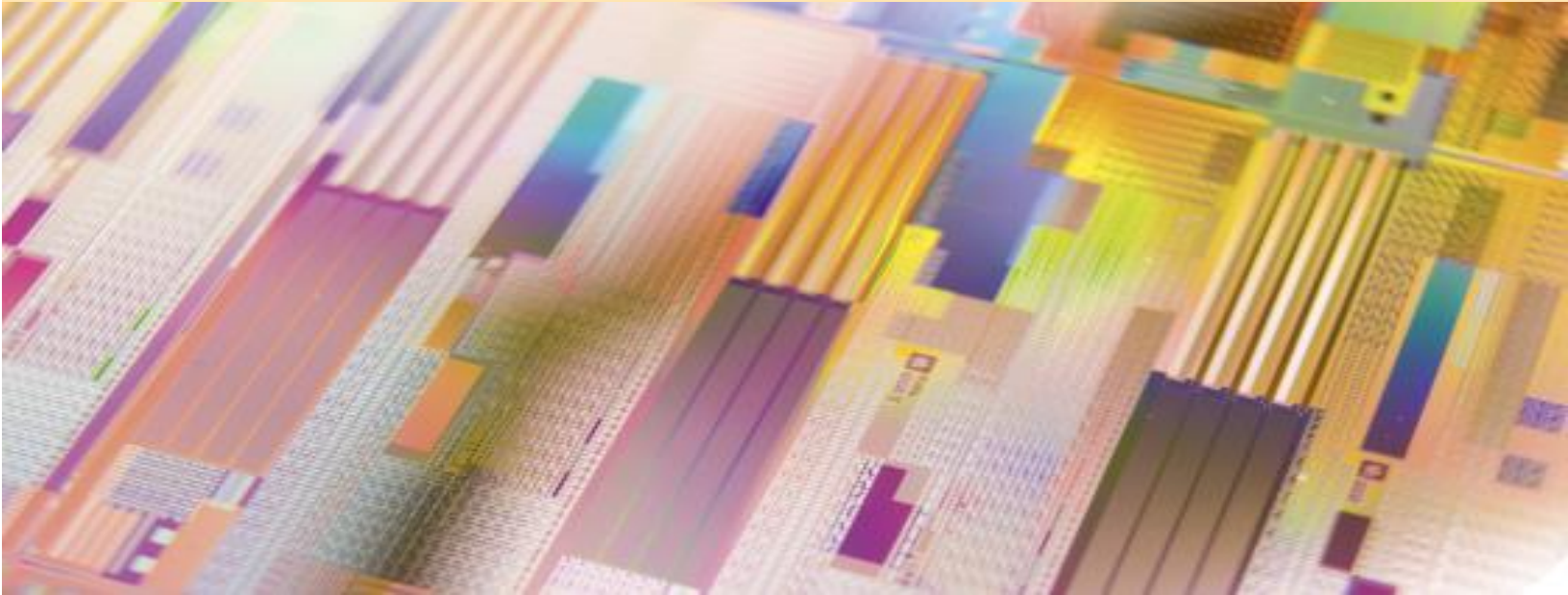# Workshop on Microelectronics and Advanced Packaging Workforce Development

November 12, 2021

Organizing Committee and Panel Moderators:

Peter Bermel, Elmore Associate Professor of Electrical and Computer Engineering, Purdue University

Bill Chappell, CTO, Azure Global – Microsoft

Cristina Farmus, Chief of Staff to the Executive Vice President for Strategic Initiatives, Purdue University

Steve Goodnick, Professor, Deputy Director of ASU Lightworks, Arizona State University

Carol Handwerker, Reinhardt Schuhmann Jr. Professor of Materials Engineering and Professor of Environmental and Ecological Engineering, Purdue University

Mark Lundstrom, Don and Carol Scifres Distinguished Professor of Electrical and Computer Engineering, Purdue University

Theresa Mayer, Executive Vice President for Research and Partnerships, Purdue University

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A recording of the workshop is available at the link below:

https://engineering.purdue.edu/Engr/AboutUs/News/Events/purdue-microelectronics-and-advanced-packaging-workforce-development-workshop

Disclaimer

This report represents summarizes the interpretation and conclusions of the workshop organizers. Questions, comments, and ideas for follow up workshops are encouraged. Please send them to Cristina Farmus at cfarmus@purdue.edu.

Executive Summary

Semiconductor electronics are among the most sophisticated technology products produced at scale. Without semiconductors, life as we know it would not be possible. Today, the U.S. consumes almost half of all chips produced globally, but manufactures only 12%. Coupled with an explosion in the demand for chips, the pandemic created chip shortages, supply chain issues, and security challenges, resulting in a new and growing appreciation that any nation that aims to control its destiny must lead in semiconductor design and manufacturing. A much larger U.S. microelectronics workforce with the expertise to design and manufacture semiconductors is urgently needed.

Purdue University organized a **workshop on November 12, 2021** to discuss challenges and opportunities related to workforce development for microelectronics and advanced packaging in the U.S. Representatives from **industry, academia, state and federal government** addressed how to modernize and scale-up educational programs, offer innovative online and hands-on training, link skill sets and educational programs to specific jobs, and improve programs for trusted and assured electronics. Special consideration was given to potential **new funding for comprehensive workforce development programs**.

The workshop, attended by over 200 virtual participants, consisted of three panel discussions: **general challenges** for workforce development in the U.S., **commercial** applications, and **defense and secure** applications. Panelists stressed that the nation's strategy to re-shore the semiconductors industry depends on growing a highly skilled, creative, innovative, and much **larger microelectronics workforce**. Talent is needed at all levels: skilled technicians and operators at the associate level, B.S., M.S. and Ph.D. engineers and scientists. The **gap is particularly critical in the defense sector**, which faces an aging workforce and the added U.S. citizenship requirement for employment.

Several recommendations stem from the issues identified. Universities must **attract more students to microelectronics and create degree programs and certificates** across the entire supply chain. New partnership models across **academia, community colleges, industry, and government** are needed to **articulate the knowledge, skills, and abilities of this new workforce**. Special attention should be paid to **hands-on training and online programs**. These investments need to be scaled up to rapidly educate thousands of students and will require **significant funding from the federal government and industry**.

The **urgency of the workforce challenge** must be immediately understood and acted upon. We must collectively develop solutions to ensure **excellence at scale**. Manufacturing incentives in the pending USICA legislation are essential to regaining U.S. microelectronics leadership and re-building our manufacturing capacity, but they must be matched by equal **investments in the educational system** to re-build the microelectronics workforce.

We thank the panelists, moderators, and participants who underscored the critical importance of the challenge. **We hope this workshop serves as a call to action for a collective effort to address the workforce challenges for a new era of U.S. leadership in microelectronics.** This workshop will be followed by others focused on the roles that professional societies can play, and best practices and synergies for secure applications.

Underlying Conditions

The workshop consisted of three panel discussions. The first was a broad look at where the microelectronics industry is, where it is headed, and what the current and anticipated challenges and opportunities are. The second panel focused on identifying strategies and opportunities for workforce development for commercial microelectronics. The third panel discussed current and planned programs for workforce development in the defense sector and how they might be grown and leveraged. While each panel provided a distinct perspective, some common underlying conditions emerged.

1. A highly skilled, creative, innovative, and **much larger microelectronics workforce** is a critical factor in the nation's strategy to re-shore and re-vitalize U.S. microelectronics.

2. There is already a serious and growing gap in the supply and demand for microelectronics technicians and engineers, and the shortage of talent will grow even larger as we grow microelectronics in the U.S. The **gap is especially serious in the defense sector, which mostly requires employees to be U.S. citizens**.

3. The **need for talent is across the spectrum**, from skilled technicians and operators at the associate degree level, to B.S., M.S. and Ph.D. engineers and scientists.

Issues and Recommendations

	Issues	Recommendations
1	How can we prepare the next generation of US students for success with microelectronics employers?	**Faculty should work closely with colleagues in industry** to understand how to prepare Associate, BS, MS, and PhD students for careers in 21st century electronics. What are we doing well? Where do we need to improve? What do we need to add? What can be eliminated to make room in the curriculum?
2	How can we help existing US microelectronics employees to continuously improve their skills?	**Microelectronics curricula needs to be revised, expanded, and re-invigorated** for a new era by offering certificates, minors, and degrees to students and practicing engineers.
3	How can we ensure US students are the most competitive for new positions in the global microelectronics industry?	Academia should work with industry and government to **articulate the specific knowledge, skills, abilities (KSA)** for the jobs that need to be filled across the country. Academics should then map these KSAs into our curricula. Good examples are NIST's NICE framework and the DOD SCALE program._ _https://niccs.cisa.gov/workforce-development/cyber-security-workforce-framework.
4	Universities are struggling to keep up with the demand for engineering and computer science talent. How to grow enrollments faster and ensure students pursue careers in microelectronics? How to attract students early and create enthusiasm for careers in microelectronics?	Universities should work with industry and community colleges to **find best practices and the best ways to partner** to increase the supply of skilled technicians._ _Universities and community colleges need to **learn how to better articulate the critical importance of microelectronics to society**, the challenge, excitement, and opportunity for impact of careers in microelectronics.
5	Microelectronics is one of the most expensive engineering majors due to the need for updated state-of-the-art laboratory facilities for hands-on training.	Universities and companies need to identify the hands-on training necessary for careers in microelectronics and find ways to share resources, while including community colleges. This gap can be closed by **receiving federal funding to upgrade training facilities and systems, and by devising creative strategies to educate students** at scale, from shared on-line simulations to collaborative facilities.

6	In an era of increased attention to college affordability, colleges are currently challenged to support rapidly growing student enrollments. Running hands-on programs and online programs is staff intensive and expensive.	Universities and community colleges need to develop a plan for **online and virtual hands-on education for microelectronics**, courses should be accessible for credit to students at university and community college. To support the additional, substantial requirements of microelectronics education and training, instructional staff, faculty, and other support staff must grow even faster, as must resources for on-line education.
7	Given the magnitude of the challenge and the opportunities that success will bring, new modes of government, industry, university partnerships to support, coordinate, and leverage programs and to accelerate the pace of innovation are needed.	Industry, academia, and government will have to address the challenge together. There must be serious discussion about different models, opportunities, and resources that can be brought to bear in the short and long term. A **strategy for stronger industry and national laboratory engagement in workforce development should be developed**. SCALE is an example in which public, private, and academic partners work together to define standards and provide opportunities for current students. See: https://www.purdue.edu/discoverypark/scale/
8	Given the exploding demands for STEM graduates, it will not be possible in the short term to meet the demand for a larger microelectronics workforce with domestic talent.	The U.S. is a desired destination for a high percentage of engineering students worldwide. We should exploit this **competitive advantage in the global competition for STEM talent** while we build out the domestic workforce.
9	How can academia avoid taking a fragmented, siloed approach to curriculum, where each university develops a new program from scratch on its own?	**Universities need to establish a microelectronics education alliance** so that the government can work with universities and companies across the U.S. to share resources, ideas, and best practices, and to amplify the message about the many opportunities for interesting and impactful careers in microelectronics. Additionally, universities should jointly engage industry partners to modernize microelectronics-related courses - from materials science to integrated circuit design to chip architecture and packaging – and to make curricular materials and industry-standard software tools accessible to faculty and students at all participating schools. This way, faculty across the country will be empowered and supported to revitalize their microelectronics curriculum to attract and develop a broad diversity of talent for the semiconductor industry.

Panel 1: Microelectronics and Advanced Packaging: Trends, Challenges, and Opportunities

Moderated by Dr. Bill Chappell, CTO Azure Global/ VP of Mission Systems at Microsoft.

Panelists:

- **Deirdre Hanford**, Chief Security Officer, Synopsys

- **Chandra Mouli**, Senior Technology Director, R&D Device Technology, Micron Technology

- **Mark Papermaster**, Chief Technology Officer and Executive Vice President, Technology and Engineering, AMD

- **Sreenivas Ramaswamy**, Senior Policy Advisor, Office of Policy and Strategic Planning, US Department of Commerce

- **Thomas Sonderman**, President & CEO, SkyWater Technology

The Panel 1 discussion was a broad look at where the U.S. microelectronics industry is today, the changes that are rapidly occurring, and the implications for the workforce of the future. While the focus of the Chips Act is on manufacturing, the U.S. is strong in chip design and design automation/EDA, and protecting that strength should be part of the semiconductor strategy. In this era of a slow-down in Moore's Law, new ways to increase performance at the leading edge must be identified. Progress will also be driven by custom (and more affordable) design, 3D IC's, heterogeneous integration and advanced packaging, each of which presents both design and manufacturing challenges. AI-assisted design will become the rule, and confidentiality, integrity, and availability will be key issues for both the defense and commercial sectors. Memory is a critical component of growing importance to all electronic systems and will require new approaches to address the exploding demands for data and the special needs of machine learning. Very large investments in R&D will be required. The U.S. is home Micron, one of the world's largest memory manufacturers which faces stiff competition from Asia. The nation's success in bringing semiconductor manufacturing back will require investments in both facilities and equipment and in the workforce. It is not yet clear where federal funds will flow. We are, in fact, at a crossroads. One road focuses on growing capacity – doing more of what we are doing now. The other road sees this as special moment in history in which we can change the trajectory and move to the front of the pack in the global semiconductor economy.

Each of the panelists spoke about the critical importance of talent and of the skills gap that is already large growing. Company survival is all about innovation, and there was discussion about the need to accelerate the pace of innovation through new modes of collaboration, shared facilities for rapid prototyping, more coordination, lowering the

barriers to design, learning how to fail fast, etc. Companies are challenged to find people with the right skills – not only for semiconductor manufacturing but for design as well. A diversity of talent is needed, not only engineers but also skilled technicians, welders, etc. Engineering enrollments in the U.S. are growing rapidly, but for the gap between supply and demand in microelectronics is growing. Growing the engineering workforce still more is essential, but part of the solution will also need to come from immigration.

The industry has been through several "near-death" experiences over the years, but creative engineers have always found new ways to keep Moore's Law going. Today, however, the challenge is a different one. Moore's Law as traditionally understood in terms of down-scaling devices will not be the main driver of progress in the coming decades. Creative new ways to increase performance and lower cost of electronics are needed. Students tend to think of semiconductors as a mature industry without the excitement of fields like machine learning, data science, autonomous systems, etc. Helping them understand that these fields depend on semiconductors and that we are at the beginning of an exciting new era of semiconductor electronics that will address the exploding demands for computing, data, sensing, and communication, will help us attract the most creative, talented, and energetic young people to careers in microelectronics.

To summarize some key take-aways from Panel 1:

- Innovation, innovation, innovation – company success is all about innovation.

- Microelectronics is not a mature, slow-moving field, it is one in which the pace of innovation is increasing.

- To secure the nation's future, semiconductor manufacturing must be re-shored and re-energized. It is not enough to just increase our design and manufacturing capacity, federal support should also be directed at changing the trajectory of microelectronics in a new, post Moore's Law era of electronics.

- There is a large and growing gap in the demand for people with the needed skills and the supply, and this is across the spectrum from skilled technicians to Ph.D.'s.

- Given the magnitude of the challenges and the opportunities too, more collaboration and coordination will be needed. Universities will play a critical role by increasing the supply of people with the needed skills, but they can also be a source of creativity and innovation in a new era of electronics.

Panel 2: Workforce Development Challenges and Proposed Solutions: Commercial Applications

Moderated by Theresa Mayer, Executive Vice President for Research & Partnerships, Purdue University.

Panelists:

- **Dr. Shekhar Bhansali**, NSF Director, Division of Electrical, Communications and Cyber Systems, National Science Foundation

- **Dr. Charles Clancy**, Senior Vice President & General Manager, MITRE Labs

- **Dr. Willie May**, Vice President for Research and Economic Development, Morgan State University

- **Dr. Todd Younkin**, President and CEO, Semiconductor Research Corporation

Panel 2 focused on talent development for microelectronics and advanced packaging which in the words of Charles Clancy, is a "whole of Nation" problem. Theresa Mayer gave some key statistics, including that the number of microelectronics and advanced packaging openings listed on publicly-accessible job databases doubled from 2020 to approximately 21,370 as of November 9, 2021. (See the appendix). To put this in context, NIST reported 464,420 openings in cybersecurity spanning job markets for: companies, national infrastructure, state and local governments, and government agencies responsible for defense and national security. These are just two examples that indicate the magnitude of the national problem with the existing STEM workforce. The expected growth in semiconductor manufacturing, advanced packaging, and their supply chains that will accompany the CHIP Act investment must be supported by a workforce that is "ready, willing, and able" to take the jobs they will offer. The charge to the panel was to discuss, from the vantage point of the commercial sector, how we might begin solving this problem. The consensus was that this is a national issue that requires us to completely reimagine how we work together.

Key take-aways of Panel 2 were:

- We must "win the hearts and minds" of students across the nation by presenting a case for their choosing rewarding and meaningful careers in microelectronics and advanced packaging. We need to create new ways to convince students across the country to pursue education and training in microelectronics and advanced packaging and then provide them with unprecedented opportunities to thrive.

a) With our current approach, we have turned microelectronics and advanced packaging into commodities, taking for granted the next generation of discoveries for "smaller, faster, smarter, cheaper" technologies needed for next year's cell-phones. Thus, the people and jobs underpinning these become essentially invisible.

b) Today's students want to both make a difference in the world and have well-paying, intellectually rewarding jobs that they and their families can be proud of. That their creativity and hard work are needed and valued will be essential to making these connections.

c) Today's students want to address major national challenges to create new technologies to combat climate change, provide clean energy and clean water, develop sustainable solutions, mitigate natural and man-made crises, including pandemics, and enable economic and national security. Solutions to many of these will rely on advances in microelectronics and advanced packaging technologies. It is up to us to make the connection real for students.

- With existing curricula, students generally have no context to connect what they are learning in standard curricula with careers and opportunities in microelectronics and advanced packaging. There is enormous potential for improvement, including:

a) sharing best-in-class curricula and classes,

b) incorporating experiential learning and internships,

c) creating R&D partnerships that create connections with potential employers,

d) providing scholarships for students at all levels and

e) developing meaningful incentives for faculty teaching, research, and networking in these topics

f) funding local facilities to support both curriculum changes and R&D, while also providing access to SOTA facilities through partnership

- One step in strengthening the national microelectronics and advanced packaging ecosystem can be in matching specific types of jobs available with the knowledge, skills, and abilities (KSAs) the students at all levels will need. The NIST-led National Initiative for Cybersecurity Education Framework (NICE) provides a model for this. The DoD SCALE program does something similar for microelectronics where DoD agencies determine the KSAs needed for specific DoD jobs in high priority areas, including radiation-hardened electronics, heterogeneous integration, system on chip, embedded systems, and supply chains. In both NICE and SCALE, the KSAs are intended to drive curriculum and integrated program development to link students to prospective employers.

- NSF has the potential to play a bigger role in workforce development in microelectronics and advanced packaging. Traditional NSF programs, such as the ERC and STC programs, do not currently have centers in this area. Proposers must learn to develop a compelling vision for transformational R&D, curriculum changes, broader societal impacts, and workforce development in microelectronics and workforce development. There will likely be substantial groundwork involved, including proposing NSF workshops to examine how to affect change at the scale necessary to affect the national microelectronics and advanced packaging ecosystem.

- Working with HBCUs and MSIs to include groups underrepresented in STEM can help address some of the gaps – e.g., 25% of Black engineers graduate from HBCUs even though HBCUs comprise only 5% of the nation's universities. However, "winning the hearts and minds" of students remains a significant challenge.

- R&D organizations, like SRC and MITRE, can have important roles to play in strengthening the microelectronics ecosystem through workforce development, particularly as they invest more in undergraduates as well as in graduate student, and in supporting diversity, inclusion, and equity. Continued discussion and analysis are necessary to examine how to do this at the scale needed at the national level.

To summarize some key take-aways and recommendations from Panel 2

- Talent is a major bottleneck for the US semiconductor & advanced packaging industry today.

- Relying on the status quo approach to fill these needs is not working, and the gap is growing. A broader, systematic strategy is needed for "winning the hearts and minds" of next-generation students and innovators from universities and colleges across the nation. Communicating this at a national, even White House-level, will be important to show the critical importance of investments in the microelectronic workforce.

- Key methods may include providing scholarship support and experiential learning opportunities for students; and increasing inclusivity.

- Realizing rapid growth in the trained microelectronics workforce will require a new commitment to microelectronic education. New approaches and substantial funding from industry and from a wide range of government agencies, such as NSF, NIST, DoE, the US Department of Education, the Department of Labor, and DoD will be needed. (Panel 3 discussed specific challenges, opportunities, and existing program supported by the DoD and NNSA DoE programs.)

Panel 3: Workforce Development Challenges and Proposed Solutions: Defense and Secure Applications

Moderated by Dr. Stephen Goodnick, Professor, Deputy director of ASU Lightworks, Arizona State University

Panelists:

- **Scott Frost**, Industrial Base Systems Engineer, Analytic Services, Inc.; Lead, National Imperative for Industrial Skills Initiative, Industrial Base Analysis and Sustainment, Department of Defense

- **Rahni Kellum**, Technical Business Development Specialist START-HBCU Program Lead, Academic Alliance Program Supporting Purdue & Illinois, Sandia National Laboratories

- **Dr. Nathan Nowlin**, Manager, Advanced Microsystems Radiation Effects, Sandia National Laboratories

- **Catherine J. Ortiz**, Principal Analyst, Analytic Services, Inc.; Industrial Base Analysis and Sustainment, Department of Defense

- **Dr. Kara Perry**, Co-Lead of the T&AM Education and Workforce Development Technical Execution Area

Panel 3 discussed the importance of developing a microelectronics workforce with specialized attributes suitable for careers in defense electronics. These include US citizenship in many cases, but also include specific knowledge, skills, and abilities. The panel discussed workforce needs across a range of levels of education, from Associate's through Ph.D. degrees, as well as a need for continuing education. Knowledge, skills, and abilities needed include a range of general skills associated with semiconductors, as well as specific topics like secure manufacturing and supply chains, as well as the physics of extreme environments (such as ionizing radiation, extreme temperatures, and more). The growing gap between the demand for microelectronics engineers in defense electronics and the supply was stressed, and the small numbers of U.S. students pursuing careers in defense electronics was identified as the biggest challenge.

Each of the panelists spoke about the importance of government agencies partnering with both industry and academia. This means that each stakeholder needs to invest time and share risk in the defense microelectronics workforce development space. Several examples of such efforts include the OUSD Acquisition & Sustainment Industrial Base (IBAS) program, which now leads the National Imperative for Industrial Skills initiative, as well as the Research & Engineering Trusted & Assured Microelectronics program, which supports several University-run programs including SCALE as part of a Public, Private, and

Academic Partnership (PPAP), and the START-HBCU program to increase research collaborations between Sandia National Laboratories and several major HBCUs nationwide. Important aspects of such models include defining a common goal by gathering input from stakeholders on specific workforce needs, as well as operating joint programs with active participation by all members.

Success in these efforts will require the DoD, national laboratories, and defense contractors to play an active role in workforce development. If will also require buy-in from academics, not only to run these programs, but also to make students aware of the opportunities for careers in defense electronics starting very early in their education while they are still undecided about their career choices. Competing against the commercial sector for microelectronics engineers is a challenge, but attractive aspects of these opportunities include higher levels of stability (30 years or more) and the opportunity to work on a wide range of interesting and socially beneficial and important projects.

To summarize some key recommendations from Panel 3:

- A stronger defense industrial base is needed to provide trusted and secure microelectronics, which requires a larger and more highly-skilled workforce.

- This will require expanding not just the number of engineers, but also the technician and operator workforce.

- A diverse range of US students need to be made aware of the range of opportunities, and the personal benefits of joining the defense microelectronics workforce, and to feel included.

- Partnerships between government, industry, and academia are needed to provide all the information and opportunities that are important for the students' success.

- A near-term goal is to increase the number of engineering students who choose careers in defense electronics, but the ultimate goal should be to greatly expand the size of the overall talent pool to meet the increasing demands.

Appendix: Summary of Anticipated Microelectronics Workforce Needs

According to a recent article, "the semiconductor industry had some 10,000 job openings that couldn't be filled fast enough, according to SEMI. 'Is there a shortage of people, yes or no? There is only one answer—yes. It's big time,' said Ajit Manocha, president and chief executive of SEMI' [1].

As of 9 November 2021, indeed.com lists 11,614 job openings in semiconductor manufacturing [2]. Similar searches for semiconductor design, semiconductor testing, semiconductor packaging, and microelectronics yield 12,326, 4,931, 2,624, and 1,489 openings, for a total of 21,370. This is approximately twice the number of openings as reported last year, on 23 September 2020, which indicates that rapid growth in the semiconductor and packaging areas is outstripping the national talent pool at this time.

If we expand the scope slightly to include cybersecurity writ large, NIST has a tracker examining national and local openings in these areas [3]. Currently, the NIST tracker reports a total of 464,420 openings nationally, with 36,248 openings in the public sector, and the remainder in the private sector. Given the overall size of the workforce, estimated at 956,341, the picture is of a rapidly growing sector that remains very undersupplied with sufficiently qualified workers. Given that cybersecurity and microelectronics draw from an overlapping set of majors and people, it appears likely that both areas are greatly undersupplied at this time.

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