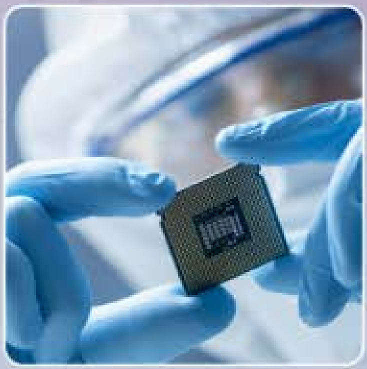
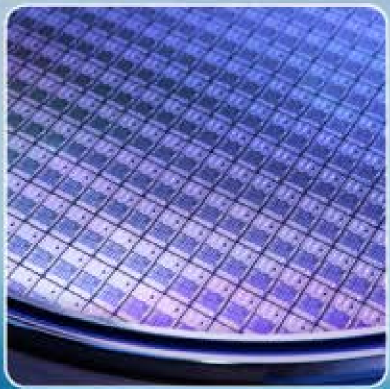
2024 Issue 3 // Volume 120

THE BRIDGE

The Magazine of IEEE-Eta Kappa Nu



Building Semiconductor Resilience



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2024 ISSUE 3 | Building Semiconductor Resilience

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Dr. Jason K. Hui

Epsilon Delta Chapter

"This issue of *THE BRIDGE* magazine focuses on the CHIPS Act, a landmark bill that was signed into law by U.S. President Joe Biden in August 2022. The act promises "to strengthen domestic semiconductor manufacturing, design, and research, fortify the economy and national security, and reinforce America's chip supply chains."

THE BRIDGE, October 2024

Letter from the Editor-in-Chief

Dear IEEE-HKN Members and Friends,

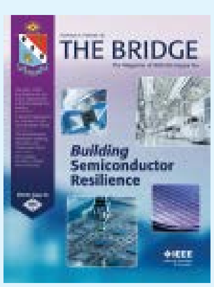
Happy anniversary! This year marks the 120th anniversary of HKN and the 140th anniversary of IEEE. On 28 October 1904, sophomore Maurice L. Carr and nine other undergraduates at the University of Illinois Urbana-Champaign formed the first chapter (Alpha Chapter) of Eta Kappa Nu based on the idea of establishing a collegiate society of electrical engineering students, 120 years ago. Carr would later serve as the society's first president. Today, IEEE-HKN spans 279 chapters worldwide and has over 200,000 members.

This issue of *THE BRIDGE* magazine focuses on the CHIPS Act, a landmark bill that was signed into law by U.S. President Joe Biden in August 2022. The act promises "to strengthen domestic semiconductor manufacturing, design, and research, fortify the economy and national security, and reinforce America's chip supply chains" [1]. We express our gratitude to Editorial Board member, Professor Hulya Kirkici for serving as guest editor and the authors of the feature articles. For more information on the CHIPS Act and opportunities for engagement, please visit the IEEE Global Semiconductors website.

We are pleased to announce that for an 11th consecutive year, IEEE-HKN and *THE BRIDGE* have been recognized with an APEX Award for Publication Excellence. Congratulations to guest editor, Professor Mohamed Essaaidi, IEEE-HKN Past President Sampathkumar Veeraraghavan, Editor-in-Chief Dr. Jason Hui, and the Editorial Board for receiving a Grand Award for the October 2023 issue on Humanitarian Technologies for a Sustainable Society. The APEX Awards attract many outstanding entries. In 2024, the competition selected only 100 Grand Award Winners out of 1,100+ entries. We also commend the winners of the 2024 IEEE-HKN Awards for their outstanding accomplishments and contributions, exemplifying a balance of scholarship, service, leadership, and character.

IEEE-HKN strives for effective communication through its various channels, including our website, YouTube, Facebook, LinkedIn, X, and this magazine. The Editorial Board welcomes your ideas and content and can be contacted by email at info@hkn.org. As always, you can access *THE BRIDGE* on the IEEE App, and you can find older archival issues in the Engineering and Technology History Wiki.

1. CHIPS for America Act & FABS Act



About the Cover

Semiconductors, materials that can conduct electricity under specific conditions, have shaped modern technology. The creation of these remarkable chips found in cell phones, computers, and all electronic devices involves hundreds of steps. The process transforms a simple silicon wafer into an integrated circuit containing billions of transistors, all within a chip–the size of a thumbnail. This cover illustration depicts how semiconductor chips are manufactured in industrial cleanrooms and inspected by process engineers.

Hulya Kirkici
Xi Chapter

"I could not imagine, that one day we, as a society, would reach the point of advanced technologies of today – computers, smartphones, smart homes, electric cars, and 24/7 connectivity through communication systems and information technologies."

THE BRIDGE, October 2024

Intro from the Guest Editor

A Whole World of Opportunities

Growing up as a little girl in a small town in Turkey, I could not imagine, that one day we, as a society, would reach the point of advanced technologies of today – computers, smartphones, smart homes, electric cars, and 24/7 connectivity through communication systems and information technologies. Most likely my first job after my bachelor's degree would have been in the microelectronics fabrication field, should I not have pursued postgraduate education and become a researcher and an educator. But then jobs in that field were not common. Over the years I taught circuits and systems, electronics, microfabrication, and pulsed power engineering which all deal with electronic devices, and yet never considered how important the workforce behind the semiconductors and fabrication of these advanced electronic devices, manufacturing, or supply chain is. We seldom think about what makes these electronic devices work and what materials are used to make them. But now we all recognize that semiconductors are at the heart of the enabling and essential technologies we all enjoy today as well as driving economic growth of the nations. Until the COVID-19 pandemic, society as a whole was unaware of the impact of the production and supply chain on electronic devices and merchandise depending on them to reach consumers. This triggered many nations, mostly Western nations and the United States to work together, share resources, and diversify semiconductor manufacturing as one article in this issue explains.

In the United States, in 2021, the Biden Administration implemented an industrial strategy to revitalize domestic manufacturing, create good-paying American jobs, strengthen American supply chains, and accelerate the industries of the future [1]. The following year the bipartisan CHIPS and Science Act of 2022 was signed. One of the thrust areas of the CHIPS Act is "Supporting Semiconductor Education and Training" programs aiming to raise student and educator awareness from all backgrounds and build the semiconductor industry's workforce. The success of the CHIPS Act will require collaboration between businesses, governments, education and training institutions, economic and workforce development organizations, unions, community-based organizations, and other supporting organizations to help recruit, train, hire, and retain a highly skilled semiconductor and construction workforce [2]. With the demand for semiconductors projected to increase significantly by 2030 and beyond, semiconductor companies are ramping up production and innovation to keep pace [3]. It is estimated that industry will add over 100,000 jobs by 2030 and educators and industry must work hand-and-hand to develop the workforce and expand economic opportunities for individuals and populations from all communities including but not limited to historically underserved communities, including women, people of color, workers in rural areas, and veterans.

When the CHIPS Act and Workforce Development issue of *THE BRIDGE* was proposed, the goal was to set the stage for opportunities and bring awareness to the next generation of engineering, computing, and technology professionals. These professionals will be at the forefront of the advancements in semiconductors from materials research, electronic device design, microfabrication processing and manufacturing, and developing advanced technologies, that we all enjoy and need. Reading this issue, we hope you find inspiration to get involved and become those in front of the advanced development and leaders of future semiconductor technologies and microelectronics.

Hulya Kirkici is Professor and former Department Chair of Electrical and Computer Engineering at the University of South Alabama. She received her B.S. and M.S. in physics from Middle East Technical University, Turkey and her Ph.D. in electrical engineering from

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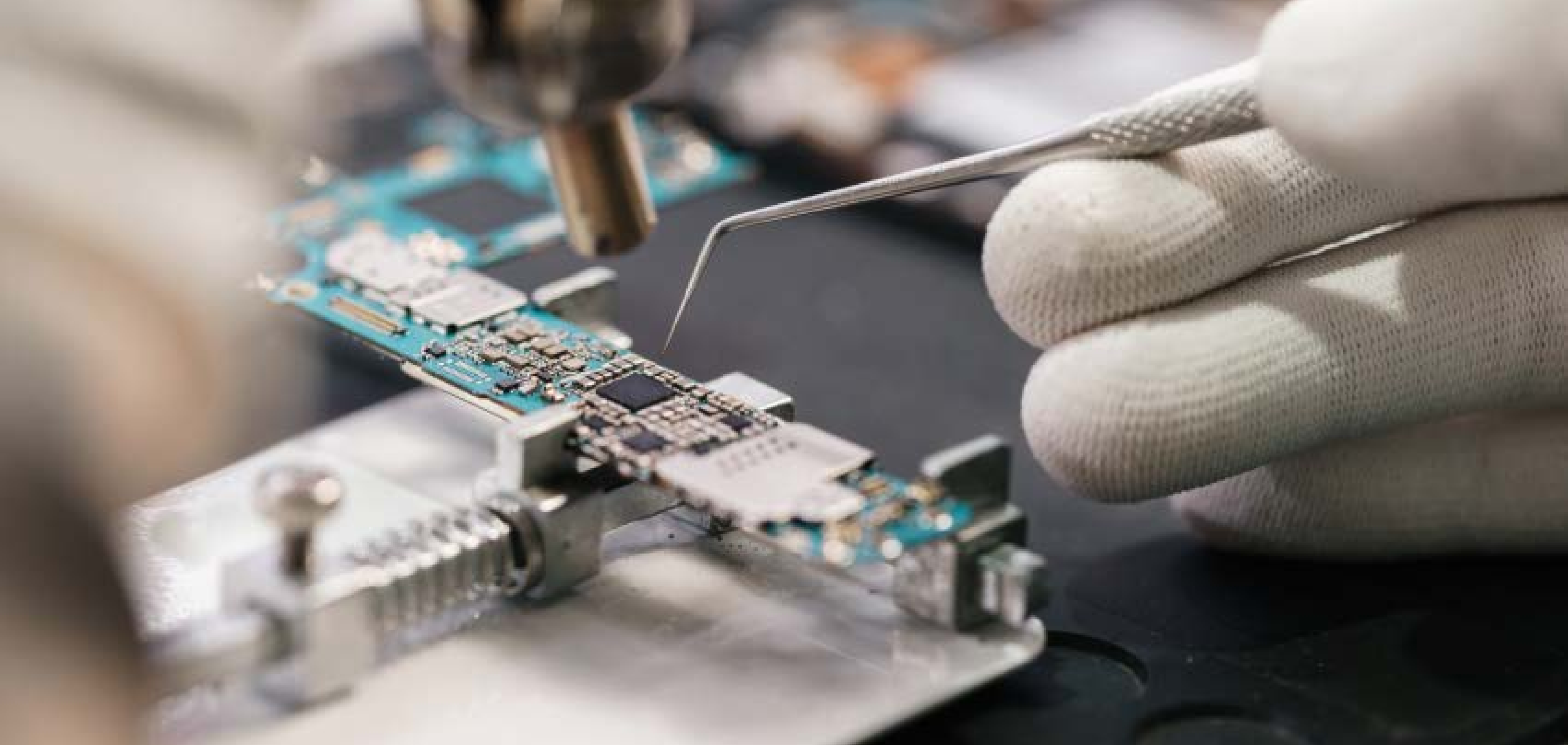

The 2022 CHIPS and Science Act and Future Opportunities in the Microelectronics Industry

Stephen M. Goodnick, School of Electrical Computer and Energy Engineering, Arizona State University, Tempe, AZ

Abstract

The microelectronics industry has been the driving force for the information age in terms of the exponential growth in computing, communications, the internet, and more recently, artificial intelligence. It has been driven primarily by the manufacture of semiconductor integrated circuits (ICs) of increasing component density and complexity. Since its beginnings with the development of the transistor and integrated circuit in the U.S. and the growth of Silicon Valley, the microelectronics industry has become fully multinational, with present-day manufacturing occurring primarily through foundries in Asia. The CHIPS and Science Act signed into law in 2022 represents the single largest investment by the U.S. federal government in the semiconductor industry, with a goal of greatly increasing domestic semiconductor manufacturing as well as expanding the ecosystem of IC design and processing tools surrounding this industry. Expectations indicate that this investment could potentially double the current workforce in the semiconductor industry, offering significant career opportunities for students and workers in IEEE fields of interest. This article provides a brief introduction to semiconductor manufacturing and the design of ICs, and a historical context for the CHIPS Act. It then concludes with an overview of the future workforce needs for the microelectronics industry, specifically, the career opportunities and challenges in terms of a modern-day approach to recruitment, education, and training to meet the demands of the future..

Introduction

The microelectronics industry has historically been and continues to be the backbone of the information technology revolution which is ubiquitous in every aspect of modern life. Semiconductor-based microelectronics (also called the semiconductor industry, sometimes used interchangeably with the microelectronics industry) is the driving technology underlying modern computing (from personal to high-performance computing), communications, the internet, and most recently, the rapid advances in artificial intelligence (AI). Here microelectronics is referred to in its broadest sense to include digital logic and memory, analog and mixed signal electronics, power electronics, high frequency electronics, optoelectronics (semiconductor lasers, light-emitting diodes (LEDs), detectors, photovoltaics, etc.), micro/nano-electro-mechanical systems (MEMS/NEMS), and neuromorphic architectures driving AI. At its heart is the integrated circuit (IC), primarily composed of monolithically integrated transistors on the same substrate, ranging from a few thousand components in power electronic modules to hundreds of billions of transistors in modern microprocessors, graphical processing units (GPUs), and solid-state memories.

The large-scale manufacture of semiconductor microelectronics involves many steps and many disciplines from end to end: physics, chemistry, materials science, engineering (electrical, computer, chemical, mechanical, etc.), and computer science. The starting point is the chemical production of very pure semiconductor material, typically as thin wafers. For silicon (Si) CMOS (complementary metal-oxide-semiconductor) IC technology (by far the largest market

Fig. 1. Semiconductor cleanroom facility (Wikimedia Commons, NASA GRC-1998-C-01261).

share), this is accomplished via the Czochralski method that entails pulling a rotating seed of single crystal Si from a molten vat to produce a high-purity, single crystal, cylindrical *boule*, which is then cut into individual wafers a few hundred micrometers in thickness. These wafers are then shipped to semiconductor fabrication facilities (or *fabs*) as the starting material for what's referred to as semiconductor processing, performed in an ultraclean environment or *cleanroom* facility (Figure 1). The surface of each wafer is patterned using optical (now deep ultraviolet *(UV)* wavelengths) lithography, similar to photography, where an image is transferred to the substrate by exposing a light-sensitive layer (called a photoresist) through a mask with the pattern. A variety of processes, like oxidation, dopant diffusion, material deposition, etching, etc., together with lithography, are used to define individual transistors and their circuits through multiple mask steps. Unique integrated circuits (which can contain hundreds of billions of transistors) are defined within individual rectangular dies across the wafer, which are then diced up to make individual semiconductor *chips* (Figure 2). Due to the economy of scale, the diameter of Si wafers has progressively increased from one-inch diameter in the 1960s to present-day state-of-the-art fabs using 300 mm (12 in) wafers, so that the number of chips produced per wafer roughly increases as the square of the diameter (i.e., the area). Semiconductor fabs are often identified in terms of their wafer handling capacity (e.g., a 300 mm fab).

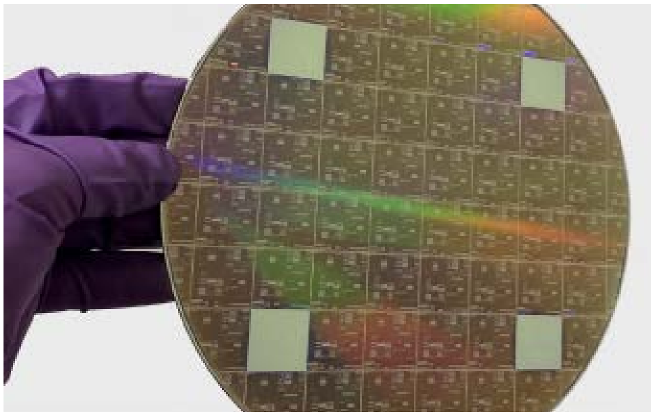

Fig. 2. 200 mm Si waver comprised of individual IC chips (Goldenvu, CC BY-SA 4.0, via Wikimedia Commons).

Another defining feature of a semiconductor fabrication process is the minimum feature size that can be defined, related to the minimum size of a transistor, which for metal-oxide-semiconductor field-effect transistors (MOSFETs, the dominant Si technology), is typically the gate length. This minimum feature size defines what is referred to as the *technology node*, which increasingly refers to a specific generation of chips rather than a specific feature size on the chip. Generally, the minimum feature size that can be defined lithographically cannot be smaller than the effective wavelength of light. With the advancements of lithography using increasingly shorter wavelengths of light through deep UV sources and immersion technology, the current technology nodes of the most advanced production facilities are below 4 nm. Ultimately, this technology node is a measure of how many transistors can be integrated per unit area on a chip, which has been a driver for *Moore's law*.

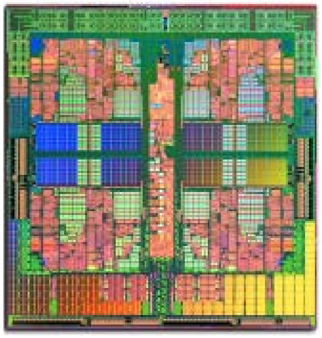

Fig. 3. Quad-Core AMD Opteron processor (Advanced Micro Devices Inc. (AMD) via Wikimedia Commons).

The exponential increase in the number of transistors per chip through reduction of transistor size, as well as the increasing size of wafers to increase the chip number, has in turn led to an exponential increase in the cost of building a semiconductor fab. For example, the deep UV photolithography tools necessary for sub-10 nm feature sizes cost around $200-300 million each. A state-of-the-art fabrication facility today costs more than $20 billion to build [1], and fewer and fewer companies can afford to maintain their fabrication facilities. These companies that run fabrication facilities are referred to as integrated device manufacturers or IDMs. A trend over the past decades, starting in the 1990s, has been for established semiconductor companies and new ventures to outsource their fabrication facilities to Asia due to lower construction and operating costs, better supply chains, and proximity to back-end and final assembly or *packaging facilities*. Most semiconductor chips are now fabricated in *foundries*, where companies can send their chip designs electronically to be mass-produced and shipped back. The world's largest foundries are all located in Asia, where 83% of semiconductor manufacturing occurs, the largest two being Samsung in Korea and Taiwan Semiconductor Manufacturing Corporation (TSMC). In contrast, while Intel is the third largest manufacturer of semiconductor chips, particularly microprocessors, which are fabricated in the U.S. in Arizona and Oregon, it does not presently provide foundry services. The rise of large-scale foundry services has in turn led to a substantial growth of so-called *fabless* companies (Nvidia being a prime example in terms of the production of AI chips) and an associated electronic design automation (EDA) industry based primarily in the U.S. that provides the increasingly sophisticated and complicated design tools necessary to design VLSI (very-large-scale integration) chips. There is also an ecosystem of semiconductor equipment manufacturers that supply wafer fabrication equipment (WFE), many of which are located in the U.S., Europe, and Japan.

In addition to the Si-based microelectronics industry, semiconductor technology emerges in other large-scale manufacturing. In relation to renewable energy and energy efficiency, two of the largest manufacturing sectors include photovoltaic cells and modules (primarily Si-based) and solid-state lighting (primarily III-V semiconductor-based). Asia, particularly China, dominates the global manufacturing market in both sectors due to the economic advantages mentioned above, despite their initial origins in the U.S., Europe, and Japan. Other smaller, more niche markets for semiconductors include high- frequency/microwave components, both III-V and Si-based, for communications, radar, and other high-frequency applications. Optoelectronics for optical communications is also a smaller but important market, using primarily III-V semiconductor materials for semiconductor lasers, LEDs, and detectors. Power electronics is also a growing area, as solid-state components increasingly replace electromagnetic devices in controlling power flow in the electrical grid. The microwave, optoelectronic, and power electronics industries are still manufactured in the U.S. and Europe, as well as Asia.

The U.S. Congress passed the bipartisan CHIPS and Science Act, which President Biden signed on August 9, 2022, in response to the loss of domestic semiconductor manufacturing and associated jobs in the U.S. to Asia, the dependence of the semiconductor industry on offshore manufacturing and supply chains, and potential national security risks. In what follows, we provide a brief historical reflection on the growth of the semiconductor industry, from the discovery of the transistor in the late 1940s to the present. This is followed by a discussion of the CHIPS Act itself and what is contained within. Related to the CHIPs Act are the workforce needs of the microelectronics industry and opportunities for careers in this field, which are discussed in the final section.

Historical Context

The microelectronics industry is based on the transistor, a three-terminal device that amplifies a signal in terms of its power and can act as an on-off switch. Detailed descriptions of the physics and operation of semiconductor devices, including transistors, are given in many standard textbooks (e.g., [2]). An excellent account of the discovery of the transistor and the later history of its impact on the growth of the semiconductor industry in Silicon Valley can be found in the book *Crystal Fire* [3, 4], as well as other articles in the current issue.

By far the most dominant transistor technology is the MOSFET. Its operation is based on the field effect, in which a field at the surface of a semiconductor can modulate the conductivity of a channel formed from the opposite type carrier from that of the bulk, with PMOS being p-channel devices (where the current is carried by positive charge) and NMOS being n-channel devices. The field-effect transistor (FET) was first proposed and patented by Julius E. Lilienfeld in 1926 [5] but the MOSFET was not realized until 1959 by Mohamed Atalla and Dawon Kahng at Bell Labs after the ability to passivate the surface of Si using thermal oxidation (forming silicon dioxide (SiO2) on Si) was demonstrated by researchers at Bell Labs earlier in the decade.

Before the demonstration of the MOSFET, the first working transistor of any kind was demonstrated more than a decade earlier in 1947 by John Bardeen and Walter Brattain at a group led by William Shockley at Bell Labs, a so-called point-contact transistor [6] based on the injection of minority carriers into a piece of bulk germanium (Ge) through metal point contacts. Eventually, two Bell Labs chemists, Morgan Sparks and Gordon Teal, successfully fabricated the semiconductor-based bipolar junction transistor (BJT) in 1951. The BJT subsequently became the dominant transistor technology for the emerging microelectronics industry for the next three decades. While initially BJTs were fabricated from Ge, advances in material synthesis led to Si quickly surpassing Ge, due to Si having a larger bandgap leading to reduced leakage currents), while the superior quality of the Si-SiO2 interface later enabled MOSFET technology. Bardeen, Brattain, and Shockley were jointly awarded the Nobel Prize in Physics in 1956 for their demonstration of the point-contact transistor and subsequent development of the BJT.

Individual transistors would not have an advantage over the vacuum tubes that they eventually replaced unless they could be miniaturized and integrated together on the same semiconductor platform to form ICs. The first demonstration of a working IC is attributed to Jack Kilby, who worked at Texas Instruments in September 1958, and was later awarded the Nobel Prize in Physics in 2000 for his contributions. In 1959, Robert Noyce at Fairchild Semiconductor demonstrated the first fully monolithic Si IC based on the development of *planar processing* by his colleague Jean Hoerni at Fairchild, in which all the circuit components were fabricated on one chip. The first commercial MOS-based IC was introduced by General Microelectronics in 1964, a spin-off from Fairchild. The Si-based planar process is the basis for all subsequent generations of ICs to the present day, albeit vastly more complicated.

In 1956, Shockley left Bell Labs to establish Shockley Semiconductor Laboratory in Mountain View, CA, where he recruited several young scientists. subsequently, what is now known as Silicon Valley in the San Francisco Bay Area (particularly around Santa Clara) saw the establishment of the semiconductor industry. However, due to his authoritarian management style, eight of the scientists left the company and founded Fairchild Semiconductor. In turn, Fairchild was responsible for seeding several spin-off companies formed by

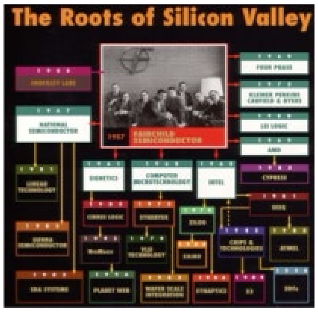

Fig. 4. The roots of the semiconductor industry in Si valley (Fairchild Semiconductors)

Fairchild employees, as shown in Figure 4. A notable example is Intel, formed in 1968 by two of the original scientists at Shockley Labs (Gordon Moore and Robert Noyce) (Figure 5) and venture capitalist, Arthur Rock. They were subsequently joined by a third technologist, Andy Grove, a chemical engineer who later was CEO of Intel during the 1980s and 1990s.

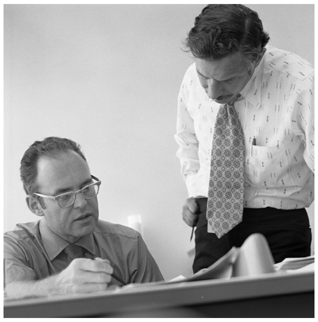

Fig. 5. Gordon Moore (left) and Robert Noyce (right), at Intel, circa 1970 (Intel Free Press, CC BY-SA 2.0, via Wikimedia Commons).

Moore's law is named after Gordon Moore, who noticed while working at Fairchild in 1965 that the number of components on an IC chip was doubling every two years. This was because the critical feature size of components (transistors, capacitors, resistors, etc.) was getting smaller. This empirical trend has been maintained by the semiconductor industry for years, until the last decade, as the number of transistors in successive generations of microprocessors increased following the trend (Figure 6). During the 1970s, 1980s, and 1990s, scaling rules were followed (Dennard scaling), where power density remained constant as dimensions were reduced, including a reduction in voltage. As device dimensions shrank into the nanometer scale (<100 nm) in the 2000s, such scaling broke down due to short channel effects. There is debate as to whether Moore's law continues to hold presently. Power management is currently a critical issue with billions of transistors per chip limiting clock speed. Physically, when we consider present-day technology nodes less than 2 nm, there are

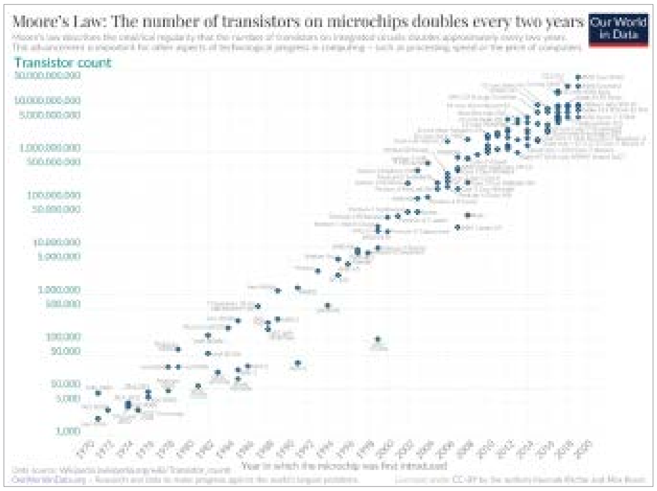

Fig. 6. Moore's Law, Transistor Count, 1970-2020

a countable number of atoms between source and drain, which represents the ultimate limit of scaling. To continue on Moore's Law requires major innovation in the technology such as going beyond planar chip design towards vertical integration (with commensurate power density issues) or beyond MOS technology itself (*post-CMOS*), including quantum devices, spintronics, etc. [7], and parallel or neural architectures that perform complicated functions like image processing orders of magnitude faster than conventional digital logic. MOSFET technology itself with the gate wrapping around the channel to mitigate the short channel effects; FinFETs the current state-of-the-art technology [8] and more recently nanosheet technology [9].

Much of the rapid growth of the semiconductor industry has been driven by the development of the microprocessor in the early 1970s at Intel as well as companies like Motorola and others. In return, microprocessors drove the development of personal computers and laptops. At the same time, the emergence of transistor-based solid-state memory technologies such as random-access memories (SRAM, DRAM) replaced magnetic core memories, which dominated the market prior to 1975. Memory and CPU (microprocessors) have increasingly become co-located on the same chip or module, starting with cache, and presently so-called *processing in memory* architectures reduces the latency of memory access and accelerates computation. In fact, architectural advances have been equally responsible for the increase in computational power as well as the number of transistors per chip.

While companies such as Intel are IDMs that design and manufacture their own chips, the *foundry* model has emerged over the past three decades, in which the semiconductor fabrication facilities are separated from fabless semiconductor companies that perform research and development on IC designs and then contract with foundries to fabricate the IC. *Pure play foundries* are those that only fabricate ICs, not design them. By far the largest is TSMC, followed by GlobalFoundries and UMC (Taiwan). Companies like Samsung also serve as foundries, as well as designing and selling chips (it is the second largest manufacturer of semiconductors, followed by Intel). Historically, the first attempt at a foundry-type model was MOSIS (Metal Oxide Semiconductor Implementation Service), which was a consortium of fabrication facilities, universities, and small companies in the early 1980s funded by DARPA (Defense Advanced Research Projects Agency), which allowed researchers to design ICs and send them out for fabrication at subsidized prices. In 1987, TSMC launched the first commercial dedicated foundry service, and today is the largest such manufacturer in the world. Simultaneously with the rise of foundry services in the 1980s, the commercial EDA industry emerged as a separate entity rather than as in-house parts of semiconductor companies. An early example is Mentor Graphics which was acquired by Siemens in 2017. EDA tools provide design through synthesis, schematic capture, and layout of components.

They also provide simulation from transistor through high-level architectural simulation and design verification. Finally, they provide the information for creating the various mask levels necessary within a given process to fabricate the circuit. The foundry typically provides a *process design kit* (PDK) to model the fabrication process within the EDA tools used to design the IC. The three largest providers of EDA tools are Synopsis, Cadence, and Ansys, all U.S.-based companies with worldwide offices.

2022 CHIPS and Science Act

The previous section provided a brief historical background on the microelectronics industry and its evolution to the present, which is the setting for the 2022 CHIPS and Science Act. While the semiconductor industry began in the U.S., by the 1970s, IDMs were already setting up manufacturing and assembly/packaging facilities outside the U.S., mainly in Asia due to decreased costs of construction and labor. In parallel microelectronic industry competitors in Japan, Korea, and later in Taiwan and mainland China (as well as Europe) entered the market, and semiconductor manufacturing in the U.S. began a long decline to the present day, where only 8% of global production occurs in the U.S., compared to 83% in East Asia [10]. At the same time, however, U.S.-based companies still account for 48% of the total semiconductor market share [11]. This is due to many U.S. companies operating fabrication facilities in other countries which are not included in U.S. manufacturing. In addition, several successful fabless companies such as Nvidia, AMD, Qualcomm, etc., are major producers of semiconductor products, supported by a global semiconductor manufacturing ecosystem.

Fig. 7. CHIPS and Science Act signing ceremony, August 9th, 2022 (The White House, Public Domain, via Wikimedia Commons).

In 2020, the COVID-19 pandemic exposed the relative fragility of global supply chains, leading to a shortage of semiconductor components that significantly impacted economic growth, particularly in key markets such as automotive electronics. Growing geopolitical tensions, particularly between the U.S. and China, have further exacerbated the potential disruption of the global semiconductor supply chain. In recognition of the threat to both economic competition and national security posed by an overreliance on offshore manufacturing, the U.S. Congress passed the Creating Helpful Incentives to Produce Semiconductors (CHIPS) for America Act in January 2021 to promote research, development, and fabrication of semiconductor products within the U.S. [12]. Later, through a bipartisan effort, Congress enacted, and President Biden signed the CHIPS and Science Act into law on August 9, 2022 (Figure 7), which appropriated $52.7 billion for domestic research and manufacturing in the U.S., the largest single investment made by the U.S. government in the semiconductor sector.

Fig. 8. TSMC facility under construction in Phoenix, Arizona (TrickHunter, CC BY-SA 4.0, via Wikimedia Commons).

The $52.7 billion investment includes $39 billion for a manufacturing incentive program as well as roughly $13 billion for research and development (R&D) and workforce investment. Additionally, there is a 25% manufacturing investment tax credit for semiconductor manufacturers, estimated at over $75 billion in support over the duration of the CHIPS Act. Some of the larger projects supported by the manufacturing incentive program include support for two new fab facilities for Intel at existing facilities in Chandler, Arizona, as well as a new fab in New Albany, Ohio (the first for Intel in the Midwest), support to TSMC to build an additional fab facility in Phoenix (Figure 8), support to Micron Technology for a new fabrication facility in Clay, New York, funding for Samsung to expand fabrication capabilities near their Austin, Texas location, and support for GlobalFoundries for additional fab capability in New York and Vermont [14].

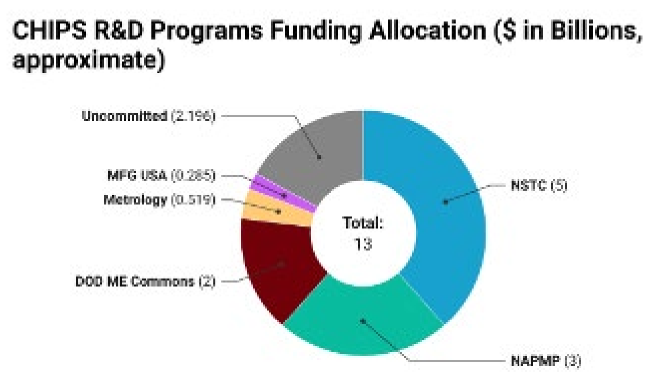

Fig. 9. CHIPS research and development funding allocations, 2024 (Source: SIA [14] and the Department of Commerce, Created with Datawrapper).

Figure 9 shows the current funding allocation of $13 billion R&D funding under the CHIPS Act. The U.S. Department of Commerce (DOC) receives an allocation of $11 billion, primarily for the establishment of the National Semiconductor Technology Center (NSTC) and the National Advanced Packaging Manufacturing Program (NAPMP). The DOC announced in July 2024 the establishment of three research facilities: one for extreme ultraviolet lithography, a prototyping facility for the NSTC, and a piloting facility for the NAPMPTwo billion dollars was also authorized for the U.S. Department of Defense (DOD) to establish the Microelectronics Commons, which has established eight hubs geographically distributed around the U.S., addressing microelectronics needs for DOD in areas such as AI, 5G/6G technology, quantum technology, and commercial leap-ahead technologies

As mentioned earlier, the CHIPS Act has been the largest federal government investment in the semiconductor industry since its inception in the 1950s and 1960s, intending to greatly increase the semiconductor manufacturing capacity and technology leadership in the U.S. Since the inception of the CHIPS Act, Europe and Japan have also undertaken similar initiatives in the semiconductor sector. According to U.S. Secretary of Commerce Gina Raimondo, one of the outcomes of the CHIPS Act is for the U.S. to produce 20% of the world's leading-edge logic chips by 2030 [15]. This investment is coupled with a projected 50% increase in semiconductor industry jobs over the same period, with substantial career opportunities in IEEE fields of interest, many of which are required to meet the current talent shortage.

U.S. Semiconductor Industry Workforce Needs

Besides the investment in infrastructure, the CHIPS Act also recognized the critical need to grow the talent pool of skilled workers needed not only today but also to meet the projected growth of the semiconductor industry. Currently, the U.S. semiconductor industry employs approximately 300,000 workers with technical education or training. Out of these, over 50% have four-year college degrees, and over 25% of those have graduate degrees. Only 20% have solely a high school degree or did not finish high school. The rest have vocational training, mostly through community colleges. Presently, U.S. universities, colleges, and community colleges do not graduate enough students to meet demand, with some estimates of 5% job vacancies in the industry (although this can be cyclical). Figure 10 illustrates the

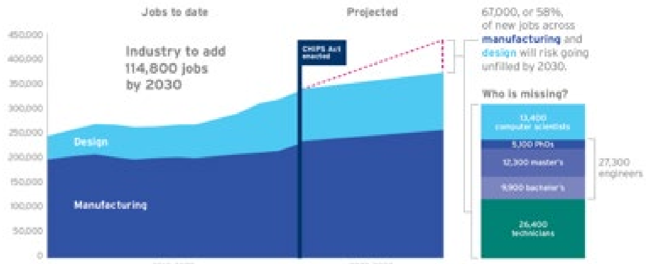

Fig. 10. Historical semiconductor workforce and the projected new jobs by specialty from 2023-2030 (Source: Semiconductor Industry Association and Oxford Economics).

Semiconductor Industry Association's (SIA) anticipated workforce needs by 2030, considering the balance of employees leaving (due to retirement or career changes), the number retained, and the number entering the workforce (from recent graduates and reskilled workers from other industries). The projected workforce needs in 2030 [16, 17] are close to 450,00 workers at various levels of education, as shown by the inset in Figure 10. Given the current rates of graduation from universities and community colleges, there will be a significant shortfall in graduates entering the workforce to meet this projected demand.

Additional sources of talent are needed to meet this demand and the future growth of microelectronics, in general. Some of this can be met through immigration, however, there is a current backlog of H-1B visas and green cards for immigrants from South Asia. Reskilling workers from other industries is also a source of talent. However, there is a significant need for increasing the number of students in technical programs in universities and community colleges to greatly increase the pipeline of students graduating to meet this workforce demand.

The CHIPS Act highlights the impact of semiconductor industry growth on the growth of U.S. jobs, as well as the need for investment in workforce development to meet the growing demand. Thus, the National Science Foundation (NSF) received an authorization of $200 million to foster the expansion of the semiconductor workforce, in response to the impending labor shortages. The Department of Commerce and NSF recently announced that they will be co-funding the Coordination Hub for the National Network for Microelectronics Education [18]. In particular, it calls for the establishment of a national network for microelectronics education, based on an industry-oriented curricula, professional development for teachers, access for students to training facilities using industry-standard processes and tools, recruitment of new faculty/instructors in microelectronic educational programs, exposure of PreK-12 students to microelectronics, and greatly increased traineeships and internships in the microelectronics industry.

The American Semiconductor Academy (ASA) [19] published a proposal for such a network, identifying several challenges in meeting the workforce needs described above in terms of current microelectronics education programs.
These include:

- A largely invisible (to students and the public) microelectronics industry
- Aging infrastructure and faculty/instructor populations
- Lack of alignment between industry needs and higher education outcomes
- Outdated microelectronics curricula
- Pipeline inequality, limiting the size and strength of the talent pool
- Talent retention (leaky pipeline)

The CHIPS Act's investment in workforce development seeks to address many of these issues by modernizing the curricula with industry involvement. A significant barrier to increasing the talent pool has been the underrepresentation of women and minorities in the technical fields supplying talent for the microelectronics industry (Figure 11), which is well below that of the population itself. Attracting more students from this underrepresented pool of talent to microelectronics programs today would go a long way toward meeting the workforce needs in 2030.

As shown in Figure 11, the microelectronics industry involves a broad range of disciplines, from basic sciences to various engineering disciplines and computer science. A broad swath of these disciplines encompasses IEEE fields of interest. Hence, for IEEE-HKN members, there are many different career paths possible within the semiconductor industry. Whereas the stereotype of the semiconductor industry in the early decades was of workers in white bunny suits handling wafers in yellow-lit cleanroom facilities, the knowledge base and skills of the modern microelectronics industry are quite diverse (in fact, due to the extreme cleanliness and automation for mass production required in the state-of-the-art technology nodes, there are far more robots than employees in cleanroom facilities). Knowledge across many levels and disciplines is essential to understanding the impact of atomic-level phenomena on system-level performance.

The challenge today, which the CHIPS Act as well as organizations such as ASA are seeking to address, is to increase the awareness of potential workers in the microelectronics industry as to the exciting career opportunities across a broad range of disciplines that are available and the growth of these opportunities in the future.

Knowledge	Skills
Packaging	Board-level integration
Heterogeneous Integration	Electronic Design Automation (EDA); Chip & System Test
Architecture	
Circuits	
Devices	Technology Computer Aided Design (TCAD); Fabrication and Characterization
Structures	
Materials	
Equipment	Maintenance & Repair
Computing, Data Analytics & Machine Learning	

Fig. 11. Disciplines contributing to the workforce in the semiconductor industry (left). Knowledge and skills required in the modern microelectronics workforce.

Coupled with this is the need to develop a modern holistic microelectronics curriculum in partnership with industry that can be shared broadly across a large network of universities, community colleges, and industry. Figure 11 provides a framework for this knowledge base and skills. The knowledge base and skills shown in Figure 11 provide a framework for this. One of the challenges of semiconductor education is the prohibitively expensive cost of constructing and maintaining fabrication facilities that can serve as educational centers, one which relatively few educational institutions can afford, particularly state-of–the-art facilities up to industry standards (as mentioned earlier, a deep EUV lithography tool may cost $200-$300 million). One proposed solution is the formation of regional educational hubs which are public-private partnerships between educational institutions and industry that provide access for students and continuing education workers to learn modern semiconductor manufacturing through traineeships/internships.

Summary

The article provides a brief overview of the microelectronics industry, its history and the recent passage of the Chips and Science Act of 2022. A review of the historical context for the CHIPS Act in terms of the growth of the semiconductor industry and Silicon Valley in the early years, to the multi-national worldwide industry today was provided, including the growth of semiconductor foundries in Asia and fabless semiconductor companies. Also discussed, was the substantial growth in the workforce needed in the U.S. resulting from the CHIPS Act, in terms of career opportunities for IEEE members and the needed modernization of education and workforce training to attract the talent necessary to meet demand.

Acknowledgements

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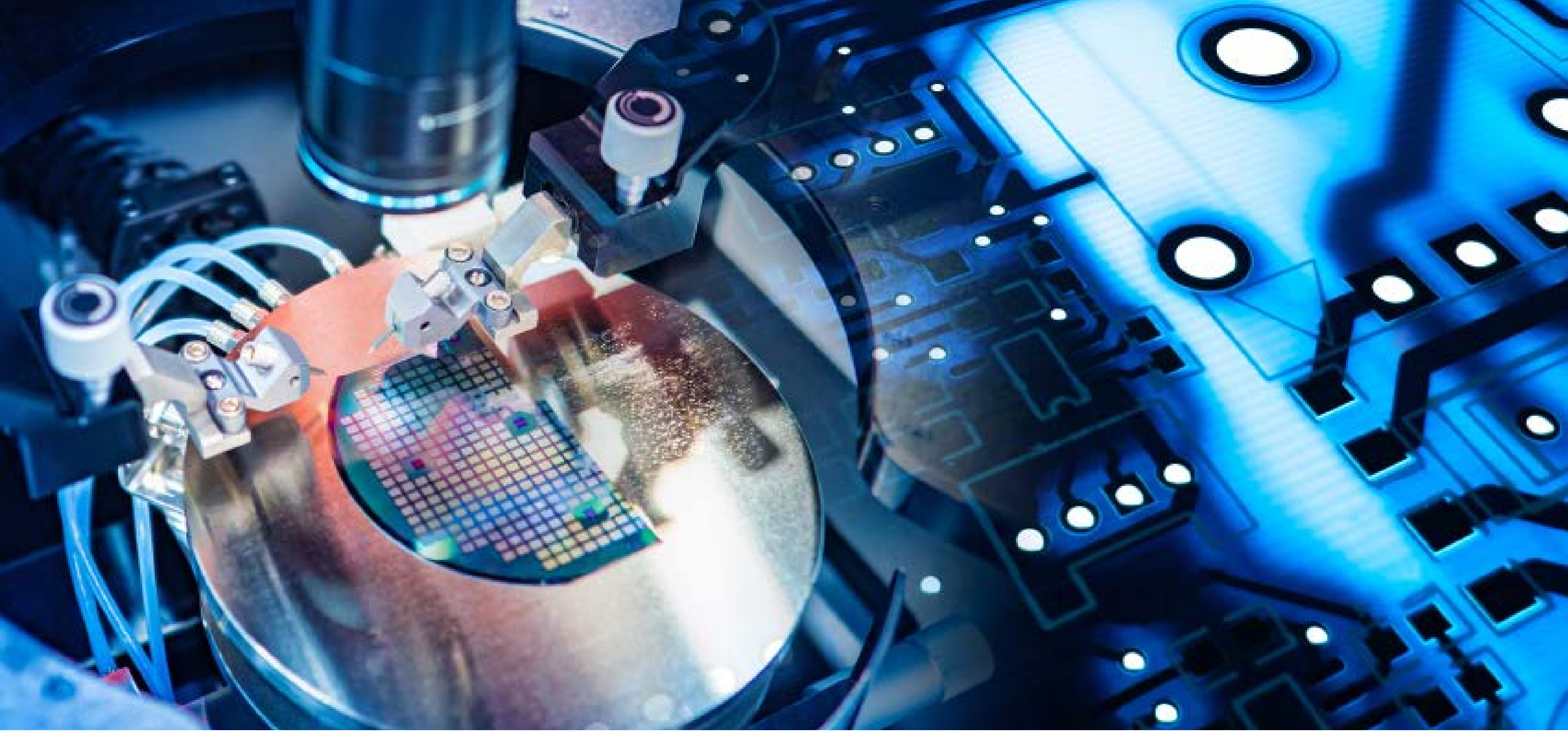

A World of Opportunity for Engineers in the Semiconductor Sector

Liesl Folks, PhD, MBA, FNAI, Prof. Electrical and Computer Engineering, University of Arizona

Introduction

For most of us, the intricate supply chains that combine to bring new goods to our doorsteps are largely invisible – hidden in a web of global business deals that we rarely glimpse. Labels "Made in X" on manufactured goods merely hint at the intricate process of raw materials to assemble component pieces from around the world into complex manufactured goods such as washing machines, cars, and healthcare devices. Complex products require complex supply chains, and semiconductor chips are the most complicated to make [1].

The chips inside our cell phones, screens, cameras, washing machines, and cars are also largely invisible to us – doing the daily tasks of logic and memory seamlessly, serving to increase our productivity and quality of life. However, the production of these chips necessitates the use of ultra-pure materials spanning more than half of the periodic table, as well as machines with thousands of parts, which can cost as much as hundreds of millions of dollars—a task that thousands of different companies undertake. Within this hidden world, there are countless jobs for engineers. U.S. students remain largely unaware of the companies in the semiconductor supply chain and the jobs they offer. Because most of these companies do not have brands we recognize because they produce goods that are sold to other companies rather than as consumer goods.

Global Chip Manufacturing

The complexity and cost of semiconductor manufacturing, especially at the leading edge of technology, has contributed to companies consolidating over recent decades. Today there are very few manufacturers producing the most complicated logic chips – companies like Taiwan Semiconductor Manufacturing Corporation (TSMC), Samsung, Intel, Micron, and GlobalFoundries – names that many people will recognize. However, there are many more companies producing chips that are somewhat less complicated, with less logic and memory functions to perform simpler tasks than we ask of our phones or computers, such as chips used in temperature controllers or to control the many systems and sensors in our cars.

Making possible the "fabs" where these chips are manufactured is an array of companies. They create many tools and resources, such as the software tools to design the chips (Electronic Design Automation (EDA) software), the chip designs made using EDA software, the raw materials and wafers used to make the chips, the sophisticated tools used to fabricate and test the chips, and the packages to protect the chips and ready them to be integrated into devices. These efforts involve thousands of small and large companies worldwide.

The global COVID-19 pandemic that started in 2020 snarled the supply chains for many goods and materials, including those needed for chip manufacturing, which in turn led to shortages of common goods that contain semiconductors – things like washing machines and cars - and raised political awareness that the global ecosystem of suppliers to the semiconductor manufacturing sector was itself fragile. In addition, recent uncertainty regarding China's intended relationship with Taiwan, along with wars in Ukraine and the Middle East, has heightened awareness of geopolitical weak points in the supply chain. Situations where there are one or a few suppliers of a particular material or component create risks for manufacturers since production can grind to a halt if any one of the inputs to fabrication is unavailable. Because semiconductors are such an important component in so many other goods that we rely on, the risks of supply disruption to chip manufacturing companies can quickly turn into risks to the nation's economic stability.

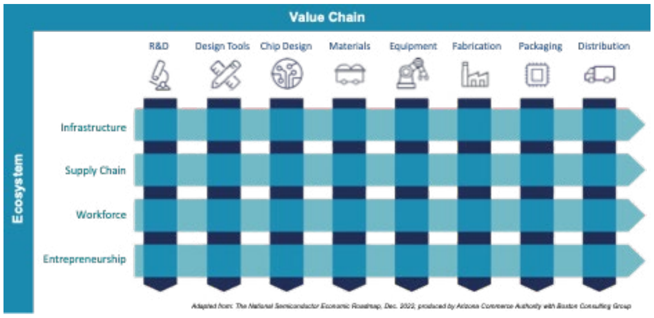

Fig. 1: Illustration of the breadth and depth of the global semiconductor sector, with the different facets of the value chain highlighted [2].

For these reasons, the U.S. Government's CHIPS and Science Act of 2022 (also known as "the CHIPS Act," where CHIPS stands for "Creating Helpful Incentives to Produce Semiconductors") created a whole-of-government initiative to try to increase the resilience of the semiconductor chip supply that underpins so much of our modern economy. The CHIPS Act aims to increase the proportion of U.S.-based companies in the global supply chain and has announced billions of dollars in subsidies and tax incentives to offset the costs of establishing new and expanded operations across the country. Now, these projects are intensifying, with the potential to generate thousands of new jobs for U.S. engineers and scientists—an exciting opportunity [3].

Interestingly, however, the global semiconductor sector is so vast and the supply chain so complex that the U.S. cannot follow a "go-it-alone" strategy to increase resilience – it would simply be impractical and too costly. Over recent decades, specific companies and nations have become highly specialized in the production of specific software, designs, materials, components, and machines, building up all the needed know-how and inputs for highly efficient operations that span the semiconductor sector, as illustrated in Figure 1. To replicate all these operations in the U.S. would take years or decades of committed effort and drive up the cost of the chips produced dramatically – likely an unpopular outcome. For this reason, Strong partnerships and business relationships with allied nations remain essential for the health of the semiconductor sector and, consequently, for the U.S. economy.

One example of this specialization dynamic is the Dutch company ASML, which is currently the only company in the world capable of producing the state-of-the-art lithography tool used to make nanoscale resistors for high-performance computing chips and to train large-scale artificial intelligence (AI) models [4]. Reports indicate that ASML sources parts for its extreme ultraviolet lithography machines from around 50 different countries, including the U.S. Although other companies continue to strive to compete, it is difficult to replicate the highly specialized scientific and engineering know-how that has allowed ASML to be the clear leader in lithography tool production. However, even with this market power as the apex tool manufacturer in its class, ASML is highly dependent on other companies to make the chemical resists, wafers, and masks that are required for the tools to do their jobs. ASML still operates within a highly complex ecosystem!

Countries have also followed specialization strategies, with some leveraging lower labor costs to become recognized experts in "assembly, packaging, and testing" (APT), whereby chips are embedded into systems that are ready to be incorporated into consumer products. Today, Southeast Asian nations like Taiwan, Singapore, Malaysia, etc. perform the majority of APT, with the U.S. performing only about two percent. (It is interesting to note that after chips are produced in the various sophisticated and expensive fabs around the world, they are routinely flown from one country to another for other steps in the manufacturing process flow because they are so small and lightweight.

So, even though the U.S. is working to mitigate the risks of a fragile supply chain and geopolitical factors within the ecosystem already created by specialization and globalization, and even though there will be real costs of doing so that will inevitably be borne by U.S. taxpayers and consumers, there are many opportunities ahead for the U.S. to strengthen its position in the global supply chain and to increase resilience. An important strategy is to identify critical minerals and components for which there are few suppliers and seek to increase the number of suppliers – either by building facilities in the U.S. or in other allied nations.

A prominent example of where this approach is necessary is the market for rare. China has become the sole volume supplier of several rare earth metals that are important for chip manufacturing and has shown a willingness to use the market power it has established over these critical materials as a global political bargaining tool, creating unsettling price and supply fluctuations [5]. Recognizing the value of its leadership position, it has also been effective in derailing the efforts of companies in other nations to establish rare [6]. The U.S. and other nations are now working to underwrite efforts by non-China-based interests to bring other suppliers of rare earth minerals and metals online to increase resilience.

The somewhat specialized wafers used for high-frequency semiconductor chip manufacturing, like gallium arsenide wafers with higher electron mobility than the standard silicon wafers used for most chips present a similar challenge. Only a few manufacturers around the world produce these wafers for volume manufacturing today, but they are critical for specialized electronics used in space and defense applications. This supply chain issue creates another point of vulnerability for the U.S. and allied nations and is drawing close attention.

CHIPS Act: Workforce Development and Educational Programs

A key concern that has emerged in discussions surrounding the CHIPS Act in the U.S. is the low level of student interest in and awareness of the semiconductor sector. This is a consequence of several decades of offshoring of manufacturing activity and reductions in hiring, leading to a lowered understanding of and interest in the sector. It is urgent that we turn this around! We once again need to have students get excited about being at the forefront of the development of the advanced semiconductor hardware that will power the energy revolution, healthcare advances, AI, quantum information science, and cybersecurity. It is incumbent on all of us in the engineering community to work with educators at every level to introduce students to the extraordinary science and engineering that goes into each new generation of semiconductor chips. To do this, we urgently need companies working in this space to become better at communicating with nontechnical audiences about the "everyday miracles" that they perform at the atomic and quantum mechanical level to bring us the technologies on which we depend. If they fail to communicate the joy and purpose of this work, students will naturally gravitate towards other fields of interest, because numerous other fields are competing for the best science and engineering talent!

According to a recent Semiconductor Industry Association study, the semiconductor sector will need nearly 115,000 additional science, technology, engineering, and mathematics (STEM) workers by 2030 to support the planned expansion of domestic manufacturing [7]. At first, this might seem easily doable – the U.S produces approximately 144,000 engineers each year [8]. But then you realize that enrollments in some of the key disciplines, such as electrical engineering, have been declining as a share of the total degrees awarded over the past two decades [9]. Furthermore, we have not been seriously discussing career opportunities in the semiconductor sector with students at any level of education over that same period. As a result, students who are in K-12 and university pipelines today are largely unaware of potential career paths that might interest them. And, of course, they have other choices! One realizes that the U.S. must immediately address this by quickly building partnerships with companies and educators to produce this many new STEM-educated workers!

One challenge we face in the U.S. is to increase our efforts to excite students about semiconductor technologies much earlier in their educational pathways [10]. By introducing concepts or examples that relate to semiconductor technologies early in the STEM curriculum for K-12 students, as well as for associate and bachelor's degree students, we can expect to have a greater chance that students could choose to pursue courses of study that lead them into great careers in the semiconductor sector. Otherwise, many students will have settled into academic paths that lead toward other industry sectors in which they have developed an interest. By introducing relevant concepts early in the education cycle, we can encourage students to seriously consider careers in the semiconductor sector.

Regular readers of *THE BRIDGE* will not be surprised to learn that the semiconductor sector continues to face challenges in increasing the representation of women and underrepresented groups within its engineering workforce [11, 12] Both educators and companies need to exert far more effort to attract more diverse students to the field and to ensure that these professionals find themselves in work environments where they feel valued and have a sense of belonging within their teams. Only then will we unleash our nation's full potential as it strives to establish a highly resilient semiconductor ecosystem.

Summary

The CHIPS Act is bringing a once-in-a-generation expansion of high-tech manufacturing in the U.S., and the decade ahead promises to be an exciting one. Our dependence on semiconductors for increased quality of life and security is sure to keep growing. HKN members are, of course! prepared to take advantage of the new world of opportunities and will undoubtedly be part of the vanguard that creates new pathways for prosperity and well-being for people everywhere.

Liesl Folks is Professor of Electrical and Computer Engineering at the University of Arizona and holds a BS and a PhD in Physics, from the University of Western Australia, and an MBA from Cornell. As a leader in academia and industry, she has long been an advocate for under-represented groups in STEM. She was elected as the first female President of the IEEE Magnetics Society and is a Fellow of the National Academy of Inventors.

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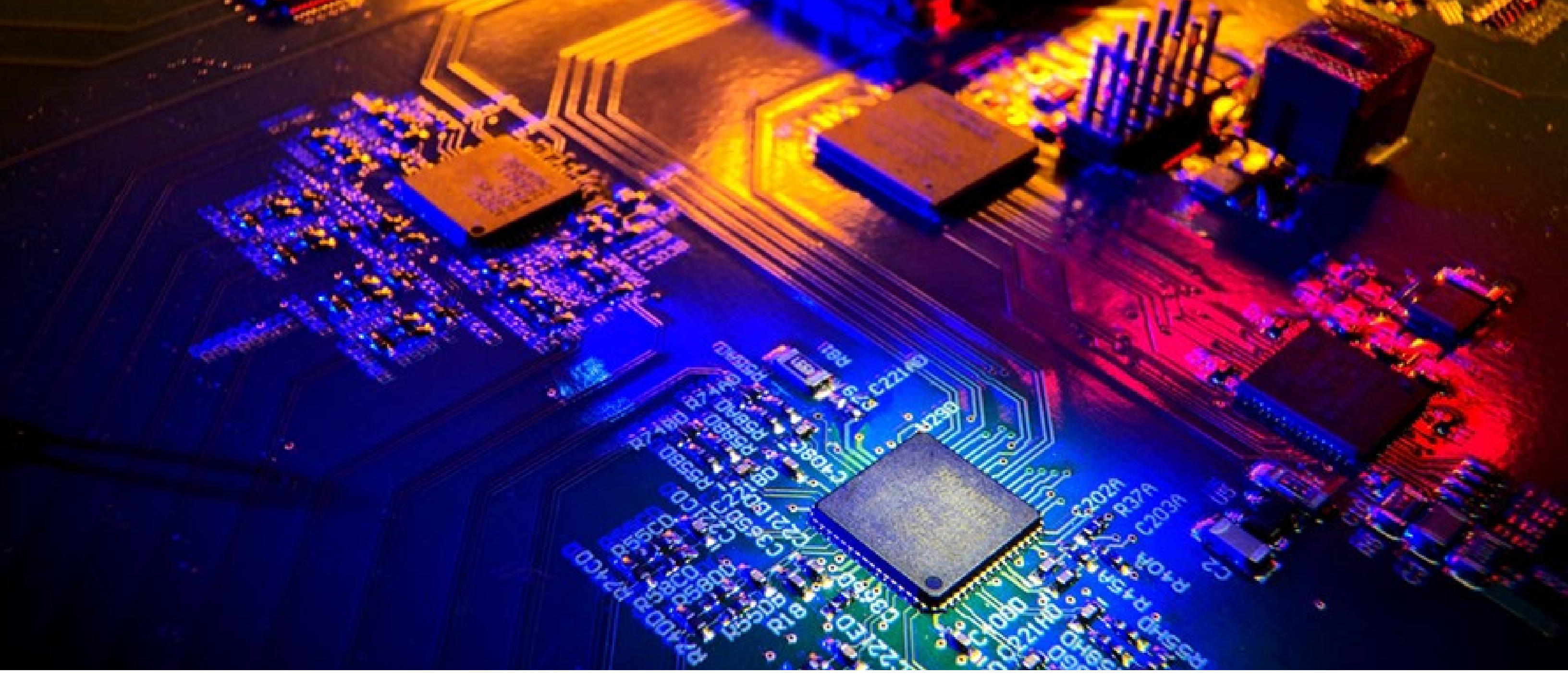


Image Source: U.S. Department of Energy

The Semiconductor Revolution: Powering Innovation and Shaping the Future

Dr. Dinesh Maddipatla, Assistant Professor, Western Michigan University; Dr. Massood Z. Atashbar, Professor, Electrical and Computer Engineering Department, Western Michigan University

Abstract

This article explores the pivotal role of semiconductors in driving technological advancements across various sectors. It delves into the state-of-the-art semiconductor technology, highlighting recent breakthroughs such as 3D transistor structures and advanced packaging techniques. The article examines the impact of the CHIPS and Science Act, a comprehensive legislative initiative aimed at strengthening the U.S. semiconductor ecosystem. It discusses how the Act empowers U.S. universities and research institutions to accelerate innovation, support workforce development, and maintain global leadership in semiconductor technology. The article also outlines the diverse career opportunities within the semiconductor industry and emphasizes the critical importance of continued investment in research, education, and workforce development to shape the future of technology.

Introduction

In today's rapidly evolving digital landscape, semiconductors have become the driving force behind technological advancements across various sectors. These tiny electronic components, often smaller than a postage stamp, have revolutionized the way we live, work, and communicate (Figure 1). From powering our smartphones and computers to enabling cutting-edge medical devices and clean energy solutions, semiconductors are the unsung heroes of the modern world [1]. As the demand for advanced technologies continues to grow, the importance of semiconductors has become more evident than ever before.

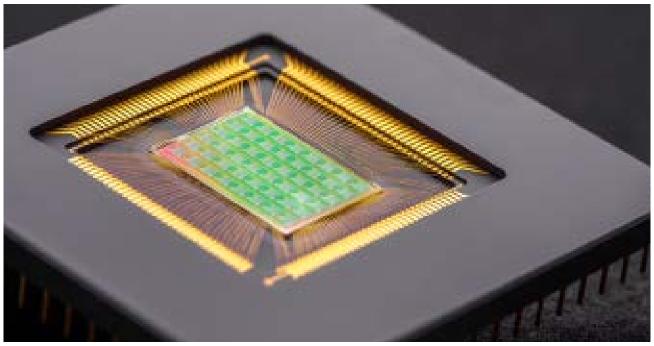


Fig. 1. Example of a semiconductor chip. ©Jacobs School of Engineering, UC San Diego (CC-BY-NC-SA 4.0)

The United States has long been a leader in semiconductor innovation, but in recent years, the nation has recognized the need to bolster its domestic semiconductor industry to maintain its competitive edge. This realization led to the enactment of the CHIPS (Creating Helpful Incentives to Produce Semiconductors) Act in 2022, a comprehensive legislative initiative aimed at strengthening the U.S. semiconductor ecosystem [2]. The CHIPS Act not only seeks to enhance manufacturing capabilities but also places a strong emphasis on supporting academia and accelerating research and development (R&D), education, and workforce development in the semiconductor field

This article delves into the critical role of semiconductors, explores the state-of-the-art in semiconductor technology, and examines how the CHIPS Act empowers U.S. universities and research institutions to drive innovation and shape the future of this transformative industry.

The Semiconductor Revolution: Powering the Digital Age

Semiconductors are materials that exhibit unique electrical properties, allowing them to conduct electricity under certain conditions while acting as insulators in others. This ability to control the flow of electrons forms the foundation of modern electronics. The invention of the transistor in 1947 marked the beginning of the semiconductor revolution, paving the way for the development of integrated circuits (ICs) and microprocessors.

Today, semiconductors are ubiquitous, found in virtually every electronic device we use. They are the "brains" behind our smartphones, tablets, and computers, enabling high-speed processing and data storage [3]. In the realm of communication, semiconductors power the infrastructure that connects the world, from 5G networks to fiber-optic cables [4-6]. They are the backbone of the Internet of Things (IoT), allowing billions of devices to communicate and exchange data seamlessly.

Beyond consumer electronics, semiconductors have transformed various industries (Figure 2) [4-7]. In healthcare, they are integral to advanced medical devices, imaging equipment, and diagnostic tools, enhancing patient care and enabling precision medicine. The automotive industry relies on semiconductors for engine management systems, safety features, and the development of electric and autonomous vehicles. In the energy sector, semiconductors are crucial for renewable energy systems, such as solar panels and wind turbines, as well as powering electric vehicles contributing to a more sustainable future and clean cities.

The State-of-the-Art: Pushing the Boundaries of Semiconductor Technology

The semiconductor industry is characterized by rapid innovation and constant evolution. Moore's Law, which states that the number of transistors on a chip doubles roughly every two years, has driven the relentless pursuit of smaller, faster, and more efficient semiconductor devices. This miniaturization has led to the development of cutting-edge technologies that are reshaping the world as we know it.

One of the most significant advancements in recent years has been the transition from planar to three-dimensional (3D) transistor structures. Intel introduced the first 3D transistor, known as the Fin Field-Effect Transistor (FinFET), in 2011, marking a major milestone in semiconductor technology [8]. FinFETs offer improved performance, reduced power consumption, and better scalability compared to traditional planar transistors. This breakthrough has enabled the development of more powerful and energy-efficient processors, fueling the growth of high-performance computing and artificial intelligence (AI) applications.

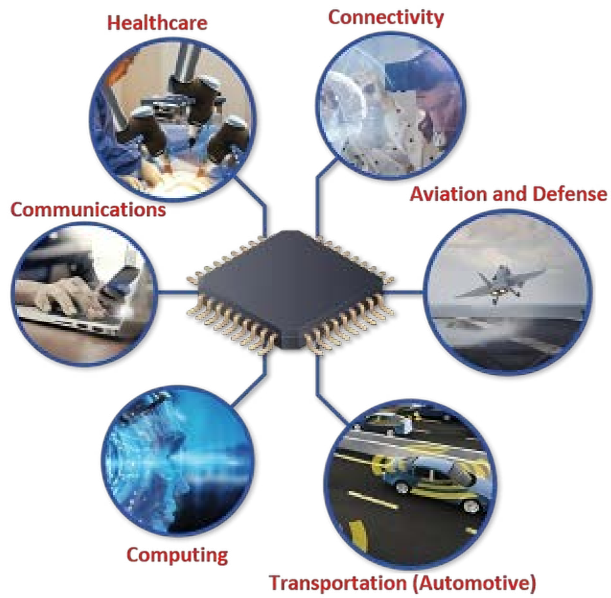


Fig. 2. Applications of semiconductors in daily life [4].

Another remarkable achievement is the development of advanced packaging technologies. As the demand for smaller and more complex electronic devices grows, traditional packaging methods are no longer feasible. Advanced packaging techniques, such as 2.5D and 3D integration, allow for the stacking of multiple chips in a single package, enabling higher density and improved performance. These technologies have opened new possibilities for system-on-chip (SoC) designs, where multiple functions are integrated onto a single chip, leading to more compact and efficient electronic devices.

The semiconductor industry is also at the forefront of emerging technologies like AI, quantum computing, and 5G. AI accelerators, such as graphics processing units (GPUs) and application-specific integrated circuits (ASICs), are being developed to handle the massive computational demands of machine learning and deep learning algorithms. Quantum computing, which harnesses the principles of quantum mechanics to perform complex calculations, relies on specialized semiconductor devices called qubits. The deployment of 5G networks, with their high-speed and low-latency capabilities, is driven by advanced semiconductor technologies, including radio frequency (RF) and millimeter wave (mmWave) devices.

The CHIPS Act: Empowering U.S. Academia and R&D

Recognizing the strategic importance of semiconductors, the United States government introduced the CHIPS Act to strengthen the domestic semiconductor industry and maintain its global leadership [2]. The Act invests $280 billion, of which $200 billion is for scientific R&D and commercialization; it appropriated $52.7 billion in funding, with $39 billion dedicated to semiconductor production incentives and $11 billion to advance research and workforce development. The Act provides $24 billion in investment tax credits to support the construction of chip manufacturing facilities, as well as $3 billion for programs aimed at leading-edge technology and wireless supply chains [2,9,10].

One of the key aspects of the CHIPS Act is its focus on supporting U.S. academia and accelerating R&D efforts in the semiconductor field. The Act recognizes that universities and research institutions play a vital role in driving innovation and advancing the state-of-the-art in semiconductor technology. By providing substantial funding and fostering collaboration between academia and industry, the CHIPS Act aims to create a thriving ecosystem for semiconductor research and development.

The Act establishes the National Semiconductor Technology Center (NSTC), which receives $5 billion to focus on cutting-edge/critical semiconductor technology research and prototyping [11]. The NSTC serves as a hub for collaboration among government, industry, academia, entrepreneurs, and venture capitalists, facilitating the exchange of knowledge and resources to drive innovation. This collaborative approach ensures that research efforts are aligned with industry needs and accelerates the transfer of technology from the lab to the marketplace.

In addition to the NSTC, the CHIPS Act allocates $3 billion to the National Advanced Packaging Manufacturing Program (NAPMP) to advance packaging technologies [12]. Advanced packaging is crucial for enhancing semiconductor performance, power efficiency, and functionality. The NAPMP supports the development of new packaging solutions, enabling U.S. universities and research institutions to contribute to this critical area of semiconductor technology.

The Act also provides up to $285 million to establish a Manufacturing USA institute focusing on digital twins for the semiconductor industry [13]. Digital twins are virtual representations of physical systems that enable real-time monitoring, simulation, and optimization. By leveraging digital twins, researchers can accelerate the development and validation of semiconductor manufacturing processes, leading to improved efficiency and quality.

Furthermore, the CHIPS Act allocates $2 billion to the U.S. Department of Defense (DoD) for semiconductor R&D initiatives, such as the Microelectronic (ME) Commons, which involves eight hubs leading semiconductor research and development projects [10]. This investment not only supports national security but also fosters technological leadership in the semiconductor field.

The impact of federal funding for semiconductor R&D cannot be overstated. Each dollar invested by the government has a multiplier effect, increasing the U.S. GDP by $16.50 [14]. These investments incentivize greater private sector R&D, sparking innovation across various industries, including automotive, agriculture, biomedical, and defense. While the growth of federal investments has been slower compared to private sector funding, increased federal support is crucial for sustaining U.S. leadership in semiconductor technology and key future technologies like AI and quantum computing.

Academia plays a pivotal role in developing the skilled workforce needed to support the growth of the semiconductor industry. The CHIPS Act supports the creation of educational and workforce development programs through the National Science Foundation (NSF), focusing on semiconductor technology and equipping students with the knowledge and skills required for careers in this field [2]. These programs include undergraduate and graduate courses, and specialized training and certification programs. By fostering industry-academia partnerships, the Act enables students and researchers to work on real-world challenges, bridging the gap between theoretical research and practical applications.

The semiconductor industry faces a shortage of skilled workers, which could hinder growth and innovation. The CHIPS Act addresses this challenge by funding training programs that equip workers with the skills needed for semiconductor manufacturing and design. These programs target both new entrants to the workforce and existing employees seeking to upgrade their skills. The Act, along with state government funding, will also promote the creation of clear career pathways in the semiconductor industry, encouraging students and professionals to pursue careers in this field through internships, apprenticeships, and co-op programs that provide hands-on experience.

Career Opportunities and Industry Outlook

The semiconductor industry offers a wide range of exciting career opportunities, spanning from manufacturing and engineering to research and development. As the demand for semiconductor technology continues to grow, so does the need for skilled professionals. Experts estimate that the industry will require more than one million additional skilled workers by 2030 to meet its demands [15].

Semiconductor engineers play a crucial role in designing and developing new semiconductor devices, circuits, and systems. They work on the design, simulation, testing, and optimization of semiconductor devices and develop innovative manufacturing processes. Process engineers, however, focus on developing and optimizing semiconductor manufacturing processes, including photolithography, deposition, and etching. They work on process control, yield improvement, and quality control to ensure the efficiency and reliability of semiconductor production.

Product engineers ensure that semiconductor products meet customer requirements and specifications. They work on product testing, failure analysis, and quality control to deliver high-quality semiconductor solutions. Applications engineers design and implement semiconductor solutions for specific applications, providing technical support, product demonstrations, and training to customers.

Research scientists conduct cutting-edge research in semiconductor technology to develop new materials, devices, and manufacturing processes. They work in academia, government research labs, or the private sector, pushing the boundaries of semiconductor science and driving innovation.

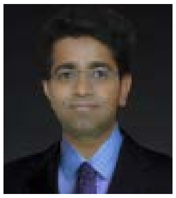
The semiconductor industry is home to some of the world's largest and most influential companies, such as Intel, Samsung, Plasma-Therm, Taiwan Semiconductor Manufacturing Company (TSMC), Micron, and Nvidia (to name a few). These companies are at the forefront of semiconductor innovation, investing heavily in R&D and driving technological advancements. Pursuing a career in this industry offers the opportunity to work with cutting-edge technologies and be part of shaping the future of electronics.

Conclusion

Semiconductors are the unsung heroes of the modern digital age, powering the technologies that have transformed our world. From computing and communication to healthcare and renewable energy, semiconductors are essential to the functioning of society. The CHIPS Act represents a strategic investment in the U.S. semiconductor industry, enhancing manufacturing capabilities, research, and workforce development.

By supporting academia and fostering industry partnerships, the CHIPS Act positions the United States to maintain its leadership in semiconductor technology. Universities and research institutions play a vital role in driving innovation, advancing the state-of-the-art, and developing the skilled workforce needed to support the industry's growth. As the demand for semiconductors continues to grow, such funding initiatives will be crucial in ensuring that the U.S. remains competitive and propels to the forefront in the global technology landscape.

The semiconductor industry offers a wide range of exciting career opportunities, and the future looks bright for those pursuing careers in this field. The semiconductor revolution has already transformed our world, but the best is yet to come. With continued investment in research, education, and workforce development, the semiconductor industry will continue to push the boundaries of what is possible, driving innovation and shaping the future of technology. As we move forward, semiconductors will undoubtedly remain at the heart of the digital age, powering the advancements that will define our tomorrow.



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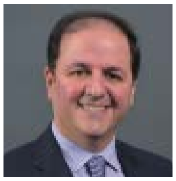

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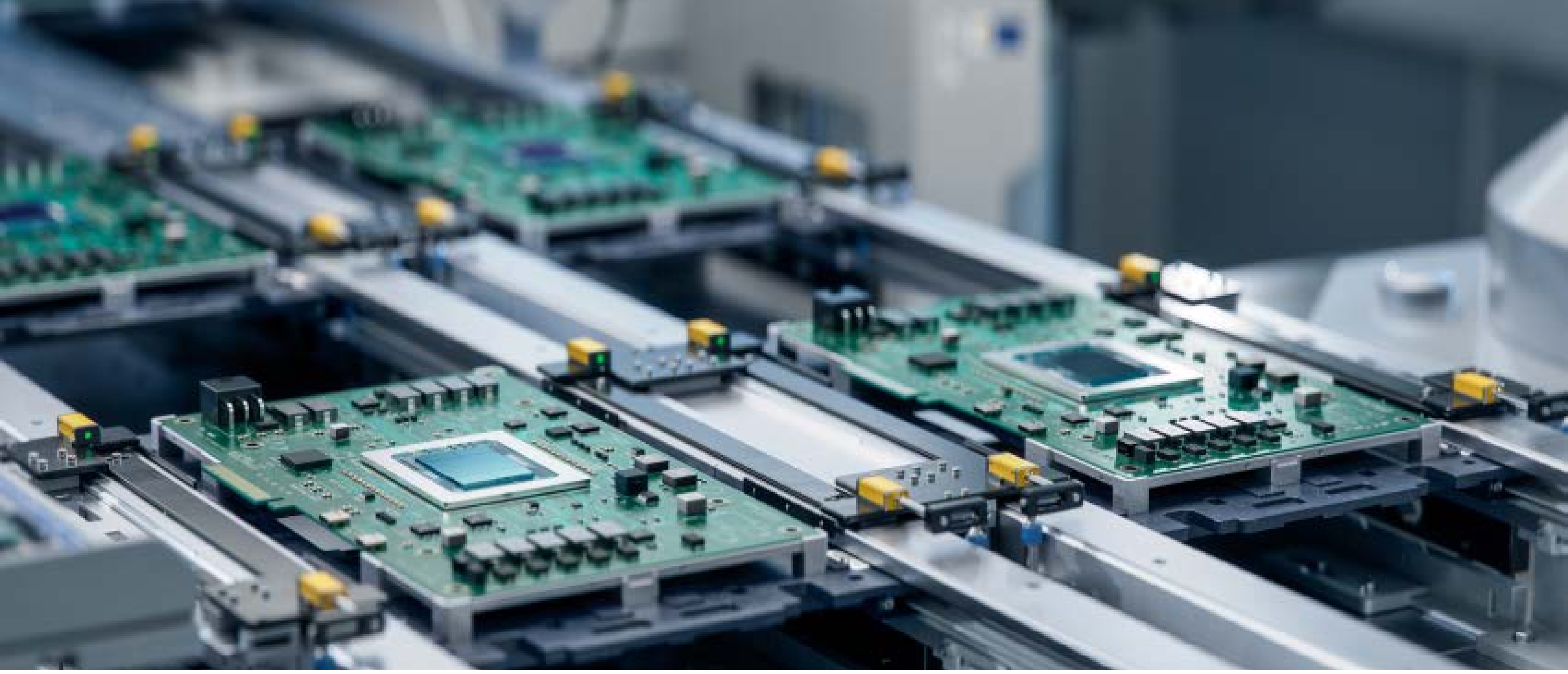

IEEE Leading the Way in Global Semiconductors

Paolo Gargini, IEEE Life Fellow, IEEE IRDS™ Chair; Kathy Herring Hayashi, IEEE Director Region 6, IEEE Chair Global Semiconductors; Jennifer Fong, Director, IEEE Educational Activities

Semiconductors are an essential building block for many of the technologies we rely on today, from computers and smartphones to cars and gaming systems. During the pandemic, a semiconductor chip shortage [1] resulted in shortfalls in many of the products people rely on. Recognizing the importance of access to these chips as a matter of national security, the U.S. Government launched the Creating Helpful Incentives to Produce Semiconductors (CHIPS) for America Fund [2] (more commonly called the "CHIPS Act") to "carry out activities relating to the creation of incentives to produce semiconductors in the United States." Signed into law in 2022, this legislation allocated nearly $53 billion for semiconductor research, design, and manufacturing, along with substantial additional funding for workforce development and innovation capacity building within the government and across the United States. It aims to strengthen the semiconductor supply chain and support U.S. semiconductor manufacturing.

Shortly after the CHIPS Act was adopted, the European Chips Act [3] was passed in 2023 to "bolster Europe's competitiveness and resilience in semiconductor technologies and applications, and help achieve both the digital and green transition." Japan and many other countries followed suit, creating their own domestic incentives to establish domestic semiconductor capabilities, while also strengthening the global supply chain and building resiliency.

IEEE members are engaged at every step of the semiconductor value chain, and together they are helping to advance this essential technology while working to ensure that these in-demand jobs are available to those that have been traditionally excluded from science, technology, engineering, and math (STEM) careers..

The Making of a Semiconductor Chip

There are several phases to creating a semiconductor chip that require specialized machines, processes, and materials. These phases include:

- **Electronic Design Automation** [4] - Design engineers use specialized software to design, test, and analyze electronic circuits that are the foundation of a semiconductor chip.
- **Manufacturing/Fabrication** [5] - In this phase, specialized equipment is used to etch designs into silicon wafers, and then lay the elements into those designs to conduct electricity. This multi-step process uses photolithography and chemical processes to build each semiconductor chip in a cleanroom.

IEEE Global Semiconductors member Hazel Stoiber (second from the right) discussed education and skills development with Region 10 members.

- Assembly & Packaging [6] - Once the semiconductor chip is manufactured, electrical connections must be established, and the circuitry must be protected. This step creates a package that allows chips to be attached to circuit boards.
- Testing [7] - Before and after packaging, a semiconductor chip undergoes testing to ensure its correct functionality and prevent potential defects.

Additionally, there are specialized equipment suppliers and consumer product manufacturers that provide the tools needed at each phase and design specialized chips for devices. All these phases employ thousands of technicians, engineers, researchers, and scientists.

At the Forefront of Chip Technology: IEEE Global Semiconductors

IEEE Global Semiconductors [8] brings together technical innovation and expertise within IEEE to help shape the future of semiconductor technology worldwide. This group is making strides to foster international collaboration and development of the next generation of the semiconductor workforce.

In August 2023, IEEE President and CEO Tom Coughlin and IEEE Region 6 Director Kathy Hayashi formed the IEEE Global Semiconductors Committee under IEEE Future Directions. This group has been actively reaching out to IEEE regions and members to support, engage, and inform members about global semiconductors.

One of the group's hallmarks is the promotion of international collaboration. Recognizing that innovation thrives in a diverse and inclusive environment, the IEEE Global Semiconductors initiative has been working with leaders around the world. For example, collaborating with IEEE Region 10 Director Lance Fung, IEEE Educational Activities and Malaysian educational institutions met to discuss strengthening the pipeline of skilled engineers. The group is also meeting with academia in Latin America to discuss the many IEEE programs that support assembly, testing, and packaging. These collaborations work to create an even greater global network of technologists.

The impact of the IEEE Global Semiconductors extends far beyond academic and research circles. In alignment with programs like the CHIPS Act, the team is reaching out to the newly created Regional Technology Hubs [9], the National Institute of Science and Technology (NIST), and grant recipients. IEEE-USA has also sponsored many events and webinars to support those interested in learning more about CHIPS Act initiatives.

IEEE Roadmaps for Semiconductors

Roadmaps help industries understand the direction in which a technology is likely to evolve and outline steps that organizations may wish to take to prepare. IEEE is heavily involved in two roadmaps related to semiconductors: the IEEE International Roadmap for Devices and Systems (IRDS™) [10] and the IEEE Heterogeneous Integration Roadmap (HIR) [11].

IEEE International Roadmap for Devices and Systems (IRDS™) Provides Guidance to CHIPS Acts Around the World

The IEEE IRDS™ is an initiative that maps systems, quantum information, autonomous machine computing (e.g., self-driving), massive memory storage, connectivity (e.g., Internet of Things (IoT)), devices, factory integration (i.e., high volume manufacturing), trends, and Environment, Safety, Health, and Sustainability (ESFHS) with a 15-year outlook. The IRDS™ is supported by eight IEEE Technical Societies as well as official European and Japanese organizations. The IRDS™ is also part of the IEEE Global Semiconductors Initiative.

Fig. 1. IRDS™ proposed NSTC and APMP structures.

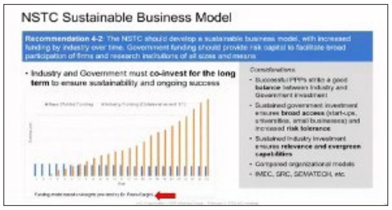

Fig. 2. Official IAC proposal to DOC of NSTC business model made on February 7, 2023

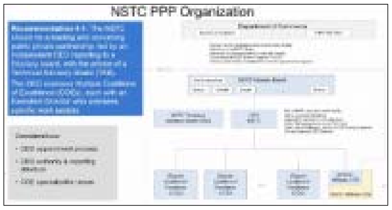

Fig. 3. Official IAC proposal to DOC of NSTC business model made on February 7, 2023.

Most roadmaps are descriptive in nature since they simply document events and parameters of the electronics industry that have already occurred and then linearly extrapolate trends into the future. On the other hand, the IRDS™ is a prescriptive roadmap that identifies major inflection points ahead of time to prevent major crises. The IRDS™ also provides possible solutions. Research organizations around the world use this information to shape their programs and provide timely, viable, feasible solutions to development organizations that turn them into highvolume manufacturing technologies and products.

The IRDS™ was initiated by IEEE in May 2016 as a continuation of the International Technology Roadmap for Semiconductors (ITRS) which was formed in 1998 and officially approved by the World Semiconductor Council (WSC) in the year 2000 as the guiding document to the semiconductor industry. As of June 2024, the IRDS™ exceeded the 1.5 million cumulative page visits worldwide.

Brief History of Events Outlining IRDS™ Guidance to Chips Acts

Before the Chips Acts

In March 2020, the IRDS™ was invited by United States Government representatives who were considering proposing a nationwide semiconductor initiative to outline trends and inflection points and make suitable recommendations. Throughout 2021, the IRDS™ made many presentations and submitted documents to the Department of Commerce (DOC). During this time, the IRDS™ proposed a prototyping structure and related technologies essential for any DOC implementation of programs aimed at re-energizing the electronics and semiconductor industries in the United States (Figure 1). Ultimately, in July 2022, the United States officially announced the formation of the CHIPS Act. Around the same time, both Europe and Japan announced their Chips Acts. Both regions selected the IRDS™ as their official guiding document. Prototyping pilot lines has already been announced in both regions.

Fig. 4. A conceptual model of the operational structure of the NSTC.

U.S. CHIPS Act step by step

In September 2022, the Industry Advisory Committee (IAC) was formed by DOC to provide recommendations on how to proceed with the formation of suitable organizations and which technologies should be part of the CHIPS Act. The IAC requested multiple presentations to formulate their recommendations. The presentation and recommendations of the IRDS™ on January 30, 2023, were the final and most important recommendations and were completely adopted by the IAC.

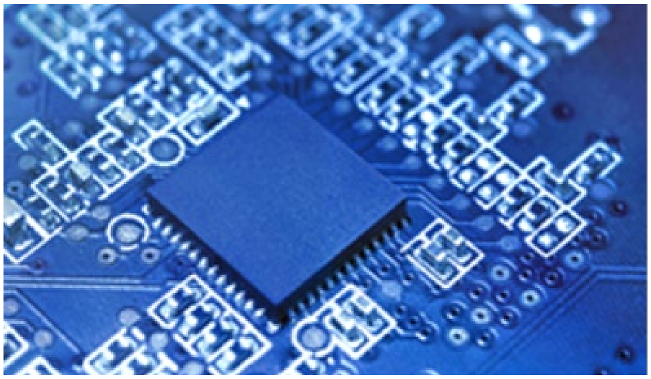

Fig. 5. A Package on a Printed Circuit Board

On February 7, 2023, the IAC included all the IRDS™ recommendations among the key points in their presentation to DOC (Figures 2 and 3). DOC included them in the final document published on April 25, 2023 (Figure 4). The technologies shown in Table 1 correspond to the IRDS™ recommendations made as far back as 2021 (Figure 1).

The first investments in gallium nitride in accordance with the IRDS™ recommendations have already been announced [12].

IEEE Heterogeneous Integration Roadmap

IEEE is also actively involved in the development of the Heterogeneous Integration Roadmap (HIR) sponsored by the IEEE Electronics Packaging Society (EPS), IEEE Electron Devices Society (EDS), and the IEEE Photonics Society, along with the external partners SEMI and the American Society of Mechanical Engineers.

The HIR provides a long-term vision of the packaging needs of the electronics industry, identifying difficult future challenges and potential solutions. The roadmap provides professionals, industry, academia, and research institutes with a comprehensive overview of the landscape and strategic technology requirements for the electronics industry's evolution over the next 10 years. It also provides a 25-year vision for the heterogeneous integration of emerging devices and emerging materials with longer research and development timelines. The purpose is to stimulate precompetitive collaboration and thereby accelerate the pace of progress.

What the world commonly refers to as the "Chip" (e.g., in the CHIPS & Science Act) is composed of multiple diverse semiconductors die integrated into a single package designed for a specific application, e.g., Artificial Intelligence (AI), assembled into a package for the global microelectronics market.

Heterogeneous integration of high-performance computing, memory, wireless and mixed-signal devices, biochips, power devices, optoelectronics, micro-electromechanical systems (MEMS), and sensors in single or even stacked packages is placing new requirements on the industrial manufacturing and research communities as these diverse components are introduced as elements for chiplet-based and other emerging System-in-Package (SiP) architectures. The HIR articulates state-of-the-art packaging technologies commonly referred to as advanced packaging.

Advanced packaging refers to combinations of distinct technologies designed, processed, assembled, and tested to enable cost, performance, power, and size-optimized interconnection of integrated circuits (ICs) and supporting elements to each other and to the system, including flip chips on build-up substrates, wafer and panel level packaging, silicon bridges, interposers with and without through-silicon vias), and inclusive of the lateral (2D) and vertical (3D) architectures using solder-based, hybrid copper-copper, and other interconnect technologies. In addition to electrical interconnects, the HIR also covers photonics and wireless interconnects.

The field of packaging includes materials, cooling technologies, power delivery technologies, signaling technologies, processes, and equipment needed for multi-die heterogeneous integration for performance, reliability, volume, cost, and time to market. The products typically include chiplets, pre-packaged components, and embedded/integrated passives to create SiP, integrated modules/subsystems, or complete functional systems. Typically, one or more of the dies will be in the leading-edge IC process node.

The primary integration technologies for the potential solutions will be complex and multifaceted, including chiplets and SiP-based architectures. To this end, the HIR is and will be at the forefront of advanced packaging going into the future.

The HIR is designed to be a system application-driven roadmap, blending the duality of market pull and technology push across the entire electronics ecosystem. Recognizing that, future technology advances will be driven by advances in system integration in response to market applications, it identifies six areas that are the leading technology drivers: High-Performance Computing (HPC) and Data Centers (including AI applications); Medical, Health, and Wearables; Autonomous Automotive; Mobile; Aerospace and Defense; and IoT. It attempts to answer the following key questions: What are the building blocks for electronic systems? What technological integration progress is needed in these basic building blocks to keep system integration on track? The building blocks envisioned in the HIR are listed as single-chip and multi-chip integration; integrated photonics; integrated power electronics; MEMS and sensor integration; 5G; and analog and mixed-signal integration. Underlying these building blocks are technical areas that cut across all the market application segments, including current and emerging materials, emerging research devices, testing, supply chain infrastructure, security, thermal management, co-design, and simulation. The HIR also identifies three

Fig. 6. IEEE Global Semiconductors co-chair Kathy Hayashi kicks off the IEEE Designing Chips with CHIPS conference in San Diego.

major technology areas for Heterogeneous Integration: SiP, 3D and 2D interconnects, and fan-in and fan-out wafer-level packaging.

In the nascent era of AI there are infinite possibilities for innovation in Heterogeneous Integration.

Beyond the Chip

While most of the attention surrounding the U.S. CHIPS Act has focused on initiatives promoting manufacturing, the law is much more expansive than that. Programs to encourage technology transfer from academia to industry, workforce development, and incentives to help small technology companies were also included. The National Science Foundation alone has launched over a dozen new programs designed to encourage technological innovation across the U.S. [13].

"Across the U.S." is key. Embedded in the CHIPS Act is language calling on government agencies to ensure that innovation programs include the entire United States, especially rural America. IEEE-USA's staff in Washington, D.C., fought for this language while the bill was being debated in Congress and played a key role in ensuring that it remained in the final law.

Once the law passed, IEEE-USA stepped up to help agencies fulfill their obligations by creating two new programs: Innovation, Workforce, and Research Conference (IWRC) and Industry Conferences.

IWRC [14] is a series of events held in rural America that bring researchers and industry leaders from a specific region together with government program officers for a day-long discussion on how they all can work together better. The events aim to foster collaborations among academia, business, and government, fostering innovation in rural America by linking local areas to the global technology ecosystem. Arkansas and South Dakota have already hosted successful IWRC events, and we are planning additional events in Alabama, Kansas, North Dakota, Maine, and New Mexico.

IEEE-USA's industry conferences bring business leaders from a specific industry and region together to discuss unique challenges and opportunities associated with the CHIPS Act, beginning with a "Designing Chips with CHIPS" event in San Diego last year. The San Diego conference examined how chip manufacturing incentives will affect chip design companies. An event occurring in the Phoenix area [15] involved the chip packaging industry's response to the CHIPS Act.

Together, IEEE-USA's efforts to assist Congress in crafting and passing the CHIPS Act, as well as ensuring its success, aim to assist technology professionals in both industry and academia in seizing the generational opportunities presented by the CHIPS Act IEEE-USA is engaging with technologists in companies and places across the entire country, broadening IEEE's reach, and impact to include every corner of the technology world.

Supporting Diversity, Equity, and Inclusion in the Semiconductor Workforce

IEEE Women in Engineering (WIE) [16] is making significant strides in promoting diversity, equity, and inclusion within the semiconductor industry. Recognizing the importance of engaging underrepresented groups, IEEE WIE is actively empowering minorities across the globe through a variety of programs. These include special activities through WIE International Leadership Summits [17], webinars, conference talks, and other activities specifically designed to provide individuals with the tools and knowledge necessary to thrive in the industry 5.0 era. By creating these opportunities, IEEE WIE helps to build a more inclusive and diverse workforce that is better equipped to drive innovation and progress in the semiconductor industry.

Moreover, IEEE WIE is deeply committed to sustaining women in engineering by addressing the unique challenges they face. Through targeted support and the creation of new opportunities, WIE is working to ensure that women not only enter the field of engineering but also continue to grow and succeed throughout their careers. These efforts are vital in fostering a more inclusive and equitable engineering community, which is essential for the long-term success of the semiconductor industry and beyond.

Additionally, IEEE Global Semiconductors is in the process of publishing a white paper titled "Sustaining Women in Engineering: Challenges and Opportunities" that delves into the significance of the CHIPS Act in addressing these challenges and promoting gender diversity in the engineering workforce.

Through these combined efforts, IEEE is advancing the goals of CHIPS Acts around the world and paving the way for a more diverse and inclusive future for the global engineering community.

IEEE Semiconductor Standards

IEEE is actively involved in the development of global standards that provide a framework for interoperability, reliability, and performance across the semiconductor industry. IEEE's standards development activities encompass a wide range of areas:

- Device terminology
- Post-manufacturing test procedures
- High-level circuit design languages for generation of transistor layouts suitable for fabrication
- Manufacturing guides
- Circuit design and performance analysis prior to fabrication
- Circuit design for test optimization

The IEEE Design Automation Standards Committee (DASC) is part of the IEEE Computer Society. The IEEE DASC is responsible for standardizing design automation and related semiconductor-related intellectual property (IP) standards within the IEEE. The DASC concentrates on standards for language-based design, modeling, integration, and verification. This includes standards for timing, synthesis, algorithms, low power, IP reuse, IP encryption, and testing.

Fig. 7. Matt Francis, IEEE Region 5 Director, and Kathy Herring Hayashi, IEEE Region 6 Director were joined by staff members from Ozark Integrated Circuits and John Brown University at the Arkansas location of this summer's Technology for Teachers:Semiconductors session.

Some of the standards from IEEE related to semiconductors include:

- IEEE 1076: VHDL Standards Series [18]
- IEEE 1497: Standard Delay Format [19]
- IEEE 1647: Functional Verification Language [20]
- IEEE 1666: SystemC® Language Reference Manual [21]
- IEEE 1685: IP-XACT XML for IP Description [22]
- IEEE 1734: Electronic Design IP Quality [23]
- IEEE 1735: Design Data Encryption [24]
- IEEE 1800: System Verilog Hardware Description and Verification Language [25]
- IEEE 1800.2: Universal Verification Methodology [26]
- IEEE 1801: Design & Verification of Low-Power ICs [27]
- IEEE 2401: LSI Package Board [28]
- IEEE 2416: System Level Low Power Modeling [29]
- IEEE 3164: Security Annotation for Electronic Design Integration [30]

To learn more and get involved in IEEE Standards development activities, visit https://standards.ieee.org/participate/.

Fig. 8. A middle school teacher participates in a hands-on activity during the Technology for Teachers workshop presented by IEEE TryEngineering.

IEEE Workforce Development Activities

As semiconductor infrastructure increases internationally, so does the need for a skilled workforce. There is currently an estimated one million additional skilled workers needed [31] by 2030 at all levels, including a projected shortage [32] of at least

67,000 workers in the United States. This provides an opportunity to expand and diversify the semiconductor workforce, creating training and jobs for those who may have traditionally been excluded from these STEM careers. IEEE has a number of initiatives underway to support workforce development for the semiconductor industry.

Pre-University TryEngineering Programs

The IEEE TryEngineering program was recently awarded a grant from onsemi [33] to develop content to help middle school teachers introduce students to the semiconductor industry. The program has recently launched a [34] resource that offers free videos, an e-book, and a lesson plan for both teachers and students. These resources provide an engaging look at what is involved in creating semiconductors, and the kinds of careers that students may wish to pursue. TryEngineering web page [34] includes videos, an e-book, and a lesson plan free for teachers and students.

Fig. 9. Students participated in a cleanroom training program for future technicians at USC. IEEE is providing microcredentials for graduates of the program that demonstrate mastery of specific skills needed by the semiconductor industry.

Three in-person teacher workshops were also held in various locations around the United States, with plans to expand the offerings. These Technology for Teachers workshopspresented middle school teachers with an overview of the science, supply chain, history, and future of the semiconductor industry.

IEEE Electron Devices Society Snap Circuits® Program

To teach students about electronic circuits in a hands-on manner, the IEEE EDS offers the Engineers Demonstrating Science: an Engineer Teacher Connection, or EDS-ETC program. The program allows EDS members to visit schools or host events and conduct activities using Snap Circuits® kits to teach about electrical and electronics engineering careers. These fun and engaging sessions are available for students in 4th through 12th grades and are a great way to inspire the next generation to consider engineering and semiconductor careers.

IEEE Metaverse Initiative Programs for Students

The IEEE Metaverse Initiative [36] is at the forefront of supporting the semiconductor industry's workforce development objectives by providing essential education and training to the next generation of engineers, particularly in the critical area of semiconductor manufacturing. The IEEE International Symposium on Emerging Metaverse Student Challenge [37] stands out as a key initiative, offering students a unique opportunity to engage with and understand the complexities of semiconductor technologies. This challenge not only fosters innovation but also equips students with practical skills that are crucial for advancing the semiconductor industry. By immersing students in real-world problems and cutting-edge technology, IEEE ensures that the future workforce is well-prepared to meet the demands of this rapidly evolving field.

Semiconductor Skills Microcredentialing

The growth of semiconductor infrastructure necessitates many technician-level roles, in addition to traditional engineering roles. This is an opportunity to engage individuals from many diverse backgrounds by providing nontraditional pathways for training and career advancement. IEEE has embarked on several projects to engage a new and diverse generation of workers in semiconductors.

IEEE is partnering with the University of Southern California (USC) and Microelectronics Commons Hubs [38] across the United States to provide skills-based microcredentials for cleanroom technician training. This program aligns with training and assessments offered by schools in the United States. IEEE has worked with the schools and industry to identify skills that the industry needs for cleanroom technicians and is standardizing the assessment instruments used to assess mastery of those skills. Schools in the program can offer stackable IEEE microcredentials to graduates of the program that are recognizable to industry. This allows individuals without formal university education to prove their qualifications for working as technicians in the industry.

Semiconductor Job Skills Catalog

Given the global nature of the semiconductor industry, many jobs with varying responsibilities and names exist. As the industry develops, there is a need to standardize these roles to help academic institutions prepare students and job seekers to attain the skills necessary to be qualified for different roles.

IEEE is collaborating with representatives from industry, associations, academic institutions, and other organizations to create a comprehensive job skills catalog that outlines the skills and competencies required for jobs across the semiconductor industry. The catalog will define six main categories of jobs requiring targeted and specialized training. These include consumer product manufacturers, electronic design automation, semiconductor manufacturers, equipment suppliers, assembly & packaging, and testing. The goal is to create a free, searchable online directory of roles and skills that can be used by job seekers, academic institutions, human resource professionals within the industry, and others interested in available jobs and skills needed to support the growth of the electronics industry globally.

Semiconductor Training and Educational Resources

IEEE offers training resources for professionals wishing to develop their skills in the industry. Courses and webinars from IEEE Societies and Councils such as the IEEE Circuits and Systems Society (IEEE CASS) [39], IEEE Solid State Circuits Society (IEEE SSCS) [40], IEEE Council on Design Automation (IEEE CEDA) [41], and the IEEE Electronics Packaging Society [42], as well as IEEE Educational Activities, are available through both the Society Resource Centers [43], as well as the IEEE Learning Network [44].

Resources include content such as:

- Universalization of IC Design from CASS [45]
- SSCS Women in Circuits [46]
- CEDA DAWN - Design Automation Webinar [47]
- EPS Courses on Electronics Packaging [48]
- …and a great deal more

To explore all these resources, visit the Education and Workforce Development page on the IEEE Global Semiconductors website: https://semiconductors.ieee.org/education [49]

These IEEE Societies and Councils also offer conferences and other events that help engineers and technology professionals stay up to date on the latest developments in their fields of interest. To learn more about IEEE Society Membership, visit https://www.ieee.org/communities/societies/index.html [50]. Student discounts are available.

Global Semiconductors Website

To stay up-to-date on IEEE semiconductor efforts, bookmark the IEEE Global Semiconductors website at https://semiconductors.ieee.org/ [51].

For IEEE-HKN members, the field of semiconductors offers the chance to work on cutting-edge technology and create innovative solutions. As future leaders in the field of engineering and technology, members of IEEE-HKN are encouraged to engage with IEEE Global Semiconductors and explore opportunities on this amazing journey of semiconductor innovation.

Dr. Paolo Gargini received a doctorate in Electrical Engineering in 1970 and a doctorate in Physics in 1975, both with full marks and honors. In the 1970s, he was a researcher at Stanford University and Fairchild Camera and Instrument in Palo Alto. In 1980, Dr. Gargini became responsible for memory protection unit technology at Intel (80286 and 80386). In 1985, he headed the first submicron team at Intel. In 1996, he became Director of Technology Strategy and was responsible for a worldwide research consortium until 2012, when he retired from Intel. During his tenure at Intel, he was a member of the Sematech, SRC, EIDEC, ASET, and SIA boards, Chairman of the I300I consortium, and NRI. From 1998 to 2015, Dr. Gargini was chairman of the ITRS sponsored by the WSC. Since 2016, he has been the Chairman of the IEEE IRDS™, sponsored by the IEEE Computer Society and supported by eight IEEE Societies and Councils (CSC, EDS, CASS, Magnetics, Signal Processing, Power Electronics, CEDA, and SSCS) and supported by Europe (SiNANO) and Japan (SDRJ). In 2009, Dr. Gargini was inducted into the VLSI Research Hall of Fame. He is an IEEE Life Fellow and an I-JSAP Fellow.

Kathy Herring Hayashi has been involved in the semiconductor industry her entire career – developing, deploying, and analyzing advanced software tools used to create computer and mobile phone chips. At Unisys Corporation, she worked in research and development, designing advanced in-house computer-aided design software tools for the semiconductor industry. Through acquisition, she transitioned to Cadence Design Systems, where some previous tools were incorporated into commercial electronic design automation tools. She then brought her professional leadership as Director at Syntricity, an early innovator in enterprise hosted software, focusing on semiconductor yield solutions.

She is currently employed at Qualcomm Inc., where she works with semiconductor workflows in large-scale computing environments. As co-chair of the IEEE Global Semiconductors Committee, Kathy interacts with global organizations, supporting and advancing major semiconductor initiatives. Kathy is the IEEE Region 6 Director and a member of the IEEE Board of Directors.

IEEE Spectrum

Interested in learning more about the CHIPS Act?

Check out these articles in IEEE Spectrum:

- United States Kicks Off CHIPS Act Funding
- U.S. Fab Capacity Could Triple in a Decade
- U.S. Universities are Building a New Semiconductor Workforce
- Intel's Troubles Complicate U.S. Chip Independence
- 4500 Fab Jobs Could Go Unfulfilled in U.S. by 2030

Jennifer Fong is the director of continuing education products and business development in IEEE Educational Activities. A former teacher, instructional designer, and entrepreneur, she currently leads product and workforce development activities at IEEE designed for those working in industry. She is also responsible for helping to facilitate semiconductor activities across IEEE, coordinating cross-unit communication and alignment of resources.

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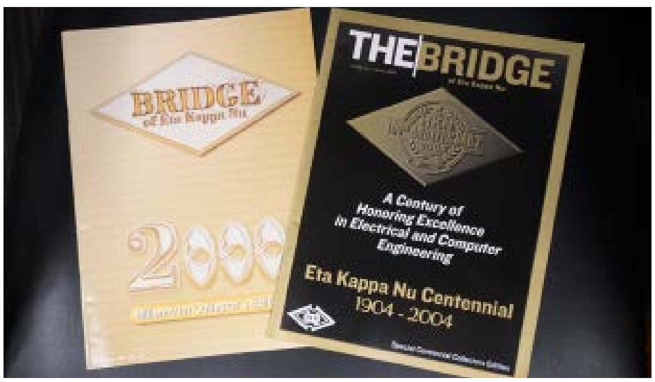
Alumni Gatherings, around the U.S. HKN's 120th Anniversary Celebrations.

The 1904 St. Louis World's Fair featured a stunning site–the Palace of Electricity which, offered seemingly endless possibilities for electricity to be a driving force for the "modern age." Perhaps Eta Kappa Nu's founding in 1904 was no coincidence. Maurice Carr led a group of young men on the University of Illinois at Urbana-Champaign campus on October 28, 1904, who envisioned an honor society to recognize electrical engineers who embodied the ideals of scholarship, character, and attitude, and to promote the profession. From this humble beginning, HKN now includes over 279 university chapters worldwide and boasts over 40,000 current student and alumni members. Since its inception, over 200,000 members have been inducted, all united by their commitment to the core principles espoused by its founders.



Historical BRIDGE covers.

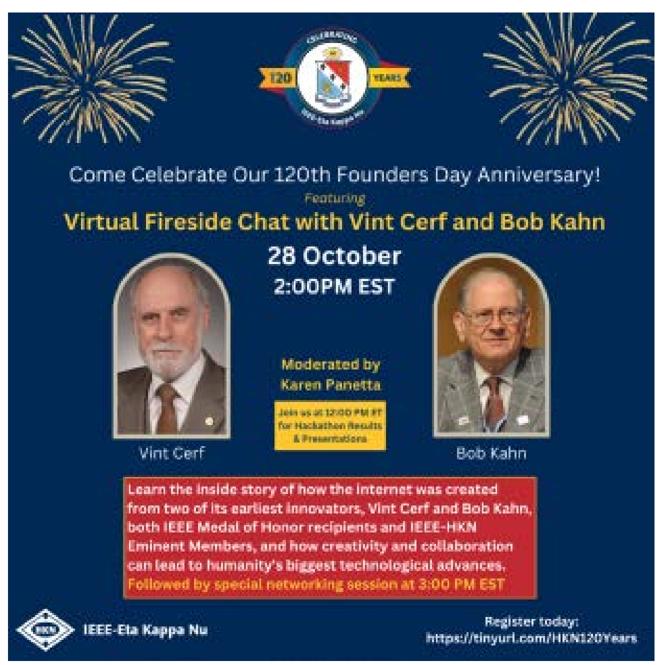
To commemorate its 120th anniversary, HKN has been organizing alumni gatherings at various IEEE gatherings throughout the year, including: the SoutheastCon Region 3 Conference, IEEE Life Members Conference, IEEE Communication Society Conference, the IEEE Power & Energy Society General Meeting, and the IEEE World Safety Forum, and at our Eminent Member Elevation ceremony at AT&T Labs.

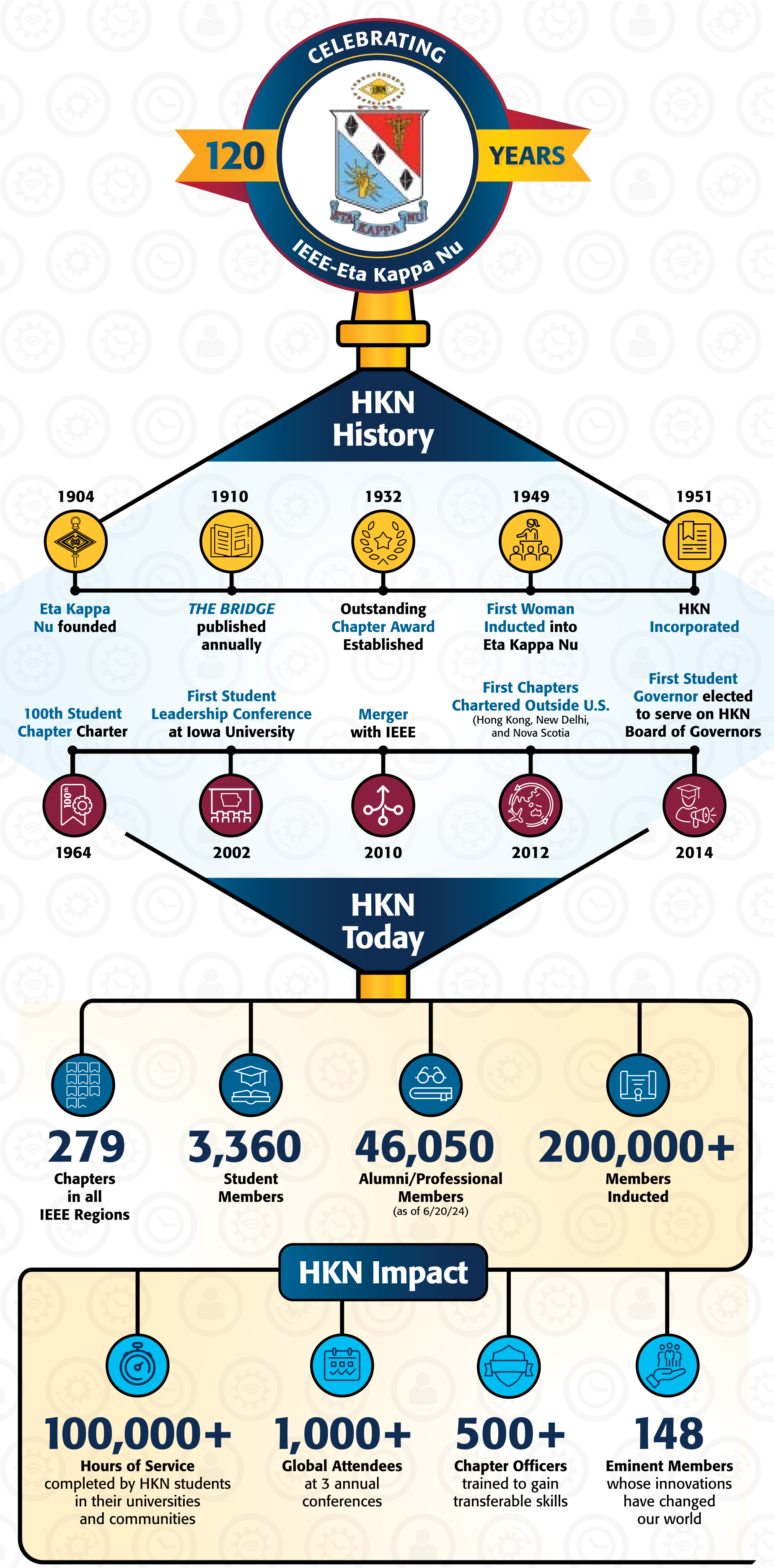
Presentation of of the 1953-1954 Outstanding Chapter Award to the Gamma Theta Chapter.

On Founders Day, 28 October 2024, there will be three special virtual events. The first-ever global Hackathon is running from 11-22 October, with the top five winning teams being announced at 12 p.m. ET. At 2 p.m. ET, Karen Panetta, 2019 IEEE-HKN President, will host a virtual fireside chat with HKN Eminent Members, Vint Cerf and Bob Kahn. This chat will feature the inside story of how they conceived and designed the architecture of the internet. A special online network session will follow at 3 p.m. ET, where participants can share their HKN stories and brainstorm how to continue the forward momentum for the next generation of engineers. The event is open to everyone, and you can register here. A dedicated web page showcases the many ways you can celebrate. The site also honors HKN's proud history with a timeline showing its growth trajectory and dynamism over the years.

left to right: Jim Conrad, 2022 IEEE-HKN President, Ryan Bales 2024 IEEE-HKN President, Jennifer Franco IEEE-HKN Secretary, and John McDonald, IEEE-HKN Governor-At-Large cutting a 120th Anniversary cake at 2024 SouthEastCon.

IEEE-HKN's success is attributable to never straying from its core founding principles while staying relevant by offering support along every leg of its members' career journeys and a vibrant network of like-minded professionals.





continued from page 5 – Guest Editor

Polytechnic University (currently NYU), NY. Previously, Dr. Kirkici was Professor of electrical and computer engineering at Auburn University, a visiting scholar and Faculty Fellow at the Air Force Research Laboratory – Wright-Patterson Air Force Base, and a visiting scientist/engineer at NASA Marshall Space Flight Center in Huntsville, AL.

Dr. Kirkici is a Fellow of IEEE and recipient of the IEEE Eric O. Forster Distinguished Service Award, IEEE William G. Dunbar Award, and the IEEE Sol Schneider Award. She is a member of the American Physical Society (APS), Sigma Xi Scientific Honor Society, Eta Kappa Nu, and the American Association of University Women (AAUW).

Dr. Kirkici served as the Governor–at–Large of IEEE-HKN (2020-23), IEEE Vice President – Publications (2019), President of IEEE DEIS (2009-2010), and Vice President of IEEE Sensors Council (2014-2015). She is a member of the IEEE-HKN *THE BRIDGE* Magazine Editorial Board (2020-present) and President-Elect of the IEEE Transportation Electrification Council (2024-present).

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Congratulations to the 2024 HKN Award Winners!

The IEEE-HKN Awards Committee is proud to announce the recipients of this year's awards:

Dr. Andrea J. Goldsmith, Dean of Engineering and Applied Science, School of Engineering and Applied Science, Princeton University, an IEEE Fellow and International Fellow of the Royal Academy of Engineering, was named the recipient of the IEEE-HKN's highest honor, the Asad M. Madni Outstanding Technical Achievement and Excellence Award. Professor Goldsmith received the award *"for her pioneering work in wireless communications and information theory leading to innovations which have shaped the performance of wireless networking and enabled fast, reliable wireless service around the world."* Through her groundbreaking research and entrepreneurial efforts, Professor Goldsmith has influenced virtually all cellular and Wi-Fi networks worldwide. Known for a wide range of breakthroughs in telecommunications, Goldsmith developed adaptive modulation techniques that have allowed engineers to vary the speed of transmission to match the rapidly shifting demands of receiving networks. The Asad M. Madni Award was established in 2019 to recognize a practitioner for distinguishing himself or herself through an invention, development, discovery, or innovation in electrical or computer sciences, engineering, or technology, with worldwide impact.

Dr. Gina Adam, Associate Professor in the department of electrical and computer engineering at George Washington University, is the recipient of the IEEE-HKN C. Holmes MacDonald Outstanding Teaching Award *"for contributions to nanoelectronics education and inclusion efforts in electrical and computer engineering."* Since joining George Washington University, Dr. Adam has taught courses in the design of logic systems, nanoelectronics, physical electronics, micro- and nanofabrication technology, and the engineering seminar. So far, she has impacted over 220 undergraduate students and more than 35 graduate students. The establishment of this award in 1972 recognized the crucial role college professors play in training and motivating future electrical and computer engineers. The award acknowledges engineering professors who, early in their careers, have demonstrated special dedication and creativity in their teaching.

Ronald Jensen, 2021 IEEE-HKN President, is the recipient of the IEEE-HKN Distinguished Service Award *"for continued service in leading and growing impactful IEEE-HKN Programs and sustained dedication to mentoring future student leaders."* Ron has been a major resource for IEEE-HKN for many years, including service as both president and treasurer. He has vast experience and skills that he has patiently shared with board members year after year. He is a master of journey mapping, which helped bring diverse perspectives and contributions to the organization's future direction. His efforts helped shape the development priorities and brought storytelling of HKN's value to donors and sponsors. In 1971, Eta Kappa Nu established this award to honor members who have dedicated years of service, leading to significant benefits for society members.

The IEEE-HKN Awards will be presented at the IEEE Educational Activities Board (EAB) Awards Presentation Ceremony on Friday, 22 November 2024, during the IEEE Meeting Series in Dallas, Texas, USA. The contributions of these winners define excellence and service to our profession. Congratulations to all!

Honoring the Pioneers of Cosmic Discovery

On Tuesday, 17 September 2024, the HKN community gathered at the AT&T Museum & Science Technology Center in Middletown, NJ, to elevate Dr. Robert Woodrow Wilson and Dr. Arno Penzias to Eminent Member and Honorary Eminent Member, respectively. Dr. Wilson and Dr. Penzias are credited for discovering cosmic microwave radiation, which is considered strong evidence for the Big Bang theory of the universe's origin. Their discovery led to a Nobel Prize in Physics in 1978 in recognition of their outstanding contributions in advancing our understanding of the universe.

Dr. Wilson speaking after accepting this honor.

IEEE Regions 1 and 2 sponsored the event in partnership with AT&T Labs, which drew over 70 attendees to celebrate Dr. Wilson's and Dr. Penzias' work. Sunil Maloo, Assistant Vice President for AT&T Labs, and Bala Prasanna, Director of IEEE Region 1, made welcoming remarks before Sean Bentley, 2024 IEEE-HKN President-Elect, presided over the elevation ceremony, followed by networking and the cutting of a 120th HKN anniversary cake.

Eminent Member Elevation Ceremony participants celebrating IEEE-HKN's 120th Anniversary.

In 1950, Eta Kappa Nu established the Eminent Member recognition as the society's highest membership classification. It is to be conferred upon those select few whose attainments and contributions to society through leadership in the fields of electrical and computer engineering have resulted in significant benefits to humankind. Only 148 individuals have received this honor since its inception. Additionally, IEEE-HKN grants the honor of Honorary Eminent Member to deserving individuals who did not receive this recognition during their lifetimes.

Congratulations to Dr. Robert Woodrow Wilson and Dr. Arno Penzias on this well-deserved recognition! Thank you to AT&T Labs and IEEE Regions 1 and 2 for your support of this event.

Celebrating the Research Contributions of Our Graduate Student Members

Graduate students, an important and growing part of the IEEE-HKN global community, are performing groundbreaking research. We have developed this award-winning section in *THE BRIDGE* to celebrate and elevate their research contributions. The HKN Graduate Student Research Spotlight is a standing feature in *THE BRIDGE*. The profiles of the students and their work will also be shared on our social media networks.

Each profile will showcase the intellectual merit and broader impact of HKN graduate student members' research and provide information about the students' backgrounds and where people can learn more about them and their work.

We will spotlight these achievements while also showing potential graduate students what is possible!

Would you like to be featured?

Fill out our submission form. Submissions will be reviewed, assembled into a profile template, and posted on HKN's social media pages. A select number of profiles will also be featured in *THE BRIDGE*.

Advertising Opportunity

IEEE-HKN is the professional home to the world's top graduate students in electrical and computer engineering, computer science, and allied fields of interest. Get your company or university in front of these students and HKN's undergraduate students who are considering their next steps by advertising in a special section of *THE BRIDGE*. Click here for more information and rates.

Pooja Algikar

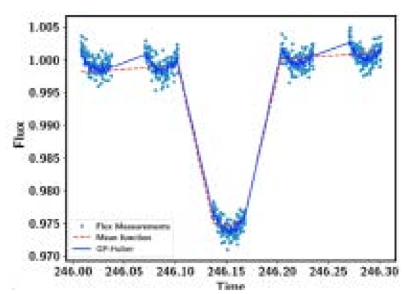
Beta Lambda

Virginia Tech, Ph.D. Candidate in Electrical Engineering

RESEARCH TOPIC

Statistical Machine Learning for Enhancing Power System Resiliency and Robustness

My Ph.D. research focuses on exploring the realm of probabilistic methods, stochastic processes, statistical Machine Learning models, robust estimators, and random matrix theory to develop data-driven uncertainty quantification methods for decision-making. Particularly, I have studied robust estimation theory and stochastic processes and devised a robust process model (RPM) in which robust hyperparameter estimation is proposed based on the Shweppe-type generalized maximum likelihood estimator. The proposed RPM is applied to capture uncertainties sourced from renewable energy sources in stochastic state estimation of large-scale power systems. It predicts hour-ahead uncertainty bounds on the voltage phasors predictions. Our work was published in IEEE Transactions on Power Systems [1]. We later proposed a full inference scheme in the robust Gaussian process regression model to learn the hyperparameters of both the mean function and the kernel function based on Gibbs sampling and Laplace approximation. In this work, we propose to use Huber likelihood to model the recorded data. This work is under review at ICML [2]. This work proposed a robust Gaussian process regression model agnostic of error distribution without additional likelihood parameters specific to the error distributions.



Transit curve mean function T (t, θ) and the proposed GP-Huber model fit.

Recently, I explored what random matrix theory has to offer for the uncertainty quantification in the applied Koopman operator during an internship at the National Renewable Energy Laboratory under the mentorship of Dr. Pranav Sharma and in collaboration with Dr. Marcos Netto from the New Jersey Institute of Technology. I was able to analytically quantify the measurement uncertainty propagated from recorded data used to estimate the Koopman operator, a linear approximation of non-linear dynamical systems, in terms of the second moments of each of its constituent elements. Using the principles from random matrix theory on the distribution of Wishart matrices, we were able to calculate the first and second moments of the elements of the pseudo inverse of the push-forward matrix in the dynamic mode decomposition, an estimation algorithm in applied Koopman operator. With the normality assumption on the uncertainty of measurements, I was able to deduce analytical expressions for the first and second moments of the random variables of the Koopman operator. For this case, the recorded data was normalized to have zero mean [3]. I realized that this is not always the case and the centrality of the data matters in the estimation of the Koopman operator. So, I expanded on this research to account for the centrality of the data where I used Sawa integrals to estimate the moments of the elements of the pseudo inverse of the push-forward matrix. This work is under review in the IEEE Transactions on Power Systems for the central case [3] and at the Conference on Decision and Control for the non-central case [4]. At a more fundamental level, this work devised a metric of trustworthiness, that is, how much one can rely on a finite-dimensional linear operator to represent an underlying dynamical system.

LEARN MORE
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Chae Eun

Lambda Xi
Hofstra University, M.S. Engineering Management

RESEARCH TOPIC
Quantitative Ultrasound Imaging & Texture Analysis in Human Tissues

My research, as a research assistant at Dr. Ghorayeb's Ultrasound Research Lab at Hofstra University, is focuses on advancing ultrasonic imaging techniques to enhance noninvasive medical diagnostics. By applying computational methods such as convolutional neural networks and texture analysis, I aim to improve the precision of medical imaging. My research involves differentiating benign from malignant breast tumors, assessing burn injury severity, and detecting osteoporosis-related bone structural changes.

Ultrasound techniques provide detailed insights into tissue morphology and pathology, presenting a safer alternative to traditional diagnostic methods that use ionizing radiation. This work has a significant broader impact, offering the medical community reliable, cost-effective diagnostic tools that reduce patient risk and enhance diagnostic accuracy. These advancements in ultrasound technology facilitate early and precise diagnosis, potentially improving treatment outcomes and patient care across various medical disciplines.

This research offers benefits that extend beyond individual patient care. Reducing the need for invasive procedures such as biopsies and enabling quicker, more accurate assessments can lead to better resource allocation in healthcare settings and potentially lower healthcare costs. The overarching goal of my research is to streamline diagnostic processes, thereby reducing the burden on patients and increasing the overall effectiveness of medical treatments across multiple subspecialties.

Ultrasound fetal lung images showing regions of interest to assess the maturity of the lung tissue

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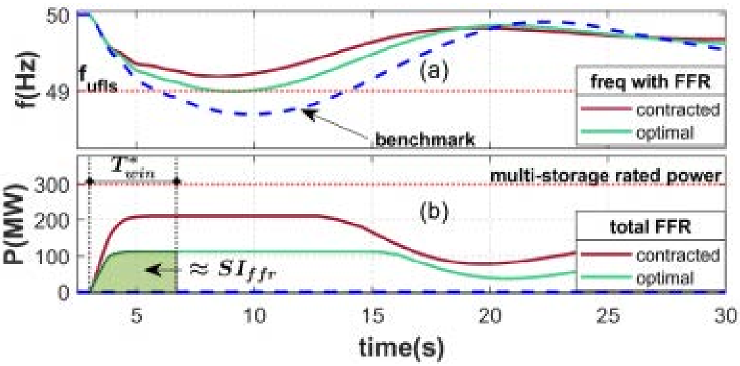
Indira Alcaide Godinez

Mu Kappa
The University of Queensland, Ph.D. in Electrical Engineering

RESEARCH TOPIC
The Frequency Contingency Reserve Determination of Utility-scale BESSs

The transition to renewable energy based on converter-interfaced inverters causes security and reliability issues, such as inadequate frequency response. However, the battery's contingency reserve is critical to ensuring the grid's security, as a lack of power reserves may lead to grid instability, whereas excessive reserves are costly.

Indira's research focuses on calculating the contingency reserves of multiple utility-scale BESSs for FFR. She has proposed a semi-analytical approach based on grid kinetic energy dissipation to define contingency containment using limited dynamic simulations. Her methodology ensures the grid security of a given dispatch case when facing a critical generation loss and provides insights for the more economical dispatch. The School of Electrical Engineering and Computer Science at the University of Queensland has supported Indira's work.



The figure shows the results of the optimal power reserve calculation for three utility-scale BESSs operating simultaneously while providing FFR. The optimal reserve is a more cost-effective solution than the typical contracted one.

LEARN MORE
www.researchgate.net/profile/Indira-Alcaide-2

CONTACT
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Roberta Bardini

Mu Nu

Politecnico di Torino, Ph.D. in Computer and Control Engineering

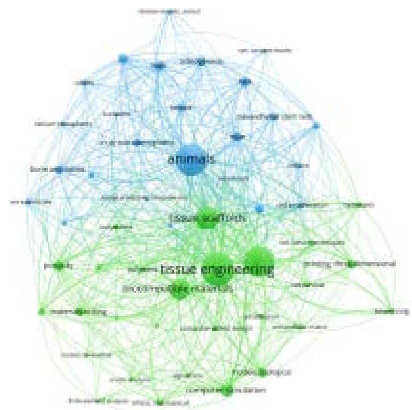
RESEARCH TOPIC

Computational systems biology and bioinformatics

Roberta Bardini is an interdisciplinary researcher in computational biology and artificial intelligence at the SMILIES Research Group, Department of Control and Computer Engineering, Politecnico di Torino, where she recently became Assistant Professor. Her journey began with the discovery of the rich intersection between computer science, artificial intelligence, and biology. For 10+ years, the adventure continues with the vision of a thriving scientific landscape where computation unlocks biological complexity and biology inspires new computing paradigms.

After earning her Master of Science in Molecular Biotechnology (2014, Università di Torino) with a Research Thesis in experimental electrophysiology, she completed a Ph.D. in Computer Engineering (2019, Politecnico di Torino) with the thesis "A diversity-aware computational framework for systems biology." During her Ph.D., she co-founded the HKN Mu Nu Chapter at Politecnico di Torino. She worked on the technology transfer of research results, and she has leadership and management roles in national and international research projects. Her current research quests include creating intelligent biofabrication solutions, analyzing neuroplasticity, and designing neuromorphic solutions inspired by nature.

Besides teaching programming courses at Politecnico di Torino, her work extends to STEM education and science communication, driven by the belief that today's stories from the scientific frontiers deserve to be told as they emerge and that it is our duty to educate - and most importantly to inspire - the scientists and tech leaders of tomorrow.



Bibliographic data-based co-occurrence map of Computational approaches to TERM Biofabrication based on either modeling or optimization (from https://www.sciencedirect.com/science/article/pii/S2001037023005111)

LEARN MORE

https://scholar.google.com/citations?user=IIKp3VoAAAAJ&hl=en

CONTACT

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2024 IEEE-HKN Student Leadership Conference Returns to Charlotte, North Carolina

IEEE-HKN 2024 Student Leadership CONFERENCE

On 15-17 November, hundreds of HKN students will be convening at the Embassy Suites Concord Golf Resort and Spa near Charlotte, North Carolina, for a weekend filled with learning, networking, and leadership development during HKN's largest in-person conference, the IEEE-HKN Student Leadership Conference (SLC). This year promises to be the largest conference, marking the first time it will not take place on a college campus. According to Jim Conrad, 2022 IEEE-HKN President and 2024 Conference Committee chair, "As our SLC continues to expand, we are looking to other models to accommodate its growth. With the Kappa Phi chapter as the host, we can retain our student involvement while taking advantage of the space offerings of a large conference venue."

This year's offerings include an expanded lineup of hands-on Friday workshops offered by Analog Devices, Test Equity/Keysight, and Texas Instruments. On Saturday, there will be 20 sessions covering cutting-edge topics such as quantum computing, smart grids, and artificial intelligence applications, as well as some aimed at building students' communication and leadership skills. A hallmark of the conference is its recruitment fair, which will feature over 35 companies, graduate schools, and IEEE societies looking for the top talent that HKN students represent. Kathleen Kramer, 2025 IEEE President, will be sharing her thoughts on IEEE's future direction. We cordially invite HKN alumni to our Awards Banquet on 16th, a special celebration of HKN's 120th anniversary.

There is still time to register, but don't wait too long. The deadline for conference registration is 6 November. We hope to see you in Charlotte!

Newly Inducted Eta Chapter Member Inspired to Start a New Chapter

Western New England University installed the Nu Lambda Chapter on 3 October 2024, making it the seventh new chapter this year. Sean Bentley, 2024 IEEE-HKN President-Elect, presided over the installation ceremony, where eight students and one professional took the oath to become HKN members. Graduate student and incoming chapter president, Daniel Williams, acted as the master of ceremonies. Dr. Steven Li will serve as the chapter's inaugural faculty advisor. ollowing his induction into the Eta Chapter at the 2023 IEEE Meeting Series last November, Dr. Li expressed his eagerness to introduce HKN to his position as an associate professor of industrial engineering and engineering management at Western New England University.

Sylvie Leal, the HKN Chapter Support Specialist, who attended the event, expressed that "it was exciting to see the growing support among the department for this new chapter." There were multiple faculty members in the audience who expressed their enthusiasm to get involved with Nu Lambda." The new chapter is already jumping into the HKN family, sending a delegation to the 2024 IEEE-HKN Student Leadership Conference in Charlotte, North Carolina. We are excited to support all the wonderful contributions that the Nu Lambda Chapter will make in the years to come!

Newly inducted charter members of Nu Lambda Chapter.

Two HKN Chapters' STEM Outreach Efforts Inspire the Next Generation of Engineers

Lambda Omicron and STEM Outreach Day (Girl Scout Day)

Held on 13 April 2024 at Miami University in Oxford, Ohio, STEM Outreach Day was a resounding success in inspiring young girls across all levels of the Girl Scouts program to pursue careers in various engineering disciplines. Generously sponsored by Purina, Swagelok, Fifth Third Bank, and Senneca Holding, the event brought together 72 enthusiastic Girl Scouts, supported by 28 parents, 30 volunteers, and four faculty members. The goal was clear: to ignite a passion for STEM fields and empower the next generation of female engineers. One of the key features of the event was its inclusivity, catering to Girl Scouts from the junior level to the ambassador level. By offering activities tailored to different age groups and skill levels, the event ensured that every participant could engage with STEM concepts meaningfully. From simple circuits and paper engineering for younger Girl Scouts to more advanced robotics and renewable energy projects for older participants, each station provided a unique learning experience that aligned with the Girl Scouts' badge requirements.

Participants at Lambda Omicron's STEM Outreach Day.

The involvement of key sponsors and other student organizations was critical to the success of the event. With their support, including Purina's dedicated station, the chapter was able to provide resources and materials for engaging activities that catered to the Girl Scouts' diverse interests and abilities. Additionally, student organizations such as Theta Tau, Kappa Delta, Robotics Club, AIAA, IEEE-HKN, and Society of Women Engineers contributed their time and expertise to operate the stations, ensuring that each activity was both educational and enjoyable for the participants. Furthermore, the event provided an opportunity for the Girl Scouts to earn different badges across various STEM disciplines. By participating in hands-on activities and completing badge requirements at each station, the Girl Scouts not only gained valuable skills and knowledge but also earned recognition for their achievements within the Girl Scouts program. This incentivized participation and added a sense of accomplishment for the participants, further enhancing their overall experience. "As I move towards graduation, looking back at my childhood, I realize that my time as a Girl Scout holds many cherished memories. I am proud to make those memories for a new generation of scouts and empower more girls to join STEM fields," stated Marguerite Smith, Lambda Omicron Chapter President.

Gamma Epsilon STEM Outreach to Local Youth

On 23 July 2024, Ayaan Qayyum and Adrian Jackson, officers in the Gamma Epsilon Chapter at Rutgers University, conducted a dynamic STEM workshop for a local summer arts program in New Brunswick, New Jersey, in collaboration with the IEEE-HKN staff members, Amy Michael and Mia Kennedy. he event aimed to introduce 45 youths, aged between 10 and 17 years old, to fundamental engineering skills like design thinking and problem analysis. IEEE-HKN staff members provided an overview of IEEE, followed by Ayaan and Adrian explaining the core principles of engineering and its practical value through the discussion of real-world applications.

Gamma Epsilon Chapter officers presenting to local youth.

The IEEE TryEngineering curriculum's "Ship the Chip" lesson plan challenged students to package a potato chip using limited materials such as cardstock, cotton balls, and popsicle sticks, emphasizing creativity, size, and weight. Students responded enthusiastically to the interactive activity, which combined education with practical experience. This approach not only captivated the students but also highlighted the significance of creativity in engineering education, aligning with the summer arts program's goal of encouraging students to express themselves creatively. Enabling students to work creatively and understand key engineering principles is a cornerstone of raising the next generation of engineers, and Gamma Epsilon is proud to have contributed to this vital mission.

> "I know that I am in the position I am today because of HKN members who came before me and wanted to help the next generation – mentors like, Dr. Steve Watkins and John McDonald."

Christian Winnigar

Gamma Theta Chapter

It is Never Too Early to Make a Philanthropic Impact

Christian Winingar has been a professional member of IEEE since August 2020 and was inducted into the Gamma Theta Chapter of Eta Kappa Nu in the fall of 2021. Christian began his college journey at Missouri University of Science and Technology in the middle of the COVID-19 pandemic. Most of his classes and meetings were virtual, like so many of us experienced during this historical time. Christian joined the IEEE Student Club to meet and form better relationships with his fellow students. Despite the virtual setting, he felt he was able to build a stronger sense of community through the club.

His involvement soon morphed into a more formal role at IEEE-Eta Kappa Nu (HKN), the honor society for IEEE. HKN members value scholarship, character, and attitude. Through the shared values of scholarship, character, and attitude, HKN members can build a community of like-minded individuals in their college and worldwide.

Before stepping into leadership roles, Christian joined different committees within the Gamma Theta Chapter, including serving on the event planning and fundraising committees. These positions allowed him to understand better how the chapter operated and prepared him to step up into a leadership role eventually.

"My experience with HKN greatly defined my undergraduate experience and helped me make lifelong friendships and professional connections," shares Christian. "I was able to grow my network and develop my soft skills outside of the classroom."

At the beginning of 2024, after earning his bachelor's in electrical engineering, Christian started his first professional role as a distribution engineer at Burns and McDonnell. His great coworkers and mentors, who offered advice and guidance on how to handle this transition, made him feel very fortunate. It did not take long for Christian to settle into his new position and re-engage with his volunteer work.

"I became more involved in IEEE by joining the IEEE Standards Association and multiple Distribution Subcommittee Working Groups. By increasing my responsibilities, I was able to challenge myself to learn new skills and gain new experiences," shares Christian. "I have had the opportunity to attend multiple conferences such as the IEEE PES General Meeting and IEEE-HKN Student Leadership Conference, attend standard development meetings, and develop my technical abilities and soft skills to become more confident in myself as a professional in industry."

Christian believes that engineers are lifelong learners. The engineering landscape is constantly changing and evolving. Professional societies, like IEEE, can offer networking opportunities, continuing education, skill development, career advancement, and the opportunity to be a part of a larger community and support system that helps you grow and change along with the engineering landscape. He particularly emphasizes the benefits of IEEE for students:

"IEEE has over 400,000 members and access to one of the largest library collections of electrical engineering and computer engineering resources, including conference papers, new research, and standards. It is important for colleges and professors to stress the importance and significance of IEEE to students and individuals in all phases of their academic engineering career. Once a student is a member, it is important for them to denote their interests and start exploring resources related to their interests, such as power systems or control systems. This will allow them to find conferences and individuals who are established in these fields and provide them with mentorship, knowledge, and community necessary to thrive."

Christian has done just that – thrive. He is already in a position to contribute to the future generation.

"I know," Christian acknowledges, "that I am in the position I am today because of HKN members who came before me and wanted to help the next generation – mentors like Dr. Steve Watkins and John McDonald."

To pay it forward, Christian is serving as the committee chair for the IEEE-HKN Alumni Committee, as well as serving on the 120th Founders' Day Planning Committee. He is also a donor, despite being a recent graduate and a new young professional. When asked why he felt the need to give back early in his career, Christian shared that he is "passionate about the continued success of IEEE" and wants to donate when he can.

Christian concludes, "Eta Kappa Nu is an amazing organization for all students. The network and relationships I have built through this group are priceless. Even now, in my early career, HKN continues to benefit me and my professional journey. If you find yourself in a position where you would like to give back, please reach out to IEEE!"

To support HKN, visit the IEEE Foundation's IEEE-HKN donation webpage and make an impact.

He predicts that "engineering will evolve through the integration of AI/ML, robotics, and continuous technological revolutions. AI-enhanced robotics will transform industries, creating smarter, more adaptive machines capable of learning and evolving. This integration will lead to breakthroughs in autonomous transportation, personalized medicine, smart infrastructure, and space exploration."

Adam M. Hudson

Kappa Phi Chapter

Priscilla Amalraj, Eta Chapter
Priscilla is the Senior Director, Global IT Business Relationships & PMO IEEE

University of North Carolina at Charlotte, Master of Science in Electrical Engineering with a concentration in Control Systems and Robotics.

Adam graduated with a Bachelor of Science degree in December 2023 from the University of North Carolina (UNC) at Charlotte, where he majored in computer engineering with a concentration in machine learning with minors in mathematics and computer science.

Adam is an aspiring engineer with a passion for robotics and control systems. Adam's dedication to exploring the development of automated systems and intelligent machines that can learn and adapt to new environments stems from his strong background in computer science. His love for space and space robotics drives much of his work, inspired by a lifelong fascination with science fiction and the dream of bringing those ideas to life.

In his spare time, he enjoys engaging in projects that blend creativity with technical skills, such as building robotic prototypes and experimenting with new technologies. Adam is passionate about STEM outreach and believes in the importance of demystifying complex topics to inspire the next generation of engineers and scientists.

His goal is to make a significant impact through innovative engineering solutions that enhance everyday life and drive technological progress. He is committed to combining theoretical knowledge with practical applications to create groundbreaking advancements in robotics and beyond.

As this year's winner of the Outstanding Graduate Student Award by the Department of Electrical and Computer Engineering at UNC Charlotte, Adam embodies HKN's commitment to scholarship, character, and attitude. He also won the Naval Horizons Essay Contest this year.

Adam is a member of IEEE-HKN and president of HKN - Kappa Phi Chapter. He is the current president of the Computer & Electrical Engineering Graduate Association, which he helped revive and restart. Adam also volunteers as the content manager for the Graduate Student Engagement Subcommittee. Adam serves on the local planning and event subcommittees for the 2024 IEEE-HKN Student Leadership Conference, stating, "I am excited to bring together all my volunteer activities at the upcoming SLC and to welcome HKN students to my city. Volunteering helps me to build skills for my future career."

Adam interned at the Robotics Research Lab, working on autonomous exploration. He also spent two summers at the Fleet Readiness Center East working on automatic test systems. His dream job is to be a research engineer working on robotics, creatively solving complex engineering problems and finding innovative solutions.

Adam loves making physical things happen through coding. This started as a passion for embedded systems and evolved to robotics. He loves engineering because of the thrill of tackling complex problems through creative and innovative methods. He doesn't like the fact that there are budget, time, and resource constraints in engineering. According to Adam, "They quickly limit creativity and innovation of solutions. However, that also requires you to come up with creative solutions."

He predicts that "engineering will evolve through the integration of AI/ML, robotics, and continuous technological revolutions. AI-enhanced robotics will transform industries, creating smarter, more adaptive machines capable of learning and evolving. This integration will lead to breakthroughs in autonomous transportation, personalized medicine, smart infrastructure, and space exploration."

The advice that Adam gives to his fellow students is: "Master the fundamentals. Engineering fields evolve quickly and a solid foundation will help you succeed.
This strong foundation will enable you to confidently explore various subfields within engineering, helping you discover and pursue your passions."

When asked to finish the sentence, "If I had more time, I would ...," he replied, "Dedicate it to expanding my personal projects, with a focus on designing and building robots. This would allow me to experiment with new technologies, refine my engineering skills, and bring creative ideas to life." We are grateful for how much Adam gives to HKN and look forward to seeing his continued growth!

Kathy Herring Hayashi

Eta Chapter

Sharing Her Love of the Semiconductor Industry and Her Advice to Follow Your Passion

Kathy Herring Hayashi began her career in the semiconductor industry by responding to a simple question, "What do you enjoy doing?" by drawing graphical flowers on the computer. One of her earliest assignments involved writing some of the first graphical interfaces for Electronic Design Automation (EDA) software, including recursive graphical layout and routing applications.

She credits her supportive parents for encouraging her to pursue a degree in technology, stating, "My dad had an interest in electronics, ham radios, and logical problems. We used to work together on a lot of puzzles and projects. My dad showed me how to use a slide rule, and my mom showed me how to use an abacus. Those interests in problem solving and learning new things carry over to my current career and are part of what I do almost every day." Her husband and two daughters, both in the medical field, continuously inspire her, and she credits them for their positive impact in the world. She views working in the semiconductor field as also having an impact on how people live, having worked on projects such as ATMs, virtual reality devices, and chips that have gone into outer space. According to Hayashi, "It is a very competitive but innovative space where we are always working on the next generation of products. I've written custom hardware description languages, synthesis, timing, and layout tools. In short, it can be very rewarding and a lot of fun."

Hayashi predicts that the increased performance and availability of computer environments in the IEEE fields of interest will lead to greater automation of current processes, thereby driving greater innovation and advanced technologies. She states, "Technologists will move up the stack and be further challenged to innovate and explore. Areas might include quantum computing, advanced space applications, and more immersive experiences. "

Hayashi offers the following advice to recent graduates entering the field: "Always keep learning, finding more about your field, and how your work fits in. The IEEE and IEEE-HKN networks are great ways to continue to network with industry colleagues, attend conferences, and keep current with your industry." The cancellation of one of her software projects taught her this lesson firsthand. Despite being devastated, she went on to discover how her work fit into the bigger picture of the very competitive market for this type of software. She realized that with some advancement in technologies that would help it scale, it could compete better with the other tools and the direction of the semiconductor industry. This led to an opportunity to work for a startup that pioneered internet-based hosted applications that are still in use today.

She also continues to grow her network, with one of her favorite IEEE-HKN memories coming from her experience meeting students from the Politecnico di Torino at the 2023 IEEE-HKN Student Leadership Conference in Houston. "We spent time exploring Houston, and I got to really learn about their experiences in technology and with IEEE. We had such an adventure and were able to laugh at eating pizza with pineapples, listening to concerts in the park, and practicing speaking in surfer lingo. I will never forget my time with these inspiring students and enjoy seeing them as they grow and impact technology by their posts on LinkedIn," according to Hayashi. As a frequent speaker at IEEE-HKN events, she continuously inspires the next generation of engineers.

Kathy Herring Hayashi has spent her entire career in the semiconductor industry, developing, deploying, and analyzing advanced software tools used to create computer and mobile phone chips. At Unisys, she was on the team that created one of the first internal mainframes on a chip using custom software. She has since worked for Cadence Design Systems, Syntricity, a local startup, and Qualcomm. In her role, she works with semiconductor workflows in large-scale computer environments. She is currently the IEEE Director of Region 6 (Western Region of the United States) and a member of the IEEE Board of Directors. She is a senior member of the IEEE and member of IEEE-HKN. She received the 2021 Women of Influence in Engineering award as one of San Diego's most influential women in engineering from the San Diego Business Journal, the 2019 IEEE Member and Geographic Activities (MGA) Innovation Award for outstanding innovation and leadership, and the 2018 Athena Pinnacle Award for an Individual in Technology sponsored by Athena San Diego recognizing leaders in technology.

The Transistor: A Small Invention that Changed the World

Burton Dicht, Eta Chapter

During National Engineers Week 2000, Apollo 11 astronaut Neil Armstrong unveiled a list of the 20 greatest engineering achievements of the 20th century. This list, compiled by a distinguished panel of engineers under the National Academy of Engineering (NAE), was based on nominations from 29 professional engineering societies, including IEEE. The selection process focused not on the "wow" factor of the technology but on the real-world impact of these achievements on people's lives [1].

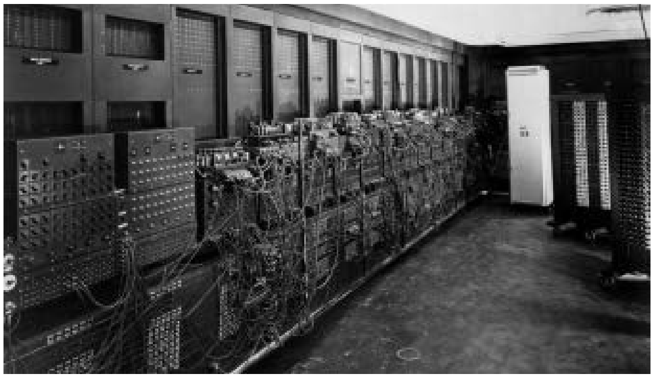
The electronics industry ranked fifth, encompassing innovations from vacuum tubes to integrated circuits. Among these technologies, the transistor stands out as a pivotal invention that revolutionized the electronics industry. Marking its 75th anniversary in 2022, *IEEE Spectrum* hailed the transistor as "The Modern World's Most Important Invention" [2]. This small device enabled the transition from bulky, unreliable vacuum tubes to efficient solid-state electronics.

The transistor quickly found applications in communications, consumer products, military equipment, and computing. Today, it remains the cornerstone of our digital world. But to appreciate its significance, we must look back at its origins.

Assorted Vacuum Tubes; Image Credit: Shutterstock

The journey to the transistor began with a need to improve upon the vacuum tube, a key technology of the early 20th century. Vacuum tubes were essential in amplifying electrical signals, making radios, early computers, and televisions possible. However, they were large, generated excessive heat, and had a short lifespan, leading engineers and scientists to seek a more reliable alternative [3].

One stark example of the limitations of vacuum tubes was the ENIAC (Electronic Numerical Integrator and Computer), the first large-scale, all-electronic computer completed in 1945. ENIAC used 17,468 vacuum tubes, weighed 30 tons, consumed enough power to light 10 homes, and required constant maintenance [4]. The cumbersome nature of vacuum tubes was humorously captured in the classic Star Trek episode "The City on the Edge of Forever," where Mr. Spock struggles to create a mnemonic memory circuit using

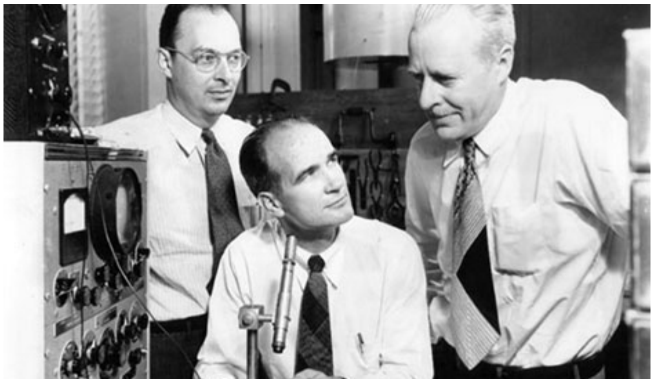


ENIAC; Image Credit: Shutterstock

1930s technology, lamenting that he's working with "stone knives and bearskins" [5].

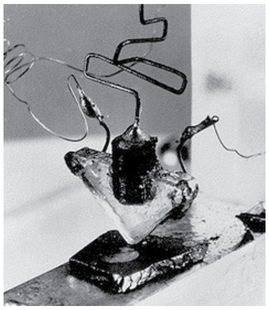
Years before the invention of the transistor, I personally encountered the frustrations of vacuum tube technology. Growing up, our family television (TV) frequently broke down, plagued by overheating tubes that needed replacing—requiring visits from the TV repairman.

The development of the transistor was deeply rooted in semiconductor research and quantum mechanics [6]. After World War II, Bell Laboratories initiated a program to advance electronics technology, focusing on creating a radar detector that could operate at high frequencies—something the vacuum tube, known as triodes, could not achieve. The semiconductor research team, led by Dr. William Shockley and including Dr. John Bardeen (IEEE-HKN Eminent Member) and Dr. Walter Brattain, worked to harness transistors as a potential replacement for triodes [4].



from left: John Barden, William Shockley, & Walter Brattain – 1948
Image Credit: AT&T

In 1946, Bardeen and Brattain assembled a device using thin tungsten strands, known as "cat's whiskers," placed on the surface of a germanium crystal. This device was the first solid-state amplifier and switch, capable of replacing the vacuum tube. Shockley later refined the design into a three-layer semiconductor sandwich. On December 23, 1947, the team presented their invention to Bell Labs leadership—the birth of the transistor [4].



The First Transistor
Image Credit: Bell Labs

Bardeen, Brattain, and Shockley were awarded the 1956 Nobel Prize in Physics for their groundbreaking work. However, the path to widespread adoption of the transistor was not immediate. Early transistors were expensive and produced in limited quantities, which slowed their acceptance by electronics manufacturers. The technology didn't gain traction until physicist Gordon Teal at Texas Instruments demonstrated that he could make transistors from silicon, a material abundant in sand. Jack Kilby (IEEE-HKN Eminent Member), an electrical engineer at Texas Instruments, further advanced the field by developing the first integrated circuit, embedding all the necessary elements onto a silicon wafer [7].

As design and manufacturing techniques improved, transistors began to replace vacuum tubes across the electronics market. While initially more expensive, transistors were smaller, more power-efficient, and more reliable. They required no warm-up time, operated at higher frequencies, and consumed less power [8]. By the 1960s, transistors had become the preferred choice, pushing vacuum tubes into obsolescence and paving the way for the digital age.

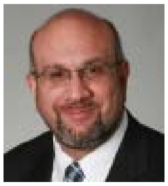
The transistor's impact extended beyond technology and into culture. In 1954, Texas Instruments introduced the Regency TR-1, the first transistor radio, which sold more than 150,000 units at $49.95 each (about $585 today). This portable, low-power radio became a symbol of freedom and mobility, influencing youth culture in the 1960s and 1970s [9] [10].

Regency TR-1 Transistor Radio, Image Credit: Nuts & Volts

Mass production of transistors eventually made them affordable to a broader audience, democratizing technology and affecting society at large. My family's first solid-state television, smaller and far more reliable than its vacuum tube predecessors, was a direct result of this technological shift.

The transistor also set the stage for the semiconductor revolution and the development of integrated circuits in the late 1950s. By packing millions of transistors onto a single chip, computing power increased dramatically while costs decreased, leading to the personal computer revolution of the 1980s. This exponential growth was driven by transistor miniaturization and power efficiency enabled by transistors were key drivers of this exponential growth.

Today, the impact of transistors on modern technology is immeasurable. They are the building blocks of nearly all electronic devices, from smartphones and laptops to medical equipment, space exploration, telecommunications, transportation, entertainment, and energy. Since their invention in 1947, experts estimate the manufacturing of 13 sextillion transistors, an increase from 2.9 sextillion in 2014 [11]. This tiny device has become perhaps the most ubiquitous invention in history, proving that even the smallest inventions can have a profound impact on the world and people's lives [12].



Burton Dicht is a member of IEEE-HKN's *THE BRIDGE* Editorial Board. He was the Director of Student and Academic Education Programs in IEEE Educational Activities. With a background in engineering and history, Burton has authored numerous articles on the history of technology and is a sought-after guest speaker on aerospace history. Additionally, Burton is a member of HKN's Eta Chapter, an ASME Fellow, and the Managing Director of Membership for the National Space Society.

For More Information:

- *Crystal Fire: The Invention of the Transistor and the Birth of the Information Age*, by Michael Riordon and Lillian Hoddeson
- *75th Anniversary of the Transistor* by Arokia Nathan (Editor), Samar K. Saha (Editor), Ravi M. Todi (Editor)
- *The Chip: How Two Americans Invented the Microchip and Launch a Revolution* by T.R. Reid
- *The Invention of the Transistor* by Clara Maccarald
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- *The Future of the Transistor Is Our Future, IEEE Spectrum*, November, 29, 2022, spectrum.ieee.org/the-future-of-transistors
- *The History of the Transistor Marches On*, August 22, 2022, www.allaboutcircuits.com/news/history-of-transistor-marches-on/

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[10] Regency TR-1, Wikipedia, https://en.wikipedia.org/wiki/Regency_TR-1

[11] How Many Transistors Are There in the World? , Wafer World, Inc., June 17, 2022, www.waferworld.com/post/how-many-transistors-are-there-in-the-world

[12] B. Lunt , Marvels of Modern Electronics: A Survey, Dover Publications, 2013, p. 32

Bernie Sander, Beloved IEEE-HKN Board Secretary Passes

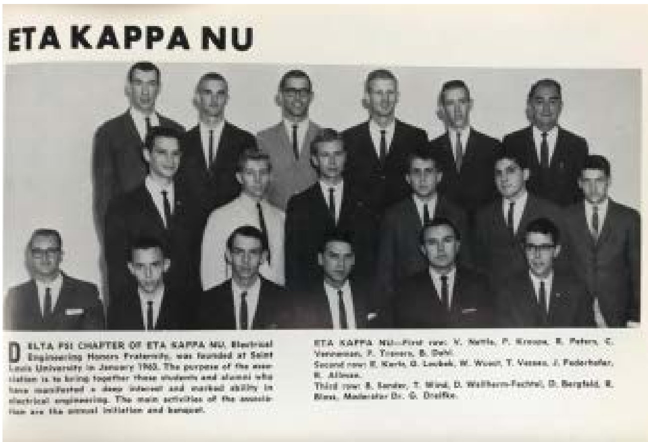
Left: Ron Jensen, 2021 IEEE-HKN President
Right: Bernie Sander at the 2022 IEEE-HKN Student Leadership Conference

It is with great sorrow that we announce the passing of Bernard (Bernie) Sander on 7 May 2024 at his home in Indianapolis, IN. He was a Life Senior Member who joined IEEE and was inducted into the Delta Psi Chapter of HKN as a student at Saint Louis University. He completed an M.S. at the California Institute of Technology and a doctoral degree at Washington University. He served as HKN Board of Governors Secretary from 2019 through 2022 as well as many other leadership positions within IEEE, including on the Awards, MGA, and IEEE-USA boards, as well as chairing the IEEE Chicago Section. He was also a strong supporter of the IEEE Foundation and the IEEE Life Members community.

Bernie retired from Bell Laboratories and Lucent Technologies, where he spent more than 31 years developing radar and switching systems. Following his retirement from Bell Labs, Bernie consulted at Northwestern and Marquette University on the design and construction of equipment used for research in human movement studies. Bell Labs Indian Hill recognized Bernie for his outstanding personal commitment and contributions to affirmative action. He was also recognized with the IEEE-USA Regional Professional Leadership Award for leadership in expanding the Science Kits for Public Libraries program in Region 4.

Bernie is survived by his beloved wife of 56 years, Toni. Together, they have volunteered time and talent to numerous ventures, including devoting over 25 years to Marriage Encounter to prepare couples for marriage. They spent time in Rwanda, where Bernie helped establish a Rwanda Student Branch. He had four children and ten grandchildren. Always a devoted volunteer and supporter of IEEE-HKN, Bernie was once quoted as saying, "There's a specialness that goes along with being a member of HKN. You work hard as a person, and because you have these skills and these abilities, there's an obligation to give back to the world. It's a challenge, but I think it's also a good challenge because it keeps your eye on the ball and keeps you moving in the direction you should be going." He lived his life according to his principles as an example to us all, and he will be missed by the entire IEEE-HKN community.

Tribute gifts in honor of Bernie can be made to IEEE-HKN via the IEEE Foundation.



Bernie Sander (third row) Delta Psi Chapter, St. Louis University

Opportunity to Volunteer at IEEE-USA CHIPS-Related Events for HKN Members

This past June, IEEE-USA hosted an Innovation, Workforce, and Research Conference (IWRC) event in Sioux Falls, South Dakota. Government employees from the federal, state, and local levels, along with top experts in academia and industry, attended this event to meet federal grant program officials and potential business partners. It was a great opportunity to discuss the importance of the CHIPS and Science Act (CHIPS Act) to the Dakotas while simultaneously introducing IEEE to new industry and academic partners.

IWRC Dakotas Opening: IEEE-USA Past President Ed Palacio, IEEE Region 4 Director Vickie Ozburn, and AFRL Regional Network- Midwest Director Dr. Stacy Manni Photo Credit: Cody Clem, AFRL Regional Network – Midwest

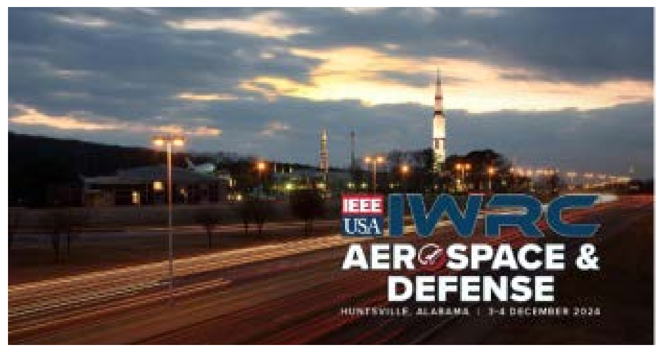
IEEE Region 5 Director Matt Francis moderating the "Engaging with the Federal Government Panel" Photo Credit: Cody Clem, AFRL Regional Network – Midwest

IEEE-USA then shifted its focus to two other CHIPS-related events. On 17 October, Scottsdale, Arizona hosted the first event, *Packaging Chips with CHIPS*. The event was a one-day summit that brought together leading thinkers from chip packaging and design companies, along with government policymakers, to discuss the chip packaging industry in light of the historic CHIPS Act and the Materials-to-Fab Center coming to Arizona State University.

The second event - our next Innovation, Workforce, and Research Conference focusing on the aerospace and defense industry, will take place in Huntsville, AL, from 3-4 December. With a reception at the U.S. Space & Rocket Center followed by a day-long summit featuring

thought-provoking experts, IEEE-USA seeks to share the opportunities the CHIPS Act has afforded, and could afford, Alabama and the southeastern United States at large.

The CHIPS Act is a historic piece of legislation that IEEE-USA's Government Relations' team played a key role in influencing. It is shaping supply chains and the semiconductor industry at a rapid pace. Under the CHIPS Act, the CHIPS Program Office manages the $39 billion grant program, which gives out grants to semiconductors and supply chains in need of financial support. The ultimate goal is to put the United States back on track to leadership with regard to chip manufacturing.



Registration for IWRC Aerospace and Defense is open. **We are looking for student volunteers** at the event to assist with registration and who would receive complimentary registration. If you have any questions, please contact Melissa Carl at m.carl@ieee.org or visit the link above.

We look forward to seeing you at an upcoming CHIPS-related IEEE-USA event! Please visit iwrc.ieeeusa.org for information about future events.