Focus on Materials

MATERIALS RESEARCH INSTITUTE MAGAZINE

SPRING 2025

Transformative Research Facilities
Labs and Beyond

PennState
Materials Research Institute

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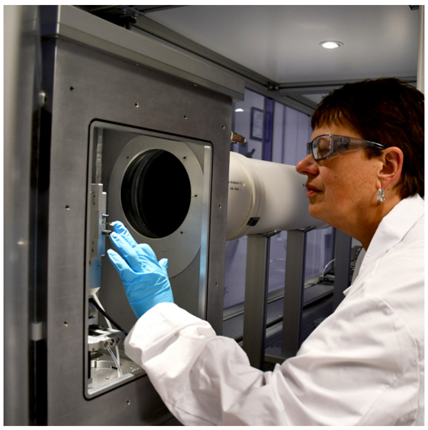

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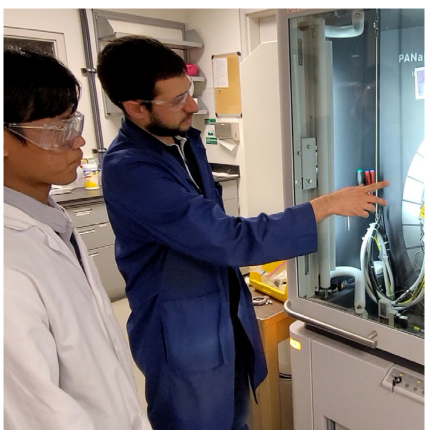

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Focus on Materials is a bulletin of the Materials Research Institute at Penn State University. Visit our website at www.mri.psu.edu

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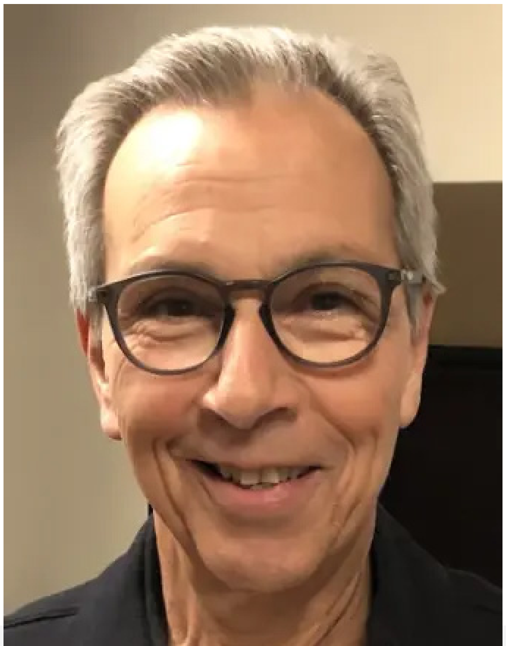
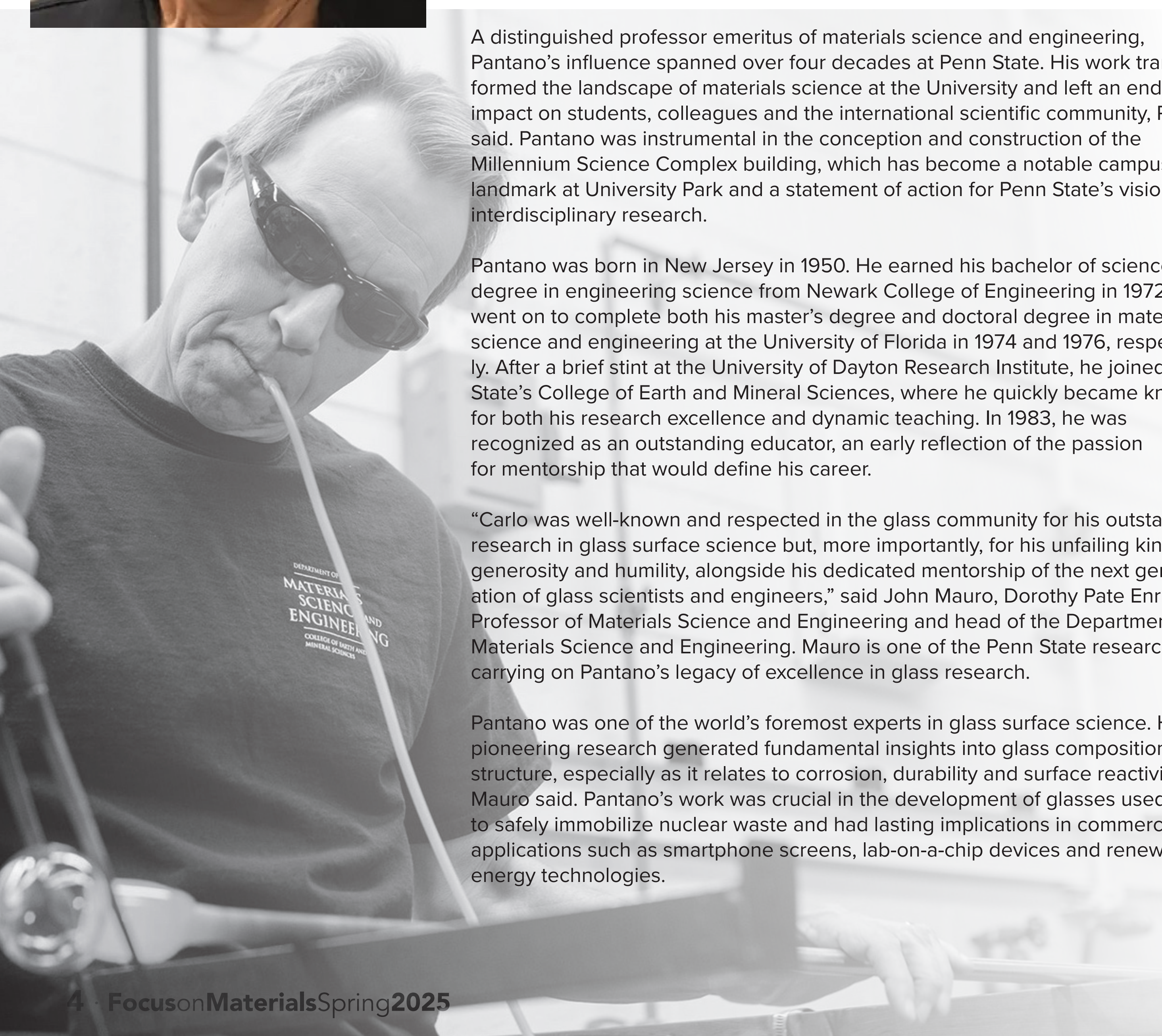


Remembering Carlo Pantano, former director of the Materials Research Institute

The Penn State community mourns the loss of Carlo G. Pantano, a globally respected glass scientist, dedicated educator and former director of Penn State's Materials Research Institute (MRI), who passed away on May 31. He was 74.

"Carlo was truly a cornerstone of the Materials Research Institute," said Clive Randall, director of MRI and Evan Pugh University Professor of Materials Science and Engineering. "His vision and dedication shaped so much of what we have built here, from groundbreaking research initiatives to fostering a collaborative environment that helped to create the interdisciplinary research world we have at Penn State now. Working with Carlo was not just professionally inspiring but personally rewarding; he had a rare combination of brilliance, humility and warmth that made every challenge feel surmountable. His legacy will continue to guide us for years to come."



A distinguished professor emeritus of materials science and engineering, Pantano's influence spanned over four decades at Penn State. His work transformed the landscape of materials science at the University and left an enduring impact on students, colleagues and the international scientific community, Randall said. Pantano was instrumental in the conception and construction of the Millennium Science Complex building, which has become a notable campus landmark at University Park and a statement of action for Penn State's vision of interdisciplinary research.

Pantano was born in New Jersey in 1950. He earned his bachelor of science degree in engineering science from Newark College of Engineering in 1972 and went on to complete both his master's degree and doctoral degree in materials science and engineering at the University of Florida in 1974 and 1976, respectively. After a brief stint at the University of Dayton Research Institute, he joined Penn State's College of Earth and Mineral Sciences, where he quickly became known for both his research excellence and dynamic teaching. In 1983, he was recognized as an outstanding educator, an early reflection of the passion for mentorship that would define his career.

"Carlo was well-known and respected in the glass community for his outstanding research in glass surface science but, more importantly, for his unfailing kindness, generosity and humility, alongside his dedicated mentorship of the next generation of glass scientists and engineers," said John Mauro, Dorothy Pate Enright Professor of Materials Science and Engineering and head of the Department of Materials Science and Engineering. Mauro is one of the Penn State researchers carrying on Pantano's legacy of excellence in glass research.

Pantano was one of the world's foremost experts in glass surface science. His pioneering research generated fundamental insights into glass composition and structure, especially as it relates to corrosion, durability and surface reactivity, Mauro said. Pantano's work was crucial in the development of glasses used to safely immobilize nuclear waste and had lasting implications in commercial applications such as smartphone screens, lab-on-a-chip devices and renewable energy technologies.

His prolific contributions were recognized by numerous prestigious awards, including the George W. Morey Award from the American Ceramic Society in 2005 for new and original work in glass science and technology. He was honored as the 2012 Kreidl Memorial Lecturer and the 2014 Scholes Lecturer in Glass Science, in addition to being named a Distinguished Alumnus of the University of Florida. Pantano was a fellow of both the American Ceramic Society and the American Vacuum Society and a distinguished member of the World Academy of Ceramics.

But Pantano was more than a brilliant scientist. He was also a visionary institution builder and tireless advocate for the kind of interdisciplinary collaboration that leads to beneficial applications for society, according to.... In 1991, he led the creation of the Materials Characterization Lab (MCL), which became a core facility at Penn State for advanced materials analysis and a critical resource for researchers across disciplines. He directed the MCL for a decade, helping to embed the principles of shared access, cross-training and hands-on learning into Penn State's research culture.

In 1998, Pantano was appointed director of the newly established Materials Research Institute. At the time, MRI existed mostly on paper. Over the next 16 years, under his guidance, it became a vibrant, collaborative hub now comprising more than 350 materials faculty across 19 departments and seven colleges. His leadership laid the foundation for MRI's evolution into one of the most respected interdisciplinary research institutes in the country, Randall said.

Among Pantano's most lasting accomplishments was his role in conceptualizing and helping to realize the Millennium Science Complex, which opened in 2011. The state-of-the-art facility, now home to MRI and the Huck Institutes of the Life Sciences, physically embodies Pantano's belief that scientific breakthroughs happen at the intersection of disciplines.

"Carlo Pantano developed the concept of the Millennium Science Complex," Randall said. "It was an enormous step in bringing the core facilities right to the center of campus. In many ways, our building stands both as a working example of effective interdisciplinary research at Penn State and as a monument to Carlo's brilliant mind."

Pantano also built bridges between Penn State and industry, especially through his connections to U.S. and international glass companies. These relationships not only led to impactful research partnerships with real benefits to society but created pathways for students to enter the workforce with real-world skills. His students, frequently recruited by industry, often credited him with giving them the foundation they needed to succeed.

A hallmark of Pantano's approach to teaching and mentorship was hands-on learning. He established a hot shop for glass fiber drawing and blowing, which served as a space where students from engineering, art and science backgrounds could work side-by-side. Through this integration of craft and science, Pantano helped demystify complex materials concepts and encouraged creativity and collaboration.

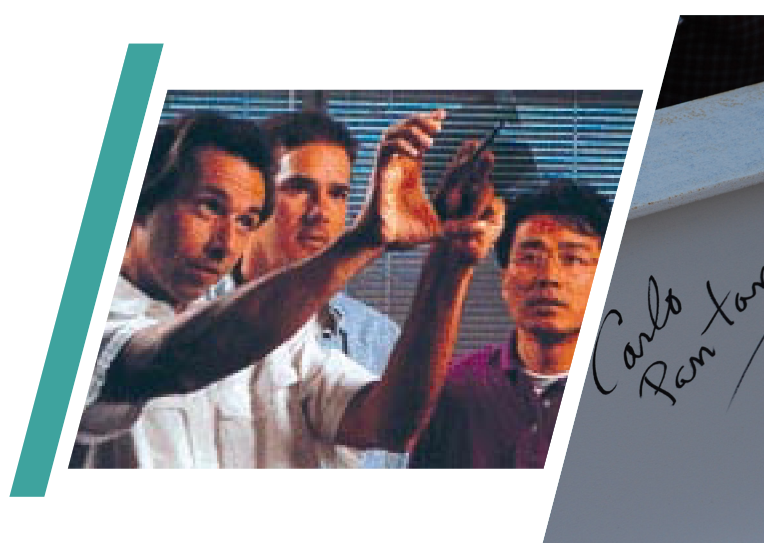
Those who worked closely with him remember not just his intellect, but his generosity, humor and genuine interest in the success of others. He was a selfless leader and collaborator whose legacy extends through the hundreds of students, faculty and staff whose lives he touched, Randall said.

Pantano was married to Jacqueline Ann Pantano for 48 years, until her passing in 2020. He often credited her support as essential to his work and achievements.

Pantano's passing is a profound loss to the Penn State community and to the broader world of materials science. Plans are underway for a university celebration of his life and legacy later in the year, to be organized by MRI in collaboration with other university partners and scientific organizations.

The family kindly requests contributions be made to the Alzheimer's Association. Online condolences may be entered at the Koch Funeral Home website.

"Carlo embodied the 'WE ARE' spirit of Penn State better than anyone else I've known," Mauro said. "He lived and breathed the Penn State values in everything he did, selflessly lifting each student, staff member and faculty colleague who crossed his path, fostering a wonderful sense of community where everyone feels valued and empowered with the tools and support they need to achieve their full potential. That's quite a legacy."



Across the country, higher education and scientific research face mounting challenges such as tightened budgets, shifting federal priorities, and growing skepticism about the role of science in society. Major discussions and education on the institutional use of facilities and administration (F&A) costs on federal grants are needed, and these are far from subsidies.

This issue of Focus on Materials highlights our facilities, and F&A enables these facilities; therefore, this funding source is vital to our mission and our support of federal needs and private industry. Collectively, this has enabled us to meet the foundational mission of Penn State and universities like us. This includes conducting research with real, high societal impacts; offering our students a very high level of education; enabling us to offer workforce training for living wage, meaningful American jobs; and finally, building partnerships with industry so we can collaborate on reaching those aforementioned achievements.

At MRI, our foundation rests not just in state-of-the-art buildings or sophisticated instrumentation, but in people. Our facilities are powered by the expertise of dedicated staff, the creativity of interdisciplinary researchers, and the energy of students eager to make a difference. These are the human elements that transform our labs into hubs of discovery and innovation which impact American scientific advances.

It's not just the facilities; it's our people's faculties. In this issue, you will read just a few of the many stories we have to tell about our facilities and their impact.

The MRI facilities are among Penn State's most valuable assets. This is true not only for materials science but for the entire university's research enterprise. From nanofabrication and materials characterization to scalable manufacturing and next-generation electronics, our core labs serve as a research engine for hundreds of investigators from dozens of disciplines. They are where ideas are tested, refined, and often born. They are also classrooms, incubators, and training grounds for the next generation of scientists and engineers.

But the impact of our facilities—and our mission—extends far beyond Penn State. We work hand in hand with industry partners, national labs, startups, and community organizations. Our tools and talent drive innovation in energy needs, electronics, manufacturing, health care, transportation, and defense. And perhaps no initiative better reflects this spirit of collaboration and global relevance than the Silicon Carbide Innovation Alliance (SCIA) and the newly launched Silicon Carbide Crystal Center.

The SCIA is a model of what's possible when we unite academic expertise with industry needs to solve urgent challenges. Silicon carbide is a critical material for next-generation power electronics, and the Crystal Center is leading the charge in research, training, and industrial partnership. It represents the future of collaborative research; its purpose-driven, interdisciplinary, and globally connected. (You can read more about SCIA and see highlights from recent events at scia.psu.edu).

As we look ahead, we can learn from history. First, our facilities help us embrace the land grant university mission, which was outlined in the Morrill Land Grant College Act of 1862, which launched the American land grant college movement. It states, "where the leading object shall be, without excluding scientific and classical studies … to teach agriculture and the mechanic arts [engineering] … in order to promote the liberal and practical education of the industrial classes in all the pursuits and professions of life."

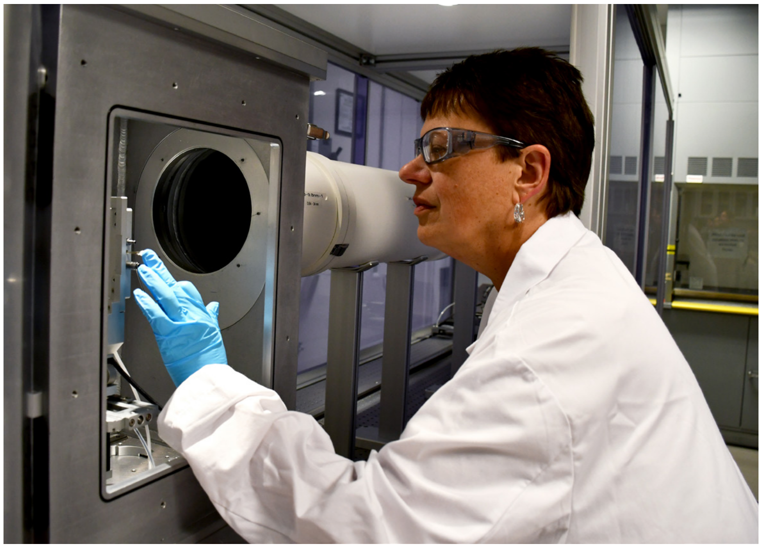
And second, Penn State weathered the storm that was the Great Depression of the 1930s, when the University partnered with industries to help each other survive that incredible crisis. It is even thought by some historians to be why the area surrounding Penn State became named "Happy Valley," as Penn State's savvy reaction to the financial collapse helped shield our region from its worst effects.

The economic challenges are always real, but so is our commitment to science, to society, and to shaping a better future together consistent with our origins and our foundations. ■

C A Randall

Clive Randall
Director, Materials Research Institute
Evan Pugh University Professor of
Materials Science and Engineering

Nichole Wonderling awarded prestigious fellowship



Credit: Jennifer M. McCann/Penn State MRI

"Continuing education is vital for everyone today regardless of discipline. Both employees and employers look for reliable training resources to bring new or transitioning employees up to speed and to refresh or broaden their skills," Wonderling said. "Lifelong learning is very important in scientific disciplines."

Nichole Wonderling, assistant research professor and X-ray scattering manager at the Materials Research Institute's (MRI) Materials Characterization Lab (MCL), has been named a fellow by the International Centre for Diffraction Data (ICDD). The fellowship recognizes exceptional contributions to the field of materials characterization and dedicated service to the ICDD community.

Recipients are selected based on nominations from ICDD members, with candidates required to have served a minimum of two years in significant roles such as board director, technical regional co-chair, committee chair, technical subcommittee chair, or leaders in noteworthy ICDD activities. The ICDD Awards Committee reviews the nominations and recommends the most deserving candidates to the ICDD Board of Directors for final approval.

Wonderling's contributions to the ICDD include serving as a lead instructor at the ICDD's X-ray clinics, chairing the education subcommittee, and playing a pivotal role in educating the materials characterization community. Her leadership in these roles has been instrumental in developing educational materials, implementing workshops, and promoting the teaching of powder diffraction methods in educational institutions.

Wonderling's professional journey reflects her deep expertise and commitment to materials science. In June 2023 she was promoted to assistant research professor at Penn State and she has managed the MCL's X-ray Scattering Facility since October 2000. Her responsibilities include overseeing the lab's operations in X-ray diffraction, particle characterization, surface area analysis, and thermal analysis facilities. Her primary expertise lies in X-ray diffraction, encompassing powder diffraction, non-ambient diffraction, micro-diffraction, Laue single crystal orientation, X-ray stress measurements, small and wide-angle X-ray scattering, and grazing incidence scattering techniques. Prior to her current roles, she held the titles of researcher and research assistant at Penn State, and earlier in her career she worked as a chemist and lab supervisor at North American Refractories.

In addition to her professional roles, Wonderling has been an active member of the ICDD since 2020. She has chaired the Education Subcommittee since 2021 and is also a member of the Scholarship and Non-ambient Diffraction committees.

"Nichole's dedication to the field of materials characterization and her contributions to the ICDD are impressive," said Josh Stapleton, director of the MCL. "Her recognition as an ICDD Fellow is well-deserved and highlights the impact of her work within the x-ray scattering community." The Fellow Award was presented to Wonderling at the ICDD Annual Meeting of Members in March. ■

Jainendra Jain named 2025 Wolf Prize laureate in physics

Jainendra K. Jain, Evan Pugh University Professor and Erwin W. Müller Professor of Physics and holder of the Eberly Family Chair in the Penn State Eberly College of Science, has been awarded, along with two others, the 2025 Wolf Prize in Physics for "groundbreaking contributions to quantum matter and its topological potential" that revolutionized "our understanding of two-dimensional electron systems in strong magnetic fields."

The Wolf Prize acknowledges scientists and artists worldwide for their outstanding achievements in advancing science and the arts for the betterment of humanity.
In his early theory research, Jain introduced a class of exotic particles called composite fermions, explaining a new state of matter consisting of the intricate sequence of fractional quantum Hall states, now known as Jain states. Jain described the composite fermion as an electron trapped inside a quantum vortex in this strange liquid, sometimes thought of as an electron bound to a quantized magnetic field.

Jain first developed his theory while he was a postdoctoral scholar at Yale University. "When the idea of composite fermions first struck me during the Christmas break of 1988, I did not know that these particles would occupy my mind every day for the next 37 years," he said. "My hope is that this prize will motivate a few more to experience the beauty of nature through composite fermions."

Under certain conditions, composite fermions form a superconductor — or a material that can conduct electricity without losing any energy at low temperatures — that theorists predicted would contain an even stranger particle, called a Majorana, which is its own antiparticle, or a particle with the same mass but different charge.

"These discoveries advance high performance electronics, enabling ultra-low resistance materials and topological quantum computing," the Wolf Foundation shared in its award presentation on March 10. "They reveal complex quantum behaviors, guiding novel materials with revolutionary properties."

Just last month, Microsoft announced a potential breakthrough in quantum computing based, in part, on the early work of Jain and others in this space.

> "I am on the theoretical understanding side of this spectrum, but I work closely with scientists who test whether the theories correspond to reality," Jain said in a recent Penn State News article. "The news from Microsoft is an example of how basic research at universities could lead to real-world applications that drive innovation — like quantum computers."

The Wolf Prize is awarded annually and honors exceptional individuals who transcend barriers of religion, gender, race, geography and political stance, according to the organization's website. In the scientific domain, the awards are conferred in medicine, agriculture, mathematics, chemistry, and physics. In the arts, the awards recognize excellence in painting and sculpture, music, and architecture.

From left to right, Mary Beth Williams, acting dean of the Eberly College of Science; Tracy Langkilde, interim executive vice president and provost; Dan Larson, Verne M. Willaman Dean Emeritus, Professor Emeritus of Physics; Jainendra Jain, Evan Pugh University Professor and Erwin W. Müller Professor in Physics; Douglas R. Cavener, Huck Distinguished Chair in Evolutionary Genetics, Professor of Biology and former dean of the Eberly College of Science; Nitin Samarth, Verne M. Willaman Professor of Physics and Professor of Materials Science and Engineering; Mauricio Terrones, George A. and Margaret M. Downsbrough Head of the Department of Physics. Credit: Michelle Bixby

Celebrating its 46th year, the Wolf Prize has established a legacy of prestigious international recognition. To date, 382 scientists and artists have been honored. International judging committees, reappointed annually and comprising world-renowned experts in their fields, select the laureates. The prize in each field consists of a certificate and a monetary award of $100,000.

Jain was named the 2025 winner alongside fellow physicists Mordehai “Moty” Heiblum, who “pioneered experimental verification of these exotic particles,” and James Eisenstein, who “co-discovered the 5/2 fractional quantum Hall state, unveiling new electron phases, including Bose-Einstein condensation in bilayer systems,” according to the foundation.

In his research, Jain specializes in theoretical condensed matter physics. He uses theoretical approaches to understand the unexpected emergent behaviors of strongly interacting quantum many-body systems, especially in low dimensions. His interests include anyons, Majorana particles, graphene physics, and various topological phenomena.

Jain was elected a foreign fellow of the Indian National Science Academy in 2024, appointed as the holder of the Eberly Family Chair in Physics in 2023, elected as a member of the National Academy of Sciences in 2021, named an Evan Pugh University Professor in 2012, honored with the Distinguished Alumnus Award by the Indian Institute of Technology, Kanpur in 2010, elected as a fellow of the American Academy of Arts and Sciences in 2008, and received the Oliver E. Buckley Prize from the American Physical Society in 2002. ■

MRI Director Clive Randall named Evan Pugh University Professor

Credit: Penn State. Creative Commons

Clive Randall, distinguished professor of materials science and engineering and director of the Materials Research Institute at Penn State, has been named an Evan Pugh University Professor. The Evan Pugh University Professorship is the highest distinction bestowed upon faculty by Penn State.

> "Clive has been a tremendous asset to the college and University," said Lee Kump, the John Leone Dean in the College of Earth and Mineral Sciences. "His contributions, including breakthroughs in cold sintering and inspirational leadership of the Materials Research Institute, are a big part of why Penn State leads the nation in materials research. He has also been a supportive mentor of early career faculty and a wonderful colleague."

Randall is a world leader in ceramics and functional materials. His research interests include discovery and compositional design of functional materials for electrical energy transduction and storage, defect chemistry and crystal chemistry and their impact on phase transition behavior, electromechanical devices based upon electrostriction and piezoelectrics, supercapacitors, thermoelectrics and microwave materials.

"I feel very humbled as the recipient of the Evan Pugh Professorship, and receive it on behalf of multiple colleagues, postdoctoral scholars, staff, visiting scientists, the many students and my family who have supported and worked with me over the years," Randall said. "Through team efforts we have done and impacted fundamental understanding through to developing processes and metrology that impact electronic components that are in all our computers, cars, and cell phones. Looking back at all the Evan Pugh's that have impacted materials research at Penn State over the years, this is clearly a case of standing on the shoulders of giants."

Randall has introduced a number of novel processing methods for fabricating bulk nanocomposites, including dielectrophoretic assembly of ceramic polymer composites, and more recently, the introduction of the cold sintering process. His group has also contributed to the fundamental understanding of the nature of polarization in ferroelectrics and related materials, size effect phenomenon, and defect dynamics in dielectric materials.

Randall joined the Penn State faculty in 1987 as a research associate in ferroelectrics. He was promoted to senior research associate in 1992, to associate professor in 1994 and to full professor in 1999. In 2021, he was named a distinguished professor of materials science and engineering. Randall served as director of the Center for Dielectric Studies from 1997 to 2013, and as co-director of the Center for Dielectrics and Piezoelectrics from 2013 to 2015, for which he still serves as a technical adviser. He has authored more than 500 technical papers and 28 patents. Randall has received many honors including election to World Academy of Ceramics, named as a fellow of the European Ceramic Society, fellow of the American Ceramic Society, fellow of the Institute of Electrical and Electronics Engineers, and fellow of the National Academy of Inventors. He also is an honorary fellow of the European Ceramic Society. He received the Faculty Scholar Medal from Penn State in 2009 and was named the Distinguished Lecturer for IEEE in 2019.

As an active member of American Ceramic Society, Randall was honored by the society with the Fulrath Award in 2002, the Spriggs Phase Equilibria Award in 2008 and selected to give the prestigious Friedberg Lecture, and the Edward Orton, Jr Memorial Lecture in 2011 and in 2021. He received, along with his students, the Edward C. Henry Best Paper of the Year twice from the American Ceramics Society Electronics Division in 2012 and 2016.

Randall earned his bachelor of science degree with honors in physics in 1983 from the University of East Anglia, and a doctorate in experimental physics from the University of Essex in 1987. ■

Work by Stuckeman architecture researcher featured in Los Angeles exhibition

A project led by Penn State researcher Felecia Davis that explores Black culture, its relationship to technology, and concepts of translation in architectural design is featured in the “Material Acts: Experimentation in Architecture and Design” exhibition that opened Sept. 28 at the Craft Contemporary arts museum in Los Angeles.

Davis, associate professor of architecture in the College of Arts and Architecture’s Stuckeman School and director of the Computational Textiles Lab (SOFTLAB) in the Stuckeman Center for Design Computing (SCDC), and her SOFTLAB team contributed six pieces from their “Dreadlock Series” project, four of which are newly commissioned by the Craft Contemporary.

Curated by Kate Yeh Chiu and Jia Yi Gu, “Material Acts considers materials as participants in and outputs of cultural practices and techniques,” and contains work from more than 20 contemporary designers, architects and artists “who approach materials as research, processes and systems,” according to the exhibition news release.

There are five sections of material production that will be on display in the exhibition: Animating, Disassembling, Feeding, Re-fusing and Stitching. Davis and her team’s work can be found anchoring the Stitching portion of the main exhibition.

> “We are interested in generative conversations about Black culture and architectural design,” she said.

At left, a flat woven dreadlock dome and, at right, a flat-stitched and felted diagrid geometry as part of the “Dreadlock Series” project led by Felecia Davis, associate professor of architecture at Penn State. Credit: Felecia Davis

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The project team is comprised of graduate student researchers Ian Danner, from the College of Arts and Architecture's School of Visual Arts; Stuckeman School architecture master's degree student Setareh Farashzadeh; and recent master's alumnae Aysan Jafarzadeh and Hiranshi Patel. Exhibition production assistance was provided by Stuckeman School staff members Jamie Heilman, Allan Sutley and Steve White Sr. in the Stuckeman Shop.

Work for the "Dreadlock Series" was funded by the Craft Contemporary Museum and Penn State College of Arts and Architecture's Research and Creative Activity Grant Program in Racial Justice, Anti-Discrimination, and Democratic Practices.

Additionally, an interdisciplinary collaborative project led by Davis and fellow SCDC researcher Benay Gürsoy, assistant professor of architecture and director of the Form and Matter Lab (ForMat Lab), titled "MycoKnit," will be featured in a material sample library that is part of the "Material Acts" exhibition.

The work from Davis' SOFTLAB team and Gürsoy's ForMat Lab team explores the use of knitted textiles as a framework and reinforcement system to develop fiber composite mycelium-based architectural structures or, in other words, sustainable building materials.

Researchers on Davis and Gürsoy's "MycoKnit" project team for the "Material Acts" exhibition are Chiara Dognini, SCDC postdoctoral scholar; Alale Mohseni, architecture doctoral candidate; Greta Miller, School of Visual Arts alumna; and Keia Jones, graduate student in the College of Agricultural Sciences. This work was funded by the 2021 Skidmore Owings & Merrill (SOM) Research Prize.

"Material Acts" is part of the Getty Pacific Standard Time cluster of exhibitions at arts institutions in California. More information about the exhibition can be found on the Craft Contemporary website. ■

Materials Research Institute names 2024 Roy Award winners

Six Penn State materials researchers have received the 2024 Rustum and Della Roy Innovation in Materials Research Award, recognizing a wide range of research with societal impact. The award is presented by the Materials Research Institute (MRI) and recognizes recent interdisciplinary materials research at Penn State that yields innovative and unexpected results.

The award includes four categories: Early career faculty, non-tenure faculty, post-doctoral scholar and graduate student. It exists thanks to a gift from Della and Rustum Roy, who are both late alumni of Penn State's College of Earth and Mineral Sciences and were long-serving faculty in the college.

This year's winners, listed below, were announced at the 2024 Materials Day event in October.

Graduate student awardees

Mingyu Yu, doctoral candidate, materials science and engineering

Yu's research focuses on creating ultra-thin, high-quality semiconductor materials using molecular beam epitaxy (MBE), a technique that builds materials one atom at a time by directing beams of atoms onto a surface in a vacuum.

Michael Miller, doctoral candidate, biomedical engineering

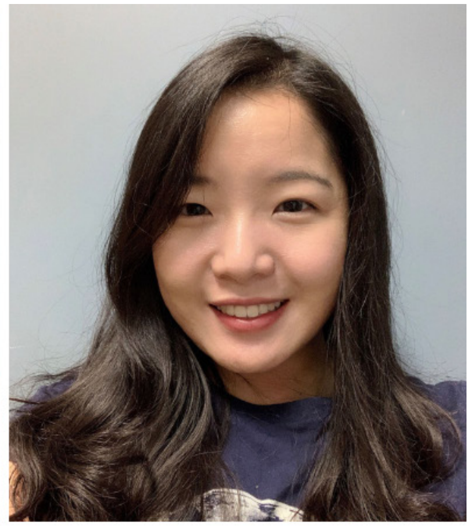
The human gut has a thick layer of mucus covering the intestinal cells that plays host to millions of bacteria that both aid digestion and defend against infection. Miller's research focuses on creating materials that replicate the gut microbiome, including the mucus, intestinal wall and bacterial community.

Post-doctoral scholar awardee

Ying Han, postdoctoral researcher in engineering science and mechanics

Han's research uses powerful transmission electron microscopy to study materials at the atomic level. This tool allows Han and his team to see how the internal structure of materials changes and how those changes affect their performance.






2024 Roy Award winners include, clockwise from top left, Mingyu Yu, Michael Miller, Ying Han, Maria Hilse, Hee Jeung Oh and Fei Fei Shi. Credit: Materials Research Institute.

Non-tenure line research faculty and research staff awardee

Maria Hilse, assistant research professor, MRI

Hilse's research focus is on the synthesis and characterization of unique materials that are extremely thin, such as one- and two-dimensional nanostructures, films and heterostructures using MBE. This method works in conditions similar to the vacuum of outer space and allows precise control over these ultra-thin films' thickness.

Early career faculty awardees

Hee Jueng Oh, assistant professor of chemical engineering

Oh's team designs specialized polymers that are highly selective, develop innovative membrane structures that did not exist before and study how the chemical and physical properties of these materials affect the movement of molecules through them. Efficiently separating molecules supports everything from traditional industrial processes to future carbon-free technologies.

Feifei Shi, assistant professor of energy engineering

Shi's research group focuses on improving energy technologies to make them more efficient, sustainable and widely available. They study how materials interact inside batteries to boost performance, extend their lifespan and make them more stable. ■

Penn State alum helps others find new careers through nanotechnology

"It's my job to show potential students that this program is good use of their resources and time. I'm very passionate about that, because it truly did change my life," Gray said.

Credit: Patrick Mansell/Penn State.

As the managing director for Penn State's Center for Nanotechnology Education and Utilization (CNEU), Zachary Gray spends a lot of his summer in the classroom. He works to teach veterans and students how to work at microscopic scales as part of a 12-week course — the same one that shifted his career path almost two decades ago.

The summer class brings roughly 20 to 30 people together to study microelectronics, semiconductors, and nanotechnology ranging from widely-used pieces like laptop microchips to novel products with unique and specified uses. The program requires a heavy lift on Gray's part, along with the entire CNEU staff, he said, but the CNEU team enjoys the experience each year.

"We teach them all in a very specialized lab. It's a very tight knit group, and I love helping others learn the things that I learned while I was in the program," Gray said. "It can become very overwhelming, but it's about finding a balance. I really enjoy seeing how excited the students get as they learn and seeing them grow."

Long before he was teaching though, Gray had to learn the skills himself. As an undergraduate student in the mid-2000s, Gray was attending a community college in Pennsylvania. His college had a partnership with Penn State that allowed him to earn a two-year degree in nanotechnology. That experience, he said, set him on a path that would define his career.

A few months after he graduated, Gray found a job opportunity that brought him back to State College. He worked in the area for close to 10 years while he worked to earn advanced degrees through Penn State. The years were a lot of work, he said, but they paid off. After he'd completed his degrees, he found a job in Arizona working with a company that distributes high-powered microscopes.

The job worked well for him. But when he was contacted by Penn State about an opening at CNEU, he said, he found himself missing State College and the University he'd attended.

"I had to do a lot of mental gymnastics. I got a spreadsheet out, and I weighed all the pros and cons," Gray said. "The swing factor was family and friends. I'd made new friends in Arizona, but I wanted to be closer to the people most important to me in this world."

The work suits Gray's needs and his career goals, he said, and it also brought him back to an area that he loves.

"I have no regrets. I've really enjoyed everything I've done since I've returned to the University," Gray said. "I'm in my late 30s now, too, and it's time to settle down a little bit, to buy a house. I knew this was a good spot to make that happen."

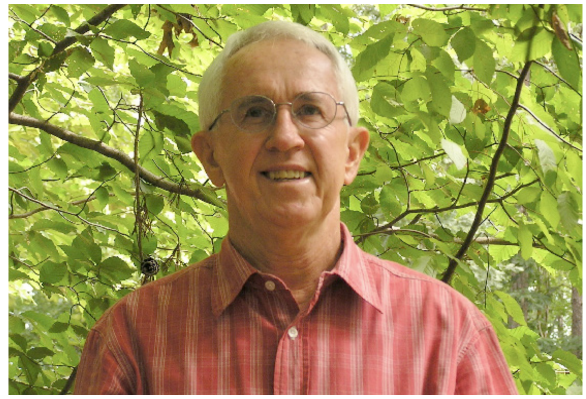
Attending a nanotechnology program at Penn State led him to a new path, Gray said, and now he gets to share the wisdom he's collected with newcomers to the field.

"The same exact program I went through as a student almost 20 years ago is still here, and it's designed to help people out."

Gray has been with CNEU for nearly three years. But the work they're doing is part of a longstanding legacy of manufacturing and workforce development at Penn State, he said, and he can see that history every day within his department.

"We've been national leaders in the areas of workforce development for nanotechnology and semiconductor processing since the late '90s," Gray said. "With this University, the people who are here, tend to stay here, because it is a good place to be. People who were involved in my graduate education, I now work with." ■

Russ Messier, pioneer in thin films research, remembered



Faculty, staff and students from across Penn State and especially in the College of Engineering and Materials Research Institute (MRI) are mourning the loss of Russ Messier, graduate alumnus and professor emeritus of engineering science and mechanics, who died on Oct. 11 at age 80 in Nashua, New Hampshire.

> "When Russ came to Penn State, he began a more than 50-year career as a materials scientist who was a significant figure and pioneer in the realm of thin-films research, and materials research in general," said Clive Randall, Evan Pugh University Professor of Materials Science and Engineering and director of the Materials Research Institute. "His work was instrumental in developing the fundamental understanding of morphological evolution with the thin film sputtering technique, developing chiral structures or sculpture thin films with sputtering, and researching diamond and boron nitride deposition leading to an international center on diamond films."

It was the Sputnik Era that sparked his love of science and drove him to win scholarships and earn money at a variety of jobs to enable him to attend Northeastern University in Boston, where he graduated with a bachelor's degree in electrical engineering in 1967. During this time, he served in an engineering co-op program at Sanders Associates, an electronics company now part of BAE, an aerospace, defense and information security company. It was here where Messier discovered a love for materials science.

This led Messier to Penn State, where he earned a doctoral degree in solid state science in 1973, completing his graduate research as part of the Materials Research Laboratory (MRL), which was merged into MRI in 2001. Celebrated Penn State researcher Rustum Roy, then the director of MRL, was his thesis adviser.

Along with his research work, he was president of the Graduate Student Association (GSA) and became interested in social justice, including working to foster understanding between student protestors and University administration during the Vietnam War and civil rights movement. In fact, it was during his GSA protest activities that he met his future wife, Linda. They were married in 1969 and had two children, Steve, born in 1970, and Tammy, born in 1974, whom they raised in State College.

Perhaps the pinnacle of Messier's research career at Penn State and MRL was his discovery of how to grow diamond-like thin films. He often joked that he should grow Linda a diamond ring or necklace, but the significance of this breakthrough reached beyond jewelry. Diamond-like thin films offer extreme hardness, durability and chemical resistance, making them valuable for protecting surfaces and enhancing the performance of tools, electronics and medical devices. His success led to his photo being featured on the front page of the Sunday edition of the New York Times on Sept. 14, 1986 as well as in USA Today on March 18, 1987.

As the founding editor-in-chief of the international journal Diamond and Related Materials, Messier was a leader in his field. He started an international consortium on diamond-like materials, bringing together experts from academia and industry. Over his career, he supervised 28 graduate students, mentored numerous faculty members and was a role model for countless undergraduate students. In 2005, after being named a Highly Cited Researcher in Materials Science — placing him in the top 0.5% of citations in his field — he retired as a full professor and was granted emeritus status. He also held the position of acting director of the MRL in 1992.

Messier retired to Clarksville, Virginia, to enjoy golf and a local lake. However, he quickly became involved in the community; mentoring the first robotics team of the local high school, the Backpack Buddies program which provides bags of food for the weekend to food insecure students and several other community projects. ■

DOE announces $14.5 million award to Energy Frontier Research Center 3DFeM

3D FeM2
Center for 3D Ferroelectric Microelectronics Manufacturing

The U.S. Department of Energy (DOE) announced today (Sept. 4) that it will continue to support Penn State's Center for Three-Dimensional Ferroelectric Microelectronics Manufacturing (3DFeM) as an Energy Frontier Research Center.

The DOE-funded center, led by Susan Trolier-McKinstry, Penn State's Evan Pugh University Professor and Flaschen Professor of Ceramic Science and Engineering, maintains the best and most complete set of facilities in the world for the deposition, characterization and integration of ferroelectric materials — materials that are useful in applications such as memory storage devices, capacitors and sensors because of their ability to maintain polarization even after an external field is removed.

The new $14,525,000 award from the DOE marks the fifth year of funding for the 3DFeM center, which involves a multi-university team led by Penn State scientists. The center is a multi-institution team which also includes researchers from Carnegie Mellon University, Georgia Institute of Technology, The University of Notre Dame, University of Maryland, University of Pennsylvania, University of Tennessee – Knoxville and University of Virginia, in partnership with Sandia National Labs, Brookhaven National Lab and Oak Ridge National Lab.

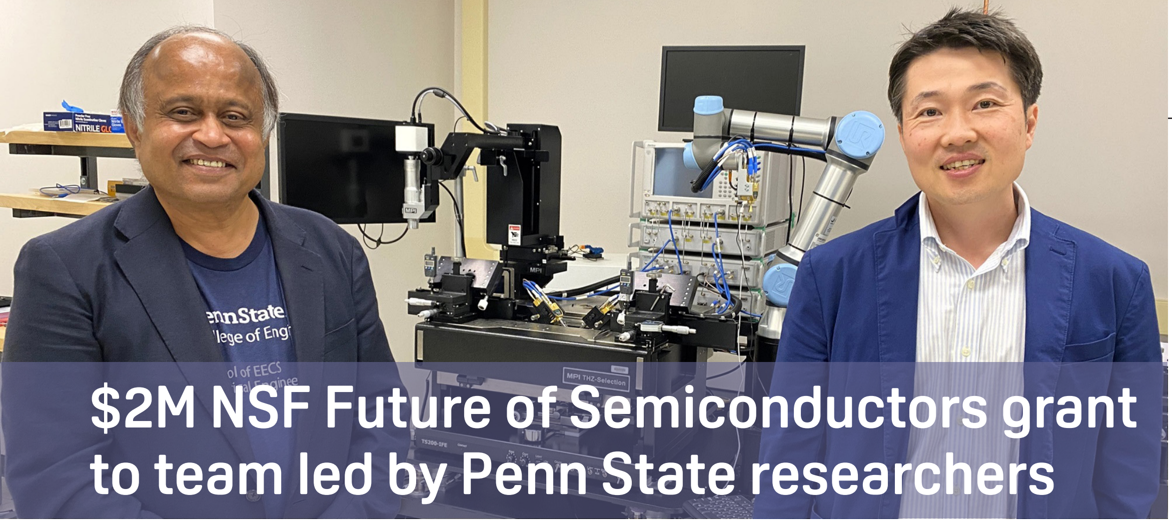
Trolier-McKinstry and her team are working on introducing a memory element that does not require power to store data. They are working to develop the fundamental manufacturing science that assists the semiconductor transition to Industry 4.0, or the Fourth Industrial Revolution, an era of connectivity and advanced-manufacturing that will require integrating robust ferroelectric materials that show outstanding properties throughout the device's lifetime, Trolier-McKinstry explained.

In addition, the team is working to stack components vertically, which is needed for the next generation of computing and artificial intelligence.

Their approach is designed to bypasses the traditional storage limits of 2D microelectronics — a problem known as Moore's Law — and increase the efficiency of moving data back and forth between memory and logic, a problem known as the von Neumann bottleneck. The team is also working with ferroelectric materials to combine memory and processing directly on the same chip, rather than separating them as traditional computers do.

In total, the DOE announced funding for 10 Energy Frontier Research Centers in nine states, designed to bring together teams of scientists to advance fundamental research. The projects were selected by competitive peer review under the DOE Funding Opportunity Announcement for Energy Frontier Research Centers.

The funding supports three new and five continuing four-year awards, including the one to center led by Penn State researchers, and two two-year transition awards. ■



$2M NSF Future of Semiconductors grant to team led by Penn State researchers

Madhavan Swaminathan, left, professor, head of the Department of Electrical Engineering, and Wooram Lee, right, associate professor of electrical engineering. Credit: Lyndsey Biddle/Penn State

In an increasingly digital world, semiconductors or “chips” serve as foundational building blocks for everything from smartphones to supercomputers. The U.S. National Science Foundation (NSF) has awarded a three-year, $2 million Future of Semiconductors (FuSe2) grant to researchers at Penn State and the University of California, Santa Barbara (UCSB), to develop wireless communications and sensing platforms through advanced chips and packaging, the process of arranging, enclosing, and protecting semiconductor devices.

The team includes Wooram Lee, Penn State associate professor of electrical engineering; Madhavan Swaminathan, Penn State professor, head of the Department of Electrical Engineering and director of the Center for Heterogeneous Integration of Micro Electronic Systems (CHIMES); and Mark Rodwell, UCSB professor of electrical and computer engineering.

Ongoing research in semiconductor and packaging technologies aims to push the boundaries of how fast and effectively systems can process information, while decreasing their size, lowering their cost and increasing their energy efficiency. As traditional silicon-based chips reach their limits, the focus is shifting toward next-generation, nano-scale materials, that allow for the next wave of technological innovation in computing. The Penn State-UCSB team aims to focus on 6G technology — the ultra-high frequency, high-speed successor to 5G networks, which is still in the early stages of research and development.

As the speed of data networks increases, the processing centers inside semiconductors must also increase their capacity to handle such a rapid influx of data, explained Swaminathan. The challenge is creating semiconductors that are compatible with the high frequency of a 6G network – and even faster networks of the future.

“The key to achieving this is through a process that resembles an assembly line, with individual parts, each with their own functions, combined into a single advanced package, the physical casing around the semiconductor chip,” Swaminathan said.

This process, known as heterogeneous integration, enables the production of enhanced, high-functioning compact electronic devices that overcome limitations to performance, functionality, size, and thermal management, he said.

For this project, Lee will focus on high-speed silicon-based integrated circuit design, Swaminathan on advanced glass packaging and Rodwell on indium phosphide amplifier design, which is needed to generate sufficient power at such high frequencies. Together, the researchers will work to integrate the three technologies into a single device.

> “The proposed work will be the basis for 6G,” Lee said. “In 6G, the fusion of physical, digital and human worlds will be connected seamlessly by advanced communication and sensing technologies, which the proposed work will implement, transforming the way we live and work through virtual reality, augmented reality, holographic telepresence, and driverless cars.”

The team also plans to educate doctoral-level scientists and engineers in various areas of semiconductor design and packaging as well as provide short courses on specialized training in semiconductor manufacturing to students and industry professionals. The overarching goal, the researchers said, is to infuse the U.S. semiconductor industry with experts, educators, and skilled technicians.

The NSF’s FuSe2 program is a national initiative granting approximately 20 awards up to $2 million each in 2024. This program is aligned with the 2022 CHIPS and Science Act, a federal statute investing $52.7 billion in funding to the development of the U.S. semiconductor industry. ■

$1.5M NSF grant to launch AI-designed biosensor research project

"We want to make sure that the next generation of engineers and scientists are not only well-trained but also have opportunities to connect with industry and explore career paths in STEM," Ebrahimi said.

To enhance biosensor development via artificial intelligence (AI) and offer STEM education opportunities to K-12 students from underserved communities, the U.S. National Science Foundation recently awarded researchers at Penn State a three-year, $1.5 million grant.

The project is supported through the Designing Materials to Revolutionize and Engineer our Future (DMREF) program and seeks to address a longstanding challenge in the biosensor research: the inability to systematically identify the best materials for biosensors detecting specific molecules. These small devices are essential tools in diagnosing diseases, detecting harmful substances and identifying environmental contaminants. However, the process of developing biosensors is often time-consuming and inefficient.

"In the field of engineering biosensing materials, much of the research work has been done through trial and error," said Aida Ebrahimi, Thomas and Sheila Roell Early Career Associate Professor of Electrical Engineering and of Biomedical Engineering, and the principal investigator of the grant. "While there have been promising results, there is no comprehensive guide to tell us which materials to use for detecting specific molecules, so researchers typically test a range of options until they find one that works." This problem is especially prevalent with two-dimensional (2D) materials — ultra-thin materials that are just an atom or a few atoms thick and are widely regarded for their potential in biosensing applications.

The research team aims to change that by developing a computationally guided approach that will make the process of material selection more efficient. At the heart of the project is a close collaboration between experimentalists and computational scientists, Ebrahimi said. Ebrahimi and Mauricio Terrones, George A. and Margaret M. Downsbrough Head of the Department of Physics at Penn State, will focus on experimentation, while Humberto Terrones, Rayleigh Endowed Chair Professor at Rensselaer Polytechnic Institute, and Trevor David Rhone, assistant professor of physics, applied physics, and astronomy at Rensselaer Polytechnic Institute, will focus on AI and computational modeling. The researchers will create a feedback loop for the experimental data and AI-driven predictions to inform each other.

Beyond its scientific goals, the project also aims to create summer camps for K-12 students, with a special emphasis on underrepresented groups in STEM fields.

"We're organizing four summer camps, including two at Penn State and two at Rensselaer Polytechnic Institute, that will focus on introducing students to materials science, nanotechnology, biosensors and artificial intelligence," Ebrahimi said. "These camps will include hands-on activities designed to inspire young students, particularly girls and underrepresented minorities, to pursue careers in science and engineering."

In addition to the K-12 outreach, the project will also support undergraduate research, curriculum innovation, and workforce development. The team plans to collaborate with industry through an advisory board and offer internships for students.

Diversity, equity, and inclusion are core values of the project. All four principal investigators are committed to fostering a more inclusive STEM community by partnering with relevant organizations.

The researchers said they also hope to have a broader impact on the scientific community by creating an open-access database.

"We're building a cloud-based database where researchers can access the results of our experiments and AI models," Ebrahimi said. "This resource will be available to the entire scientific community, helping to accelerate materials discovery in biosensing and other fields." ■

$4.5M grant to fund 3D-printed high-performance ceramics project

High-performance ceramics that can withstand extreme temperatures of thousands of degrees Celsius and rapid changes in temperature without degradation enable hypersonic vehicles in aerospace and defense applications, but current technologies limit their production. A new approach, led by Penn State researchers, using laser processing may help produce these materials at lower temperatures, potentially enabling fabrication via 3D printing.

Robert Hickey, associate professor of materials science and engineering at Penn State, and Michael Hickner, a professor at Michigan State University, will lead the team, which has been awarded a five-year, $4.5 million Multidisciplinary University Research Initiative grant by the U.S. Department of Defense (DoD), through the Office of Naval Research (ONR).

The project, titled "Photochemical and Photothermal Additive Manufacturing of Preceramic Polymers," seeks to create a one-step process to produce ultra-high-temperature ceramic materials without bulk heating. The team is focusing on the potential of using light to convert polymer precursor molecules — starting materials that are easy to process — into the final ceramic product.

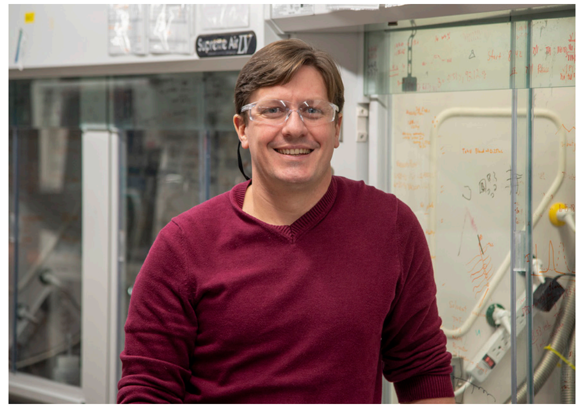
> "The big problem currently in forming ceramics is the high temperatures and high energy required," Hickey said. "That has been a detriment, especially for 3D printing, which is currently very hard to do precisely with these materials."

Converting polymer precursors to ceramics currently involves heating the materials in bulk to high temperatures — a process that can lose as much as 50% of the precursor material. The process can also change the geometry of the finished ceramic parts, contributing to the trickiness of precise 3D printing, Hickey said.

Using high-intensity lasers, the scientists estimate that they can produce chemical reactions in the precursor materials that will allow them to rapidly densify into hardened ceramic materials without bulk heating. This would enable rapid, high-fidelity 3D printing, the researchers said, because heating materials with light leads to faster processing than traditional thermal methods.

In addition to Penn State and Michigan State, the team also includes researchers at the Massachusetts Institute of Technology (MIT) and the University of Southern California (USC).

The MURI program involves teams of researchers investigating high-priority topics and opportunities that intersect more than one



Robert Hickey, assistant professor of materials science and engineering, is co-leading a five-year, $4.5 million Multidisciplinary University Research Initiative grant. Credit: Matthew Carroll.

traditional technical discipline. For many military problems, this multidisciplinary approach serves to stimulate innovations, accelerate research progress, and expedite transition of results into naval applications, according to the ONR website.

The project will involve synthesizing novel precursors, exploring different ways to promote light-based ceramic conversion, gaining computational insights into the reaction conversion pathways and feeding the insights back to precursor design and synthesis, the researchers said.

The findings could have future DoD impacts in the area of advanced hypersonic vehicles, the scientists said. The ability to additively form ceramic materials that can perform at ultra-high temperatures into new shapes significantly opens the design window for advanced re-entry vehicles.

Also contributing from Penn State is Jon-Paul Maria, professor of materials science and engineering.

Priya Vashishta, professor of chemical engineering and materials science and Aiichiro Nakano, professor of computer science, at the University of Southern California and Alexander Radosevich, professor of chemistry at the MIT, are co-PIs on the project. ■

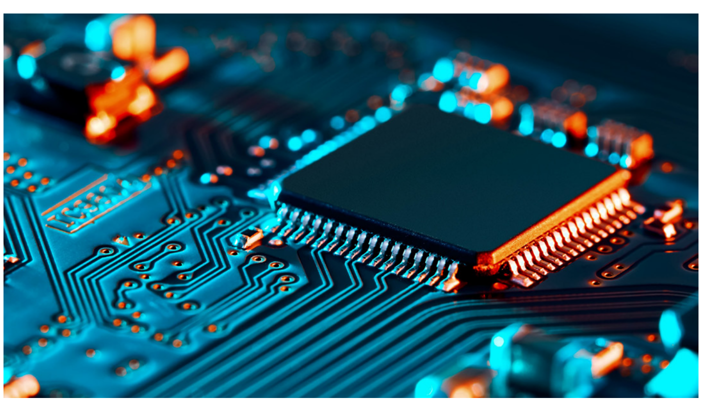
$3M grant targets integrated semiconductor for smarter, greener electronics

The microelectronics industry is nearing a tipping point. The silicon chips at the heart of everyday electronic devices are running into performance limits, raising the need for new materials and technologies to continue making faster, more efficient devices.

To help address this challenge, researchers at Penn State will receive $3 million from the Defense Advanced Research Projects Agency (DARPA) as part of a larger grant awarded to Northrop Grumman, a defense, aerospace, and technology company. The joint project will aim to develop a novel method for integrating gallium nitride, a high-performance semiconductor material, with silicon substrates. Gallium nitride provides superior performance and faster switching speeds for power-intensive applications, while silicon offers scalability and affordability. According to the researchers, this hybrid approach can lead to more efficient power electronics with lower production costs, making them ideal for high-demand applications like electric vehicles, power electronics and data centers, where efficiency and durability are critical.

"Silicon is the common platform for microelectronics but it is challenging to combine new semiconductor materials with silicon," said Joan Redwing, distinguished professor of materials science and engineering and director of the Penn State Materials Research Institute's (MRI) Two-Dimensional Crystal Consortium, a U.S. National Science Foundation Materials Innovation Platform and national user facility. "To overcome this, we need new approaches to densely integrating advanced materials with silicon, and that is exactly what this project is about. Our work with Northrop Grumman is designed to explore integrating gallium nitride directly onto silicon using two-dimensional materials as interlayers."

To achieve this, Penn State will work with Northrop Grumman on heterogeneous integration, a process in which materials with distinct and different properties are combined to create more efficient devices. For this project, the researchers will work to integrate gallium nitride with silicon.



A novel method for integrating gallium nitride, a high-performance semiconductor material, with silicon substrates may lead to improved future electronic devices, according to researchers at Penn State. Credit: Adobe Stock

Gallium nitride is a wide bandgap semiconductor, meaning it can withstand higher electric fields and sustain higher voltages and temperatures. Silicon is a lower bandgap semiconductor, but it's cheaper and benefits from the well-established silicon manufacturing infrastructure. Combining gallium nitride's ability to handle high voltages and high switching speeds with silicon's wide use in digital electronics will create chips that leverage the strengths of both materials.

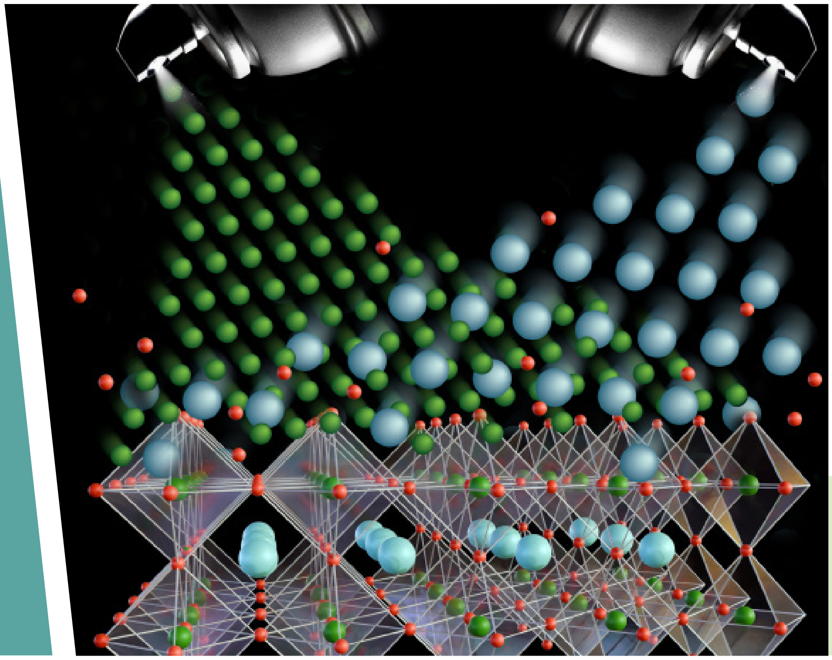
"Data centers are expected to need 160% more power by 2030, largely because of the growing use of artificial intelligence," said Joshua Robinson, professor of materials science and engineering and Penn State's principal investigator on the DARPA project. "Our work could help reduce that energy demand and contribute to a more sustainable future."

The team's work could also lead to smaller, faster and more efficient power electronics, which manage electricity flow in everything from smartphones to washing machines. For consumers, this would mean reduced energy bills and devices that generate less heat.

A potential hurdle is traditional methods of integrating gallium nitride with silicon can be complex and costly, often requiring interlayers that introduce thermal resistance and limit device performance. With the DARPA grant, Penn State researchers aim to develop a novel solution using 2D materials that are one to a few atoms thick, such as molybdenum disulfide and gallium selenide, as "seed layers" to grow gallium nitride on industry compatible silicon (001). Silicon (001) is the preferred crystal orientation used in current semiconductor technology. A seed layer provides a template or foundation that influences the structure, orientation, and quality of the material grown on top.

The equipment and methodologies developed through this grant will be available to other researchers through MRI's user facilities, Robinson said, with the goal of fostering collaboration and innovation among a variety of partners. ■

Research Snapshots are brief summaries of significant materials-related breakthroughs by Penn State researchers.



"Atomic spray painting" of potassium niobate, a material commonly used in advanced electronics, onto a substrate could enable the tuning of properties of the resulting thin film. Credit: Jennifer M. McCann/Penn State MRI

Straining a material's atomic arrangement may make for cleaner, smarter devices

By Jamie Oberdick

What's the best way to precisely manipulate a material's properties to the desired state? It may be straining the material's atomic arrangement, according to a team led by researchers at Penn State. The team discovered that "atomic spray painting" of potassium niobate, a material used in advanced electronics, could tune the resulting thin films with exquisite control. The finding, published in Advanced Materials, could drive environmentally friendly advancements in consumer electronics, medical devices, and quantum computing, the researchers said.

The researchers use molecular beam epitaxy (MBE), a technique that involves depositing a layer of atoms on a substrate to form a thin film. In this case, they produced a thin film of strain-tuned potassium niobate.

According to the researchers, the novel MBE technique — in combination with a crystal that serves as a substrate template — creates the strain needed to tune the material.

To "spray paint" the potassium niobate for the study, Gopalan turned to a former Penn State colleague, Darrell Schlom, who is currently the Tisch University Professor in the Department of Materials Science and Engineering at Cornell University. They grew the thin films at the U.S. National Science Foundation-funded Platform for the Accelerated Realization, Analysis, and Discovery of Interface Materials (PARADIM) thin film growth facility, which Schlom co-directs at Cornell. Schlom noted that both he and Gopalan worked at Penn State on the first-ever strain tuning of ferroelectric materials approximately 20 years ago.

"The superior strength of coupling between strain and polarization in potassium niobate compared to other ferroelectrics allows for a unique opportunity where relatively small amounts of strain can result in colossal tuning of both the ferroelectric structure and its polarization," said co-author Sankalpa Hazra, doctoral candidate in materials science and engineering. "A primary consequence of this superior strain sensitivity is that the ferroelectric performance of potassium niobate can be remarkably enhanced even surpassing those of lead titanate or lead zirconate titanate which are considered to be industrial standard levels of ferroelectricity for device applications."

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Demonstrating the strain tuning of potassium niobate is particularly noteworthy, Hazra said, because potassium niobate is lead-free. While lead raises human toxicity and environmental concerns, the best ferroelectric materials — such as lead titanate and lead zirconate titanate — tend to include lead.

Without strain tuning, potassium niobate's ferroelectric properties tend not to be as strong as its lead counterparts, but Hazra said the current study shows the potential of potassium niobate as a strong, yet environmentally friendly and safe, ferroelectric material.

According to Hazra, the research team also discovered that strain tuned-potassium niobate's ferroelectric performance remained stable even at high temperatures. Typically, ferroelectric materials, when heated, lose their polarization — meaning they are no longer able to switch their electrical charge.

"In our work, we've shown that applying strain can increase the temperature at which the material loses its ferroelectric properties," said Venkatraman "Venkat" Gopalan, a professor of materials science and engineering and professor of physics at Penn State and corresponding author of the study. "What's even more impressive is that with just a 1% strain, we can push that temperature to over 975 degrees Kelvin, which is close to the point where the material starts to degrade." ■

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Discovery could eliminate need to refrigerate vaccines and protein-based drugs

By Mallorie McIlwain and Adrienne Berard

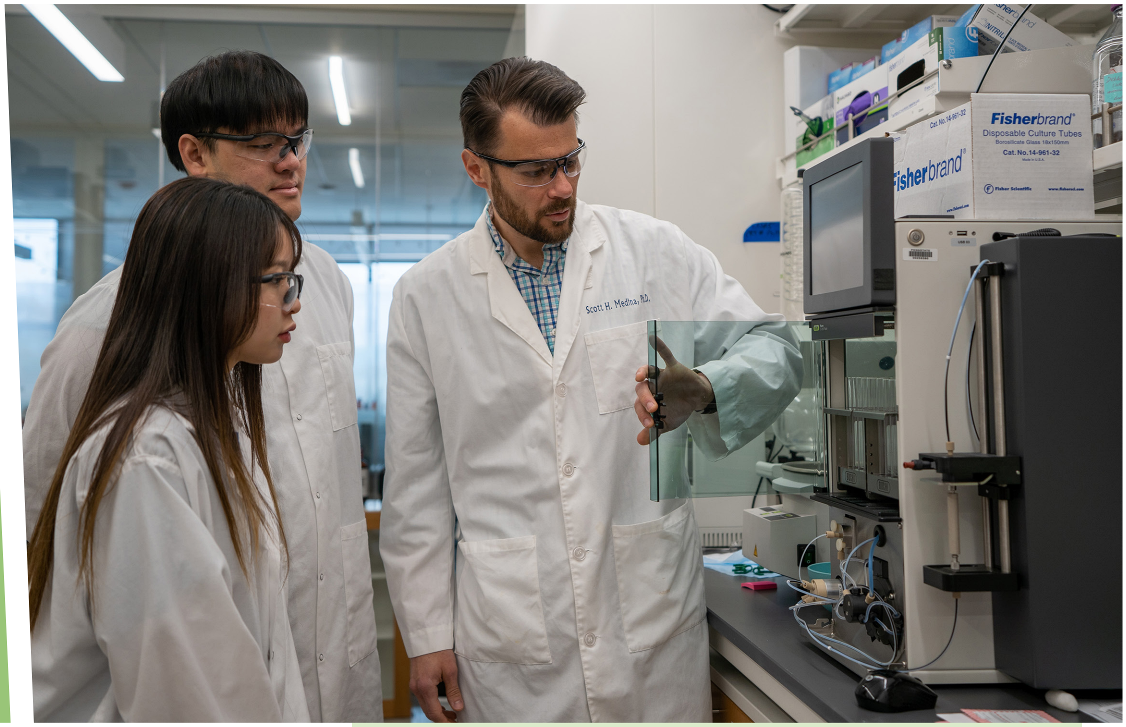
A new storage technique can keep protein-based drugs and vaccines stable without keeping them cold. The discovery, led by researchers at Penn State, could eliminate the need for refrigeration for hundreds of life-saving medicines like insulin, monoclonal antibodies and viral vaccines.

"Over 80% of biologic drugs and 90% of vaccines require temperature-controlled conditions. This approach could revolutionize their storage and distribution, making them more accessible and affordable for everyone," said Scott Medina, study lead and William and Wendy Korb Early Career Professor of Biomedical Engineering at Penn State. "This would save billions of dollars currently spent on keeping these products cold throughout the supply chain and potentially enable the use of protein therapies in environments where constant refrigeration is not possible."

The research was recently published in the journal Nature Communications. Through a series of experiments, the research team replaced the water-based solution commonly used in protein-based medications with a perfluorocarbon oil and tested five different proteins with a range of health-related functions such as antibodies and enzymes.

When tested in mice, the researchers found the new solution was just as effective as the refrigerated versions and showed no signs of toxicity, meaning there were no adverse health effects from the oil-based solution.

The researchers also found that the oil-based solution was naturally sterile for the protein samples, noting that they could not be contaminated by bacteria, fungi or viruses which require a water-based environment to grow and survive.



Scott Medina, right, William and Wendy Korb Early Career Professor of Biomedical Engineering at Penn State, and his students. Credit: Penn State

There was one problem: proteins in water-based environments spread themselves evenly throughout the liquid. In oil, they're not so soluble, Medina explained. So, the team developed a surfactant — a molecule that coats the surface of the protein — to shield the surface of the protein in a way that would allow it to evenly disperse itself throughout the solution.

The surfactant also created a protective shell around the protein, keeping it stable and preventing it from breaking down even at temperatures up to 212 degrees Fahrenheit, which would normally cause water to boil.

Protein-based drugs and vaccines are typically sensitive to heat, light and movement, all of which can cause them to lose their structure and function over time, Medina explained. Refrigeration helps to slow down that degradation process, so the medication will remain effective until it is administered. Medina said these findings have the potential to limit or eliminate cold chain logistics, which is the supply network necessary for getting the therapies from where it is being produced to the various distribution centers prior to being administered to the patients.

In 2020, another team of researchers found that cold chain logistics are projected to cost $58 billion globally by 2026.

“If something goes wrong in the process, the activity of the protein therapy could be lost, the drug could no longer be effective or it becomes contaminated and the patients could potentially be harmed,” Medina said.

The researchers said their approach has the potential to reduce costs and barriers for pharmaceutical companies, which could lead to more savings and better access for the patients in need of these therapies.

“This new method could also lower barriers and allow the drugs to be distributed in resource-scare environments across all populations,” Medina said. “We could even use this for those on the battlefield, where these therapies would be needed but access to refrigeration is limited.” ■

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Researchers developed an electronic tongue that can identify various liquid samples using artificial intelligence. Credit: Jennifer M. McCann/Penn State MRI

A matter of taste: Electronic tongue reveals AI inner thoughts

By Ashley WennersHerron

A recently developed electronic tongue is capable of identifying differences in similar liquids, such as milk with varying water content; diverse products, including soda types and coffee blends; signs of spoilage in fruit juices; and instances of food safety concerns. The team, led by researchers at Penn State, also found that results were even more accurate when artificial intelligence (AI) used its own assessment parameters to interpret the data generated by the electronic tongue.

According to the researchers, the electronic tongue can be useful for food safety and production, as well as for medical diagnostics. The sensor and its AI can broadly detect and classify various substances while collectively assessing their respective quality, authenticity and freshness.

"We're trying to make an artificial tongue, but the process of how we experience different foods involves more than just the tongue," said corresponding author Saptarshi Das, the Ackley Professor of Engineering and professor of engineering science and mechanics. "We have the tongue itself, consisting of taste receptors that interact with food species and send their information to the gustatory cortex — a biological neural network."

As the brain learns the nuances of the tastes, it can better differentiate the subtlety of flavors. To artificially imitate the gustatory cortex, the researchers developed a neural network, which is a machine learning algorithm that mimics the human brain in assessing and understanding data.

"Previously, we investigated how the brain reacts to different tastes and mimicked this process by integrating different 2D materials to develop a kind of blueprint as to how AI can process information more like a human being," said co-author Harikrishnan Ravichandran, a doctoral student in engineering science and mechanics advised by

Das. “Now, in this work, we’re considering several chemicals to see if the sensors can accurately detect them, and furthermore, whether they can detect minute differences between similar foods and discern instances of food safety concerns.”

This approach uses game theory, a decision-making process that considers the choices of others to predict the outcome of a single participant, to assign values to the data under consideration. They found that, instead of simply assessing individual human-assigned parameters, the neural network considered the data it determined were most important together, with the Shapley additive explanations revealing how important the neural network considered each input data.

The researchers explained that this assessment could be compared to two people drinking milk. They can both identify that it is milk, but one person may think it is skim that has gone off while the other thinks it is 2% that is still fresh. The nuances of why are not easily explained even by the individual making the assessment.

According to Das, the tongue’s capabilities are limited only by the data on which it is trained, meaning that while the focus of this study was on food assessment, it could be applied to medical diagnostics, too. And while sensitivity is important no matter where the sensor is applied, their sensors’ robustness provides a path forward for broad deployment in different industries, the researchers said.

Das explained that the sensors don’t need to be precisely identical because machine learning algorithms can look at all information together and still produce the right answer. This makes for a more practical — and less expensive — manufacturing process.

“We figured out that we can live with imperfection,” Das said. “And that’s what nature is — it’s full of imperfections, but it can still make robust decisions, just like our electronic tongue.” ■

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‘Kink state’ control may provide pathway to quantum electronics

By Ashley WennersHerron

The key to developing quantum electronics may have a few kinks. According to a team led by researchers at Penn State, that’s not a bad thing when it comes to the precise control needed to fabricate and operate such devices, including advanced sensors and lasers. The researchers fabricated a switch to turn on and off the presence of kink states, which are electrical conduction pathways at the edge of semiconducting materials. By controlling the formation of the kink states, researchers can regulate the flow of electrons in a quantum system.

“We envision the construction of a quantum interconnect network using the kink states as the backbone,” said team leader Jun Zhu, professor of physics at Penn State. Zhu is also affiliated with Penn State’s Center for 2-Dimensional Layered Materials. “Such a network may be used to carry quantum information on-chip over a long distance, for which a classical copper wire won’t work because it has resistance and therefore cannot maintain quantum coherence.”

The work, published recently in Science, potentially provides a foundation for researchers to continue investigating kink states and their application in electron quantum optics devices and quantum computers.

“This switch operates differently from a conventional switch, where the electrical current is regulated through a gate, similarly to traffic through a toll plaza,” Zhu said. “Here, we are removing and rebuilding the road itself”.

Kink states exist in a quantum device built with a material known as Bernal bilayer graphene. This comprises two layers of atomically thin carbon stacked together, in such a way that the atoms in one layer are misaligned to the atoms in the other. This arrangement, together with the use of an electric field, creates unusual electronic properties — including the quantum valley Hall effect.

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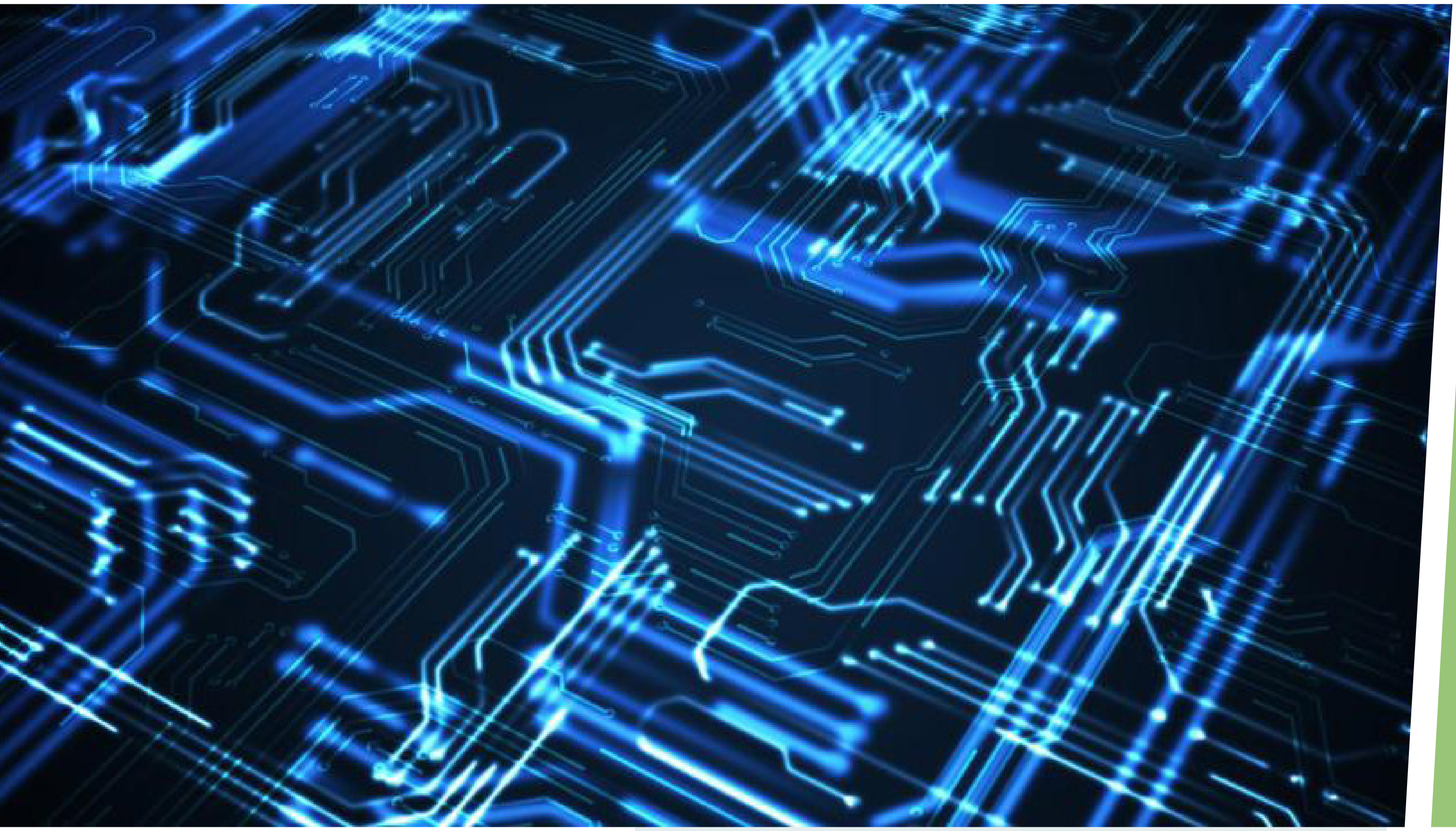
Full articles on all snapshots can be read at **mri.psu.edu/news**



New work led by researchers at Penn State may provide new concepts to construct interconnects — quantum information highways — in quantum computers Credit: vchal/Getty Images.

This effect refers to the phenomenon of electrons occupying different “valley” states — identified based on their energy in relation to their momentum — also move in opposing forward and backward directions. Kink states are manifestations of the quantum valley Hall effect.

“The amazing thing about our devices is that we can make electrons moving in opposite directions not collide with one another — which is called backscattering — even though they share the same pathways,” said first author Ke Huang, a graduate student pursing a doctorate in physics at Penn State under Zhu’s mentorship. “This corresponds to the observation of a ‘quantized’ resistance value, which is key to the potential application of the kink states as quantum wires to transmit quantum information.”

Both graphite and hexagonal boron nitride are compounds commonly used as lubricant for paints, cosmetics and more. Graphite conducts electricity well while hexagonal boron nitride is an insulator. The researchers used this combination to contain electrons to the kink states and control their flow.

“The incorporation of a graphite/hexagonal boron nitride stack as a global gate is critically important to the elimination of electron backscattering,” Huang said, noting that this material use was the key technical advancement of the current study.

The researchers also found that the quantization of the kink states remains even when the temperature is raised to several tens of Kelvin, the scientific unit of temperature. Zero Kelvin corresponds to -460 degrees Fahrenheit.

“Quantum effects are often fragile and only survive at cryogenic temperatures of a few Kelvin,” Zhu said. “The higher temperature we can make this work, the more likely it can be used in applications.” ■

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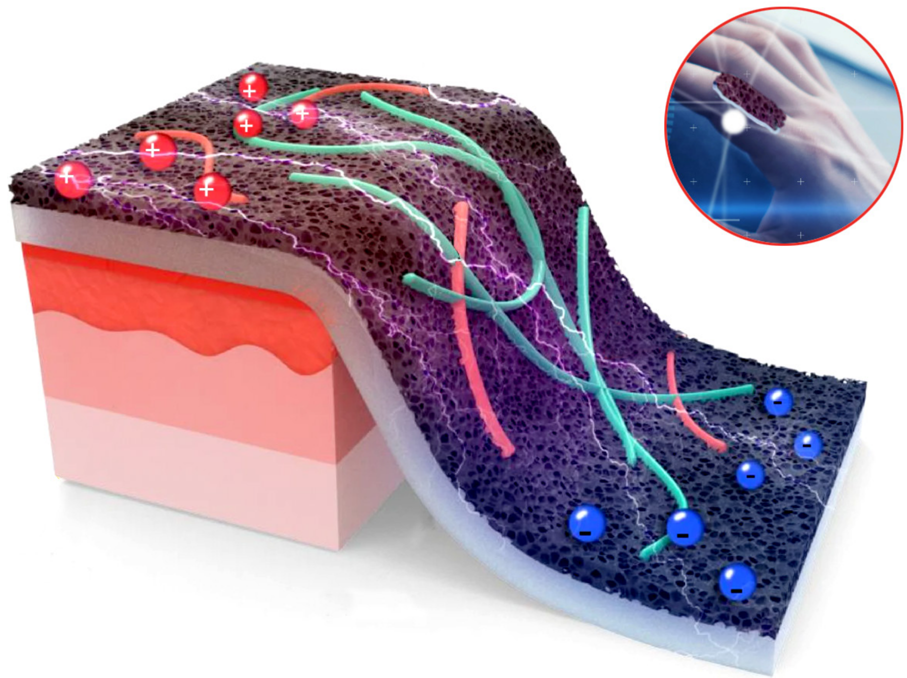

New smart sensor takes the pain out of wound monitoring

By Jamie Oberdick

A major challenge in self-powered wearable sensors for health care monitoring is distinguishing different signals when they occur at the same time. Researchers from Penn State and China's Hebei University of Technology addressed this issue by uncovering a new property of a sensor material, enabling the team to develop a new type of flexible sensor that can accurately measure both temperature and physical strain simultaneously but separately to more precisely pinpoint various signals.

"This unique sensor material we've developed has potentially important applications in health care monitoring," said Huanyu "Larry" Cheng, James L. Henderson, Jr. Memorial Associate Professor of Engineering Science and Mechanics (ESM) at Penn State and co-corresponding author of the study published in Nature Communications.

"By accurately measuring both temperature changes and physical deformation or strain created by a healing wound and measure that by separating the two signals, it could revolutionize the tracking of wound healing. Doctors could get a much clearer picture of the healing process, identifying issues like inflammation early on."

The researchers aimed to accurately measure temperature and strain signals without cross talk by using laser-induced graphene, a two-dimensional (2D) material. Like all 2D materials including regular graphene, laser-induced graphene is one to a few atoms thick with unique properties, but with a twist. Laser-induced graphene (LIG) forms when a laser heats certain carbon-rich materials — like plastic or wood — in a way that converts their surface into a graphene structure. The laser essentially "writes" the graphene directly onto the material, making it a simple and scalable way to produce graphene patterns for electronics, sensors, and energy devices.

LIG has been used before in various applications. Previously, Cheng and his team have used LIG for gas sensors, electrochemical detectors for sweat analysis, supercapacitors, and more. However, the researchers said they believe they discovered a new property of LIG for the first time that makes it ideal for a multi-purpose and accurate sensor.

IMAGE ABOVE: The flexible sensor, uses laser-induced graphene to simultaneously but separately measure temperature and strain, potentially enabling better wound healing. Credit: Penn State MRI

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"In this particular study, we kind of stumbled upon the fact that this material also has thermoelectric properties," Cheng said. "We believe this is the first time anyone has reported laser-induced graphene having thermoelectric capabilities. And that's really important for what we're trying to do here, which is to separately measure both temperature changes and physical strain or deformation." Thermoelectric properties in a material refer to the ability to convert temperature differences into electrical voltage and vice versa, enabling such materials to be used for applications like energy harvesting and temperature sensing. According to Cheng, this newly identified thermoelectric property of LIG makes it easy to separate the two sensor measurements and ideal for health care applications such as a sensor embedded in a bandage.

"When you have materials that are sensitive to both temperature and strain, it can be tricky to tell which signal is causing changes in the material," Cheng said. "But by using this thermoelectric effect in the laser-induced graphene, we can essentially decouple those two measurements. We can look at the electrical resistance to get information about the strain, while also measuring the thermal voltage to determine the temperature. This is why doctors could use it to track both temperature fluctuations and physical changes in the wound site and give a much clearer picture of how the healing is progressing."

He also noted that the sensor is highly sensitive, detecting temperature changes as small as 0.5 degrees Celsius. The material's design takes advantage of the way porous graphene and thermoelectric components work together, making it nearly four times better at converting heat into electricity. The sensor can also stretch up to 45%, as well as conform to different shapes and surfaces, without losing function.

"The porous structure of this material creates a lot of tiny spaces and channels that allow it to interact with its surroundings in a very sensitive way," Cheng said. "This makes it well-suited for interfacing with human soft tissues, in contrast to more rigid thermoelectric materials, such as ceramic-based ones." ■

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Making rechargeable batteries more sustainable with fully recyclable components

By Mariah Lucas

Rechargeable solid-state lithium batteries are an emerging technology that could someday power cell phones and laptops for days with a single charge. Offering significantly enhanced energy density, they are a safer alternative to the flammable lithium-ion batteries currently used in consumer electronics — but they are not environmentally friendly. Current recycling methods focus on the limited recovery of metals contained within the cathodes, while everything else goes to waste.

A team of Penn State researchers may have solved this issue. Led by Enrique Gomez, interim associate dean for equity and inclusion and professor of chemical engineering in the Penn State College of Engineering, the team reconfigured the design of these solid-state lithium batteries so that all their components can be easily recycled. They published their findings in ACS Energy Letters.

"As the need for rechargeable batteries grows, we need to think about the end-of-life of this technology," Gomez said. "We hope our work highlights the possibilities in recycling of solid-state batteries, with the help of some key design elements."

Traditionally, most of the core battery components have gone to waste because they mix during the recycling process, forming a "black mass," according to the researchers. This black mass is rich in materials needed for batteries but separating them out remains a challenge. In solid-state batteries, the use of solid electrolytes compounds this problem, as they become intermixed with the black mass.

To more easily separate these components from the other metal components in a coin cell battery, researchers

Yi-Chen Lan, left, and Po-Hao Lai, both doctoral students in chemical engineering, were co-authors on the paper. Credit: Poornima Tomy/Penn State

inserted two polymer layers at the interfaces between the electrode and the electrolyte prior to the start of the recycling process.

"We proposed that by dissolving the polymer layer during the recycling process, you can easily separate the electrode from the electrolyte," said Yi-Chen Lan, doctoral student in chemical engineering and first author on the paper. "Without the polymer layer separating them, you would have the electrode and electrolyte mixed together, which makes them hard to recycle."

Once the researchers successfully separated out the components, they made a composite with the recovered metals and electrodes using cold sintering — the process of combining powder-based materials into dense forms at low temperatures through applied pressure using solvents. Cold sintering was developed in 2016 by a team of researchers led by Clive Randall, director of Penn State's Materials Research Institute and distinguished professor of materials science and engineering. Gomez and his team recently demonstrated the recycling of solid-state electrolytes using cold sintering.

"We used cold sintering to combine the recovered electrodes with recovered composite solid electrolyte powders, then reconstructed the battery with the polymer layers added," said Po-Hao Lai, a doctoral student in chemical engineering and co-author on the paper. "This enables us to recycle the whole battery, which we are then able to recycle again after its use."

After testing its performance, they found that the reconstructed battery achieved between 92.5% and 93.8% of its original discharge capacity.

"While the commercialization of all-solid-state lithium batteries is still in its early stages, our work provides important insights and ideas for designing recyclable versions of these batteries," Lan said. "While we're not quite there yet, the long-term goal is to apply this innovation to larger batteries that could be used in devices like cell phones and laptops, once all-solid-state technology becomes more prevalent." ■

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Pictured is an RF magnetron sputtering system, one of the deposition tools used to make the films in this study. Credit: Provided by Jon-Paul Maria.

Proximity effect: Method allows advanced materials to gain new property

By Matthew Carroll

Ferroelectrics are special materials with polarized positive and negative charges — like a magnet has north and south poles — that can be reversed when external electricity is applied. The materials will remain in these reversed states until more power is applied, making them useful for data storage and wireless communication applications.

Now, turning a non-ferroelectric material into one may be possible simply by stacking it with another ferroelectric material, according to a team led by scientists from Penn State who demonstrated the phenomenon, called proximity ferroelectricity.

The discovery offers a new way to make ferroelectric materials without modifying their chemical formulation, which commonly degrades several useful properties. This has implications for next-generation processors, optoelectronics and quantum computing, the scientists said. The researchers published their findings today (Jan 8) in the journal Nature.

"This work shows we can generate ferroelectricity in a material that does not have those properties just by stacking it with a material that is ferroelectric," said Jon-Paul Maria, professor of materials science and engineering at Penn State and lead author of the study. "And, so, it has to be that the two materials are talking to each other. We call it proximity ferroelectricity because it is an effect of being in contact."

In recent years, scientists at the University of Kiel in Germany and at Penn State have developed new families of nitride and oxide ferroelectric materials — respectively — with comparable properties but with much simpler structures and preparation methods that can be integrated directly into mainstream semiconductors, like silicon, thus maximizing the technology impact, the scientists said.

The new work builds on those discoveries, demonstrating a method to create similar materials but without needing the chemical modifications previously required for fabrication, the scientists said.

"The community got very excited in the last few years about two new emergent families of ferroelectrics that show very promising future impacts on electronic devices," Maria said. "This is now another step in that process. It's a second time that we've been stunned about what we did not know about ferroelectricity after 100 years of research."

Maria and his team previously developed one such ferroelectric material that offers enticing performance but requires trade-offs: magnesium-substituted zinc oxide thin films. The zinc oxide has desirable properties, but it is not ferroelectric by itself. Adding magnesium allows scientists to make the material ferroelectric but degrades important properties such as heat dissipation during device operation and the ability to transmit light over very long distances.

Using proximity ferroelectricity, the researchers found they could now turn pure zinc oxide ferroelectric by stacking it with a ferroelectric material like the magnesium-substituted zinc oxide thin films.

"Imagine that I have the ability to stack these layers on top of each other, where one is ferroelectric and the other is normally not, but through proximity ferroelectricity," Maria said. "It can exhibit the polarization reversal in its pure state. That's the real appeal."

In addition, the ferroelectric layer can represent as little as 3% of the total volume of the stack, meaning the vast majority is material with the most-desired properties. The ferroelectric, or switching layer, can be placed on the top or bottom or as an isolated internal layer, the scientists said.

The researchers observed proximity ferroelectricity in oxide, nitride and combined nitride-oxide systems, suggesting that there is a generic mechanism and that the technique could provide new avenues for ferroelectric property engineering and material discovery.

Maria said the work only scratches the surface of what's possible with the technique and that future research should explore other possible compositions. ■

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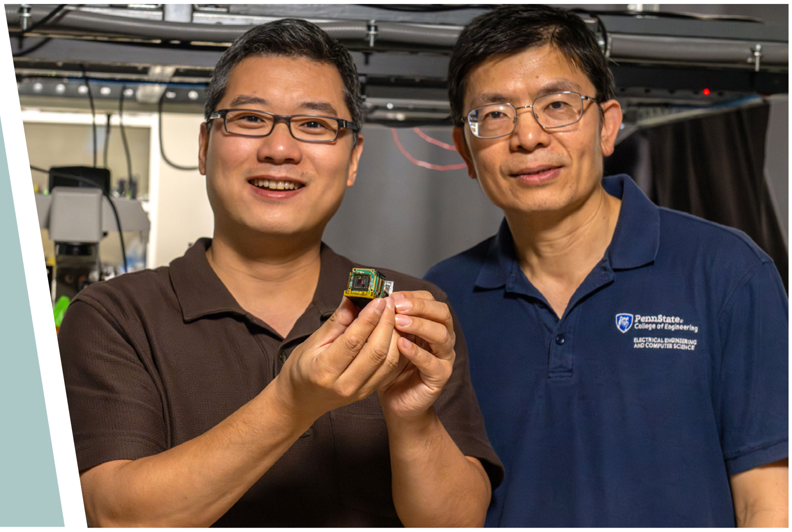

Xingjie Ni, left, associate professor of electrical engineering, displays a camera sensor integrated with a three-millimeter-by-three-millimeter metasurface. Zhiwen Liu, right, co-corresponding author on the paper, is a professor of electrical engineering.
Credit: Kate Myers/Penn State

Seeing like a butterfly: Optical invention enhances camera capabilities

By Mariah Lucas

Butterflies can see more of the world than humans, including more colors and the field oscillation direction, or polarization, of light. This special ability enables them to navigate with precision, forage for food and communicate with one another. Other species, like the mantis shrimp, can sense an even wider spectrum of light, as well as the circular polarization, or spinning states, of light waves. They use this capability to signal a "love code," which helps them find and be discovered by mates.

Inspired by these abilities in the animal kingdom, a team of researchers in the Penn State College of Engineering developed an ultrathin optical element known as a metasurface, which can attach to a conventional camera and encode the spectral and polarization data of images captured in a snapshot or video through tiny, antenna-like nanostructures that tailor light properties. A machine learning framework, also developed by the team, then decodes this multi-dimensional visual information in real-time on a standard laptop.

The researchers published their work today (Sept. 4) in Science Advances.

"As the animal kingdom shows us, the aspects of light beyond what we can see with our eyes holds information

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that we can use in a variety of applications," said Xingjie Ni, associate professor of electrical engineering and lead corresponding author of the paper. "To do this, we effectively transformed a conventional camera into a compact, lightweight hyperspectro-polarimetric camera by integrating our metasurface within it."

Hyperspectral and polarimetric cameras — which often are bulky and expensive to produce — capture either spectrum or polarization data, but not both simultaneously, Ni explained. By contrast, when positioned between a photography camera's lens and sensors, the three-millimeter-by-three-millimeter metasurface, which is inexpensive to manufacture, captures both types of imaging data simultaneously and transmits the data immediately to a computer.

The raw images must then be decoded to reveal the spectral and polarization information. To achieve this, Bofeng Liu, a doctoral student in electrical engineering and co-author of the paper, built a machine learning framework trained on 1.8 million images using data augmentation techniques.

"At 28 frames per second — primarily limited by the speed of the camera we used — we are able to rapidly recover both spectral and polarization information using our neural network," Liu said. "This allows us to capture and view the image data in real-time."

Researchers tested their metasurface and neural network by video recording transparent "PSU" letters under different laser beam illuminations. They also captured images of the glorious scarab beetle, known for reflecting circularly polarized light visible to others of its species. Having immediate access to hyperspectro-polarimetric information of different objects could benefit consumers if the technology were commercialized, Ni said.

"We could bring our camera along to the grocery store, take snapshots and assess the freshness of the fruit and vegetables on the shelves before buying," Ni said. "This augmented camera opens a window into the unseen world."

Additionally, in biomedical applications, Ni said, hyperspectro-polarimetric information could be used to differentiate the material and structural properties of tissues within the body, potentially aiding in the diagnosis of cancerous cells.

This work builds on Ni's prior research and development of other metasurfaces, including one that mimics the processing power of the human eye, and metalenses, including one capable of imaging far-away objects, including the moon. ■

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'Nanodot' control could fine-tune light for sharper displays, quantum computing

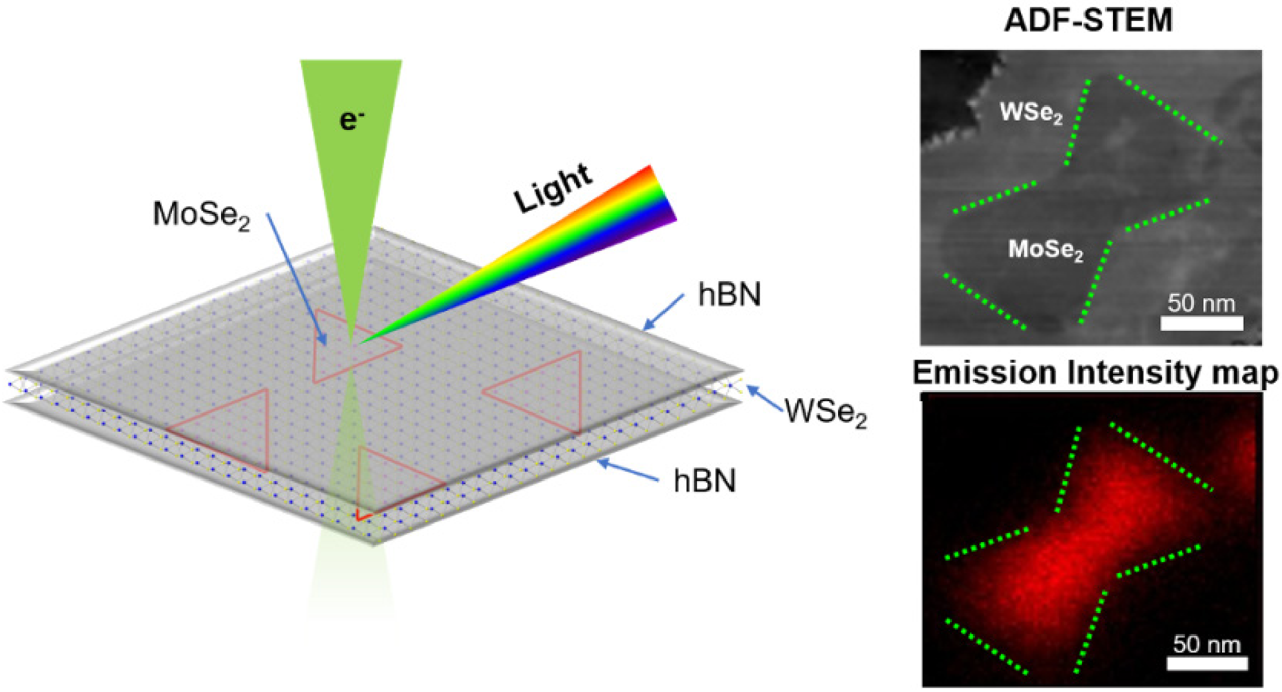
By Jamie Oberdick and Ashley WennersHerron

Newly achieved precise control over light emitted from incredibly tiny sources, a few nanometers in size, embedded in two-dimensional (2D) materials could lead to remarkably high-resolution monitors and advances in ultra-fast quantum computing, according to an international team led by researchers at Penn State and Université Paris-Saclay.

In a recent study, published in ACS Photonics, scientists worked together to show how the light emitted from 2D materials can be modulated by embedding a second 2D material inside them — like a tiny island of a few nanometers in size — called a nanodot. The team described how they achieved the confinement of nanodots in two dimensions and demonstrated that, by controlling the nanodot size, they could change the color and frequency of the emitted light.

"If you have the opportunity to have localized light emission from these materials that are relevant in quantum technologies and electronics, it's very exciting," said Nasim Alem, Penn State associate professor of materials science and engineering and co-corresponding author on the study. "Envision getting light from a zero-dimensional point in your field, like a dot in space, and not only that, but you can also control it. You can control the frequency. You can also control the wavelength where it comes from."

The researchers embedded nanodots made of a 2D material called molybdenum diselenide inside another 2D material, tungsten diselenide, and then aimed a beam of electrons at the structure to make it emit light.



On the left is an illustration of the experimental setup from this study. On the upper right is a dark-field STEM image of the molybdenum diselenide nanodot. On the lower right is an artificially colored light emission intensity map of the same region. Credit: Provided by the researchers.

"By combining a light detection tool with a transmission electron microscope, which is a powerful microscope that uses electrons to image samples, you can see much finer details than with other techniques," said Saiphaneendra Bachu, first author who served as the primary doctoral student on the study before earning a doctorate from Penn State in 2023 and is now a TEM analysis engineer at Samsung Austin Semiconductor. "Electrons have tiny wavelengths, so the resolution is incredibly high, letting you detect light from one tiny dot separately from another nearby dot."

They found that larger dots give off one type of glow, while smaller dots produce another. When the dots are extremely tiny — less than 10 nanometers wide, which is about the size of 11 hydrogen atoms arranged in a line — they behave in a unique way, trapping energy and emitting light with higher frequency, which equates to a smaller wavelength.

This phenomenon is called quantum confinement. It occurs when the dots are contained in a space so small that their energy becomes quantized, meaning it becomes a discrete characteristic that enables new properties, including novel electronic and optical capabilities. In this case, the researchers confirmed that nanodots confined fundamental particle pairs known as excitons at the interface of molybdenum diselenide and tungsten diselenide.

By precisely controlling the excitons in materials, scientists can manipulate the light they emit more effectively, which they said could lead to faster and more secure quantum systems, as well as other customizable, energy-saving devices like higher resolution screen displays.

The control comes from adjusting the band gap — essentially the energy threshold electrons must cross to make a material emit light — of a semiconductor material. Materials with lower dimensions, like a single layer of 2D tungsten diselenide, can have a direct band gap, which is more efficient at emitting light compared to its thicker, indirect bandgap counterpart, Alem said.

But light emission efficiency and other electronic and optical properties vary even among a family of related 2D materials — like molybdenum disulfide, tungsten disulfide, molybdenum diselenide and tungsten diselenide — because they each have different band gap energies.

"By mixing them — like combining molybdenum diselenide and tungsten diselenide in specific ratios — you can fine-tune the band gap to emit light at a specific color," Bachu said. "This process, called band gap engineering, is possible because of the wide variety of materials in this family, making them an excellent platform for studying and creating these light sources." ■

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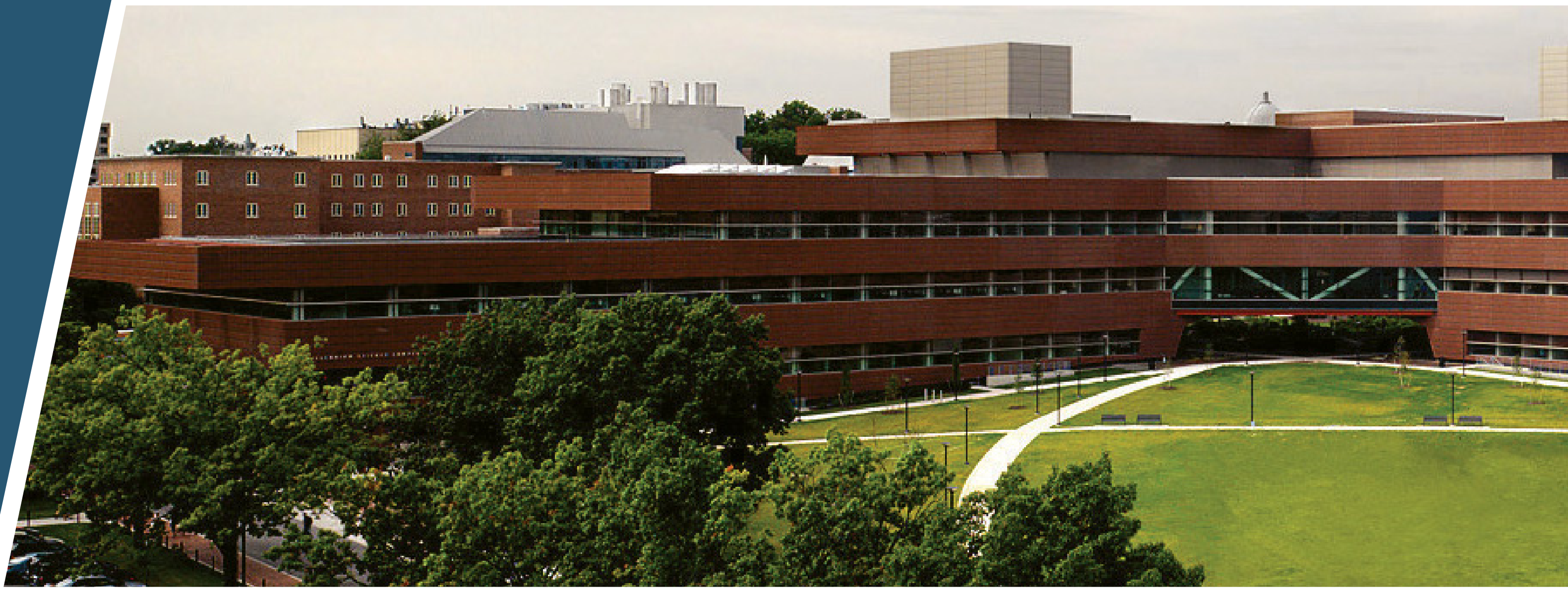

Facilities (and the people using them) drive innovation at Penn State

In the heart of Penn State's University Park campus stands the Millennium Science Complex (MSC), a striking architectural feat that houses the Materials Research Institute (MRI). Beyond its impressive facade, the MSC is a hub of scientific discovery, education, and collaboration, embodying the University's commitment to advancing materials science for the greater good.

At MRI, research facilities are more than just rooms filled with instruments; they are dynamic ecosystems led by innovative minds where game-changing progress and invention thrive. The Materials Characterization Lab (MCL), the Nanofabrication Lab, and the Two-Dimensional Crystal Consortium-Materials Innovation Platform (2DCC-MIP) are core facilities that exemplify this ethos. These facilities are led by experienced researchers such as the 2DCC-MIP's Joan Redwing, a leading expert in semiconductor materials; the MCL's Joshua Stapleton, an expert in advanced materials analysis; and the Nanofab's Daniel Lopez, a leader in nanoscale device engineering and fabrication.

While MRI research happens at other facilities across the University, these labs are the heart of the institute. They provide researchers with access to state-of-the-art equipment and expert staff, enabling groundbreaking work in semiconductors, nanotechnology, and advanced materials. The facilities and expertise that this section of Focus on Materials spotlights is just the tip of the iceberg.

The MCL offers a suite of advanced analytical tools, including scanning electron microscopy and X-ray photoelectron spectroscopy, facilitating detailed material analyses. The Nanofabrication Lab provides capabilities in deposition, etching, and lithography, supporting the creation of novel devices and structures. Meanwhile, the 2DCC-MIP focuses on the synthesis and characterization of two-dimensional materials, fostering innovation in electronics and flexible devices.

These facilities are not only centers of research but also integral to education and workforce development. Students at all levels engage directly with cutting-edge equipment, gaining hands-on experience that prepares them for careers in industry and academia. This approach aligns with Penn State's land-grant mission, emphasizing practical education and public service. It is worth noting that while the research itself at MRI, and at Penn State in general, has enormous value to our society it also trains graduates to make even more beneficial breakthroughs at wherever their careers take them.

Credit: Penn State/MRI

Industry partnerships further amplify MRI's impact. Collaborations with companies like Morgan Advanced Materials and onsemi have led to the establishment of initiatives such as the Silicon Carbide Innovation Alliance (SCIA). The SCIA aims to advance U.S. silicon carbide technology and workforce development, positioning Penn State as a central hub for research and training in this critical area.

The success of MRI's facilities is also a testament to the dedicated staff who manage and maintain them. Facilities manager Sarah Eichfeld and her team ensure that the MSC operates seamlessly, supporting researchers' needs and maintaining the building's specialized features, such as vibration-minimized "quiet labs." Their work enables scientists to focus on discovery without interruption.

As Penn State continues to expand its research capabilities, initiatives like the cleanroom expansion across campus to demonstrate a commitment to staying at the forefront of materials science. These developments not only enhance research opportunities but also reinforce the university's role in driving innovation and economic growth.

In this special section of Focus on Materials, we delve deeper into the stories of Penn State's research facilities, exploring how they serve as both the physical and intellectual infrastructure of modern materials science. From fostering student engagement to enabling industry collaborations, these facilities are at the core of transformative research and education. ■

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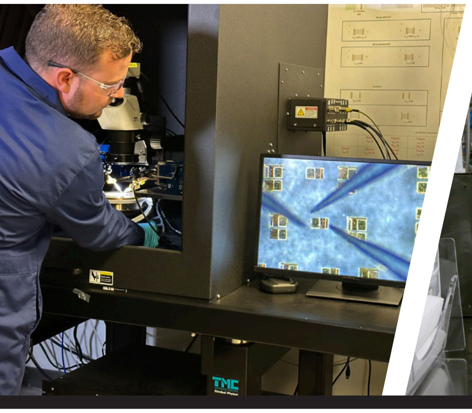

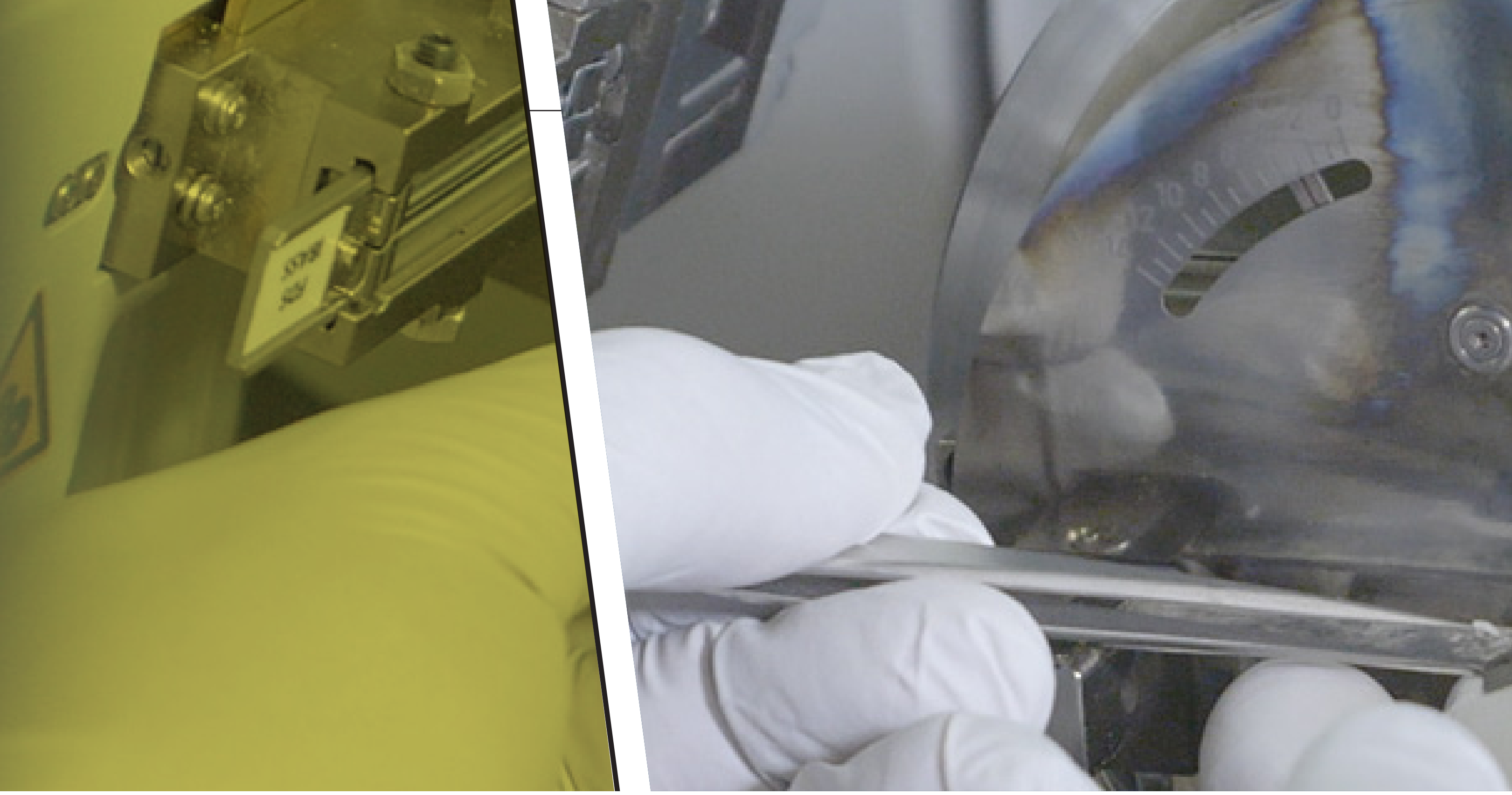

MRI powers optical network innovation through collaboration with Infinera/Nokia

When optical networking company Infinera was acquired by telecommunications giant Nokia in early 2025, it was hailed as a strategic move that would solidify Nokia's leadership in data transport technology. But behind this $2.3 billion deal lies a story of innovation that's been quietly unfolding in central Pennsylvania, thanks to a long-standing partnership between Infinera and Penn State's Materials Research Institute (MRI).

For more than a decade, Infinera, now part of Nokia, has been tapping into the cutting-edge tools and collaborative environment at MRI to drive forward its most advanced research and development projects. From surface analysis to nanofabrication, the facilities and expertise at MRI have helped Infinera push the boundaries of fiber optics technology.

"They initially approached us to do some testing, which led to more projects, and over time we sort of became their go-to lab for certain types of measurements," said Jeff Shallenberger, associate director of the Materials Characterization Lab (MCL). "They're located fairly close about two hours away, and one of their senior people is a materials science graduate from Penn State. He's pretty high up in the semiconductor world, but very hands-on. He likes to come up here and see his samples in person."

"Back in 2015, we started using the MRI facilities because they had equipment we just couldn't afford or justify in-house," said John Osenbach, a fellow at Infinera/Nokia and the Penn State alumnus Shallenberger was referring to. "It began with analytical techniques like Auger, XPS, SEM, FIB, and X-ray work. Over time, the collaboration deepened and expanded, especially as our technical challenges became more complex."

As a company specializing in optical systems, devices that convert digital signals into light for fiber optic communication, Infinera's work sits at the intersection of materials science, engineering, and applied physics. Developing these modules requires extreme precision, advanced materials, and rapid prototyping, all areas where MRI excels.

Osenbach notes that the Millennium Science Complex at University Park, home to MRI's world-class Nanofabrication

Credit: Corey Beasley

Lab and Materials Characterization Lab, was a major factor in deciding to partner with Penn State. These facilities include a 9,500-square-foot cleanroom and specialized "quiet labs" built to minimize vibrations and electromagnetic interference, allowing for atomic-level precision.

But according to both Osenbach and his colleague Michael Vecchio, another Penn State alum and hardware reliability engineer, it's not just the tools that make MRI an invaluable partner, it's the expertise and willingness to collaborate of its people.

> "The expertise is just phenomenal," Osenbach said. "When I talk with someone like Jeff Shallenberger about best characterization approach for a particular issue we are working, I can say, 'Here's what I'm trying to see — can we do this?' And Jeff knows how to get us there. He knows how to tweak the process, adjust the resolution, and make it work. That level of collaboration is incredibly rare."

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Randy McEntaffer

Department Head and Professor of Astronomy and Astrophysics and Professor of Physics

What is your research focus?

I specialize in fabricating diffraction gratings for ultraviolet and X-ray astronomical space missions.

How do the research facilities help you with this work?

The reason I came to Penn State in 2016 was to use the nanofabrication facility at the Materials Research Institute (MRI). Within six months, we outpaced four years of previous research. Having the ability to do every step of fabrication in-house was critical. The standout tool is the electron beam lithography system. What makes it powerful isn't just the equipment—it's the expertise. Chad Eichfeld's leadership enabled us to optimize it for our unique large-format gratings, something that was previously considered impractical.

How important is student access to these facilities?

It's tremendously important. Many of my students use the facilities extensively and often stay on as postdocs or research professors. The work they do there often forms the backbone of their theses and gives them real credibility across fields, especially since we're primarily astronomers.

What are the potential societal benefits of your research?

Our work supports NASA missions and fundamental physics research. But beyond space science, we've developed new types of photonic devices—like one that led to a Nature paper—by manipulating light in ways never seen before. These have potential applications in cameras, sensors, and other optical technologies. We're also exploring how biomimetic structures, like insect-inspired "hairs," might cool crops like wheat in harsh environments to improve food security, particularly in places like Sub-Saharan Africa. ■

Vecchio echoed that sentiment: "There's massive benefit in being able to sit down in a lab and work alongside the people running the equipment. We've made real-time decisions together over Zoom calls, looking at samples live. That kind of speed and flexibility is something you don't often get through collaboration."

In the last 16 months alone, Osenbach and his team have spent more than 20 trips working hands-on in MRI's cleanroom to develop a new proprietary process. This work is directed at leading edge products to meet the accelerating bandwidth, power, and cost challenges imposed by the industry. The success of that work helped position Infinera for its acquisition by Nokia, which aims to use Infinera's technology to power next-generation optical networks, which are in many ways the backbone of our digital world.

> "Before their Nokia merger, John would tell you they're a smaller company in the semiconductor world and to stay competitive, they really rely on access to resources like MRI that let them punch above their weight," said Josh Stapleton. "A smaller company is not going to build a $5 billion nanofab, but by working with us, they get access to cutting-edge fabrication and characterization capabilities. And it's not just about access, because the co-location of facilities and the flow of expertise between them creates real synergy. They're not just collecting data, they're using it to innovate."

Beyond technical innovation, this partnership has broader implications for Pennsylvania and beyond. By enabling high-tech companies like Infinera to thrive, Penn State plays a direct role in boosting the state's innovation economy and workforce development.

"We're not just using Penn State's tools," said Vecchio. "We're training early-career engineers there, building relationships with faculty, and creating a feedback loop between academic research and industrial application."

Osenbach noted that the collaboration has enriched both sides.

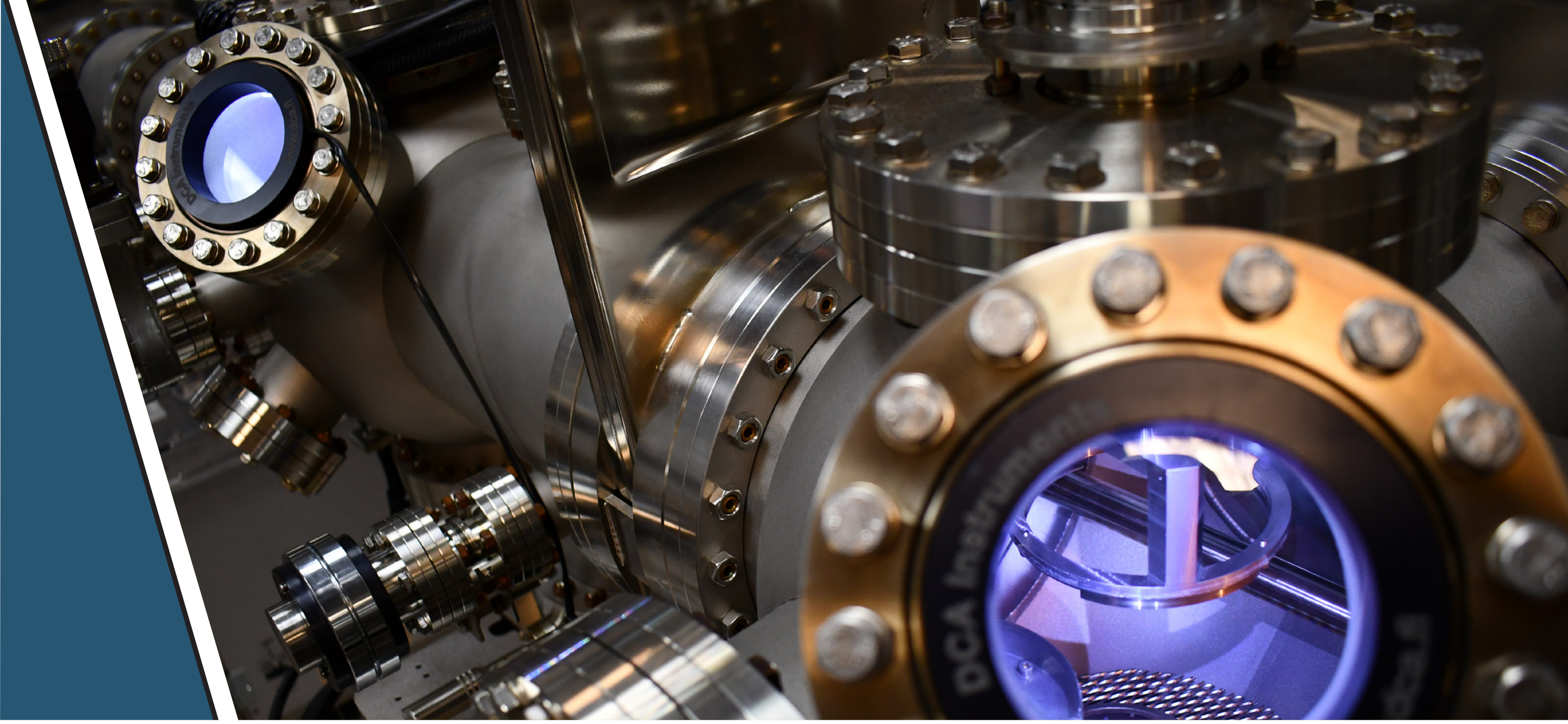
> "We learn a ton from MRI's experts, but I think they benefit too," Osenbach said. "We bring real-world problems, things you don't necessarily see in academic research. That applied lens gives their team a better sense of how their tools and techniques impact industry, and I think that enhances their ability to support other companies down the line."

The work also contributes to solving global challenges. As the demand for high-speed internet, cloud computing, and AI infrastructure skyrockets, innovations in optical networking are essential for building sustainable, efficient, and scalable communications systems. Through this partnership, MRI is playing a role in ensuring that the digital backbone of the world can keep up with future demands, and all while supporting Pennsylvania talent and industry.

"Working with MRI accelerates everything we do," Vecchio said. "From failure analysis to materials selection, they help us move faster and smarter. That means better products and more competitive technologies, right here in Pennsylvania."

As Nokia integrates Infinera's capabilities into its global operations, the foundation built through the partnership with MRI will remain a key asset. The collaboration exemplifies how academic institutions can fuel innovation not just in theory, but in practice, which is helping companies grow, helping people connect, and helping society advance.

"It's been one of the most enjoyable parts of my job," Osenbach added. "It gets me out of the office, back in the lab, and working alongside brilliant people. That kind of partnership? You can't put a price on it." ■



Credit: Jennifer M. McCann/Penn State MRI

Tools of Discovery: How new equipment Is powering research breakthroughs at Penn State

From growing perfect crystals to testing materials in real-world conditions, Penn State's advanced lab tools are making scientific breakthroughs possible

Great ideas and brilliant researchers are essential for discovery—but so is having the right equipment. At Penn State, scientists are pushing the boundaries of materials science thanks to new, state-of-the-art tools that let them explore questions they couldn't answer before.

Take crystal growth, for example. Zhiqiang Mao, professor of physics, materials science and engineering, and chemistry, leads research using a unique tool called the double-crucible vertical Bridgman (DCVB) furnace. It's the first of its kind in the world and allows scientists to grow large, ultra-pure crystals. This is something critical for creating better electronics, sensors, and communication devices.

"Large single crystals with just the right composition are the foundation for many technologies," Mao said. "They're also essential for understanding the basic science behind materials."

Unlike traditional methods, this new furnace avoids common problems like impurities and uneven layers. That means researchers can make better materials for everything from cell phones to solar panels.

Another game-changing area is a technique called in situ testing. It means researchers can watch how materials behave while they're being exposed to things like heat, pressure, or gas. This is similar to what they'd experience in real life.

> "In situ testing gives us a window into how materials change and perform," said Jordan Meyet, who leads in situ capabilities at the Materials Characterization Lab (MCL). "Instead of guessing, we can see exactly what's happening."

For example, if a scientist is developing a new sensor for detecting carbon monoxide, they need to know how the material reacts to that specific gas, not just to air in general. "You have to expose the sensor to the actual gas it's supposed to detect," Meyet said. "That's how you find out what really works."

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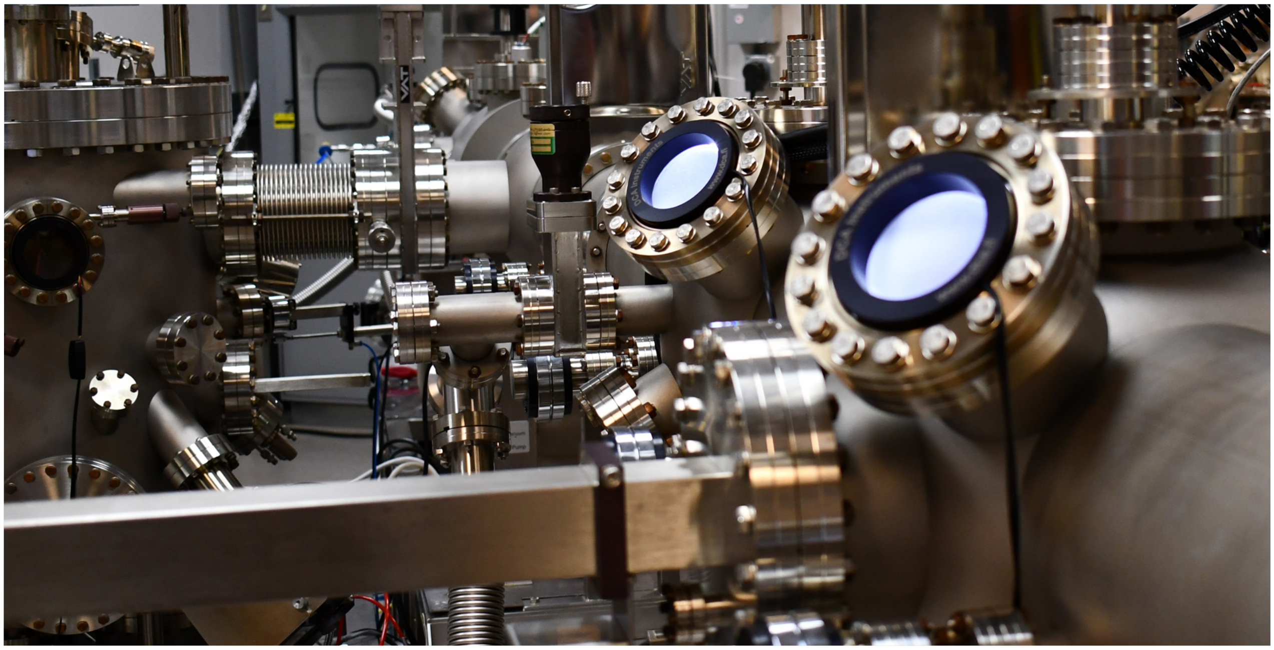


Credit: Jennifer M. McCann/Penn State MRI

To make this possible, Penn State built a custom gas system that delivers exactly the right environment for experiments. It's safe, precise, and permanent; meaning researchers don't have to rebuild it every time. That makes experiments easier to repeat and the results more trustworthy.

"Reproducibility is key," Meyet said. "When everything stays the same, you know the results come from the material, and not from a setup error. It also helps us teach others how to do this kind of research the right way."

Josh Stapleton, associate research professor and the director of the MCL at the Materials Research Institute, says that's part of the broader mission. "The researchers who know they need these tools are already using them," he said. "But there are many more who could benefit if they knew what's available. We want to spread the word."

MRI is also pioneering new ways to make two-dimensional (2D) materials, which are just one or a few atoms thick. These materials are key to building future technologies like advanced computing and flexible electronics.

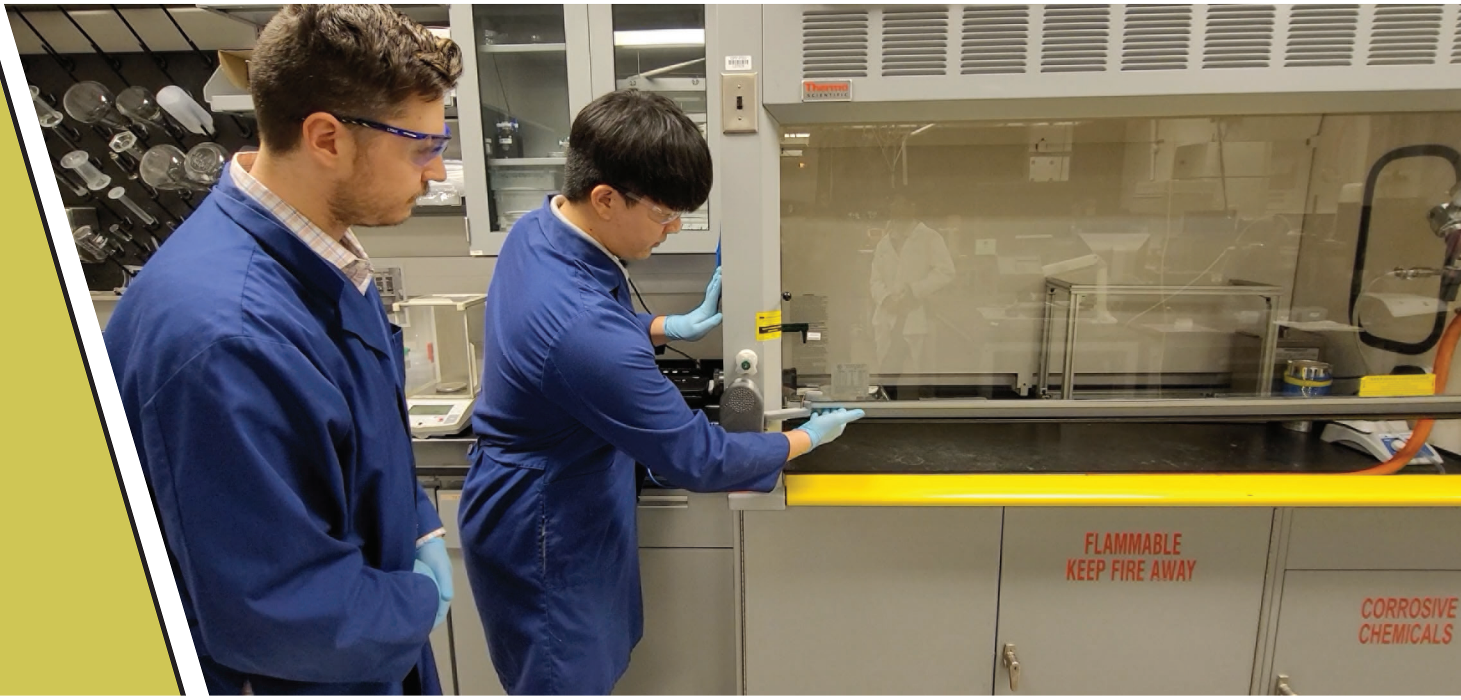
Josh Robinson, professor of materials science and engineering and director of the onsemi Silicon Carbide Crystal Center (SCIA) at Penn State, oversees a tool called the confinement heteroepitaxy (or CHet) system. It's located in the Materials Research Institute as part of the 2D Crystal Consortium Materials Innovation Platform, and lets researchers grow 2D forms of traditionally 3D materials at the wafer scale. That's a big step toward using these materials in real-world electronics.

> "We're growing 2D materials directly on wafers used in the semiconductor industry," Robinson said. "That opens the door for future applications like brain-inspired computing or next-gen quantum devices."

Each of these tools, from crystal growth to gas testing to 2D material synthesis, is more than a piece of equipment. It's a gateway to new research, new partnerships, and new possibilities. These tools attract collaborators from across the country and around the world, including industry partners eager to prototype and test new ideas.

"Penn State isn't just supporting today's research," Stapleton said. "We're building the tools and infrastructure that will shape science and technology five or ten years down the road."

As new equipment comes online and more researchers use it, Penn State is helping transform big ideas into real-world impact, one experiment at a time. ■



Credit: Seana Wood/Penn State MRI

Opening Doors to Discovery: Penn State's MRI offers undergraduates hands-on Research opportunities

At Penn State's Materials Research Institute (MRI), undergraduate students are gaining invaluable hands-on experience in cutting-edge scientific research. Through a variety of programs, these students are not only advancing their academic knowledge but also accessing state-of-the-art research facilities, often for the first time.

Immersive Programs for Aspiring Researchers

MRI offers several undergraduate programs that connect students directly with faculty, researchers, and professional staff in advanced materials science and engineering. These initiatives provide practical experience that strengthens technical skills and encourages interdisciplinary collaboration.

One notable program is the 2DCC and Nanofab Undergraduate Summer Research Program, which runs from May 27 to July 31, 2025. This opportunity allows students to work in small, interdisciplinary teams on real-world research projects. Participants receive a stipend of $6,600 for the summer and gain extensive exposure to MRI's sophisticated research tools.

Another standout initiative is the MRI Undergraduate Fellowship Program, which immerses students in laboratory work at the Millennium Science Complex. The fellowship is designed to prepare students for future scientific careers by providing real-world experience alongside Penn State's research staff and faculty.

Ellery Schlorff, a recent Penn State graduate and former MRI Undergraduate Fellow, described the experience as a turning point in their academic journey.

"Working in the Materials Characterization Lab has been one of the most transformative parts of my education at MatSE," Schlorff said. "It's one thing to learn concepts from a textbook but seeing them jump off the page through real-world applications gave those ideas an entirely new meaning."

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Credit: Seana Wood/Penn State MRI

The Role of MRSEC and Collaborative Research

MRI's partnership with the Center for Nanoscale Science, a Materials Research Science and Engineering Center (MRSEC), provides further avenues for undergraduate involvement. Through the Nanoscale Physics & Materials Research Experiences for Undergraduates (REU) Program, students participate in advanced materials research under the guidance of faculty and graduate mentors. This National Science Foundation-sponsored initiative equips students with practical lab skills and promotes mentorship that extends throughout their academic journey.

In addition, the Partnerships for Research & Education in Materials (PREM) Program links undergraduates from institutions like California State University Los Angeles and North Carolina Central University with Penn State researchers. The PREM Program offers summer research experiences, collaborative projects, and professional development, ensuring students gain valuable experience in materials research.

Gaining Access to World-Class Facilities

What sets these programs apart is the direct access they provide to MRI's advanced facilities. For many undergraduates, this is their first opportunity to operate sophisticated instruments used in materials characterization and synthesis.

The Materials Characterization Laboratory (MCL) is a core MRI facility where students receive hands-on training from experienced research staff. This guidance ensures students develop practical skills in handling cutting-edge equipment for imaging, chemical analysis, and other essential research techniques.

Schlorff said that access to the X-ray lab within MCL played a major role in preparing them for graduate school.

> "One of the most valuable skills I've developed is experimental design. I'm often given a problem and must figure out how to best leverage the tools available to provide a meaningful answer," Schlorff explained. "That level of independent problem-solving has been critical for my growth."

Students are also mentored by research staff, including experts like Nichole Wonderling, who Schlorff credits as a major influence.

"She always made time to support me, whether that was troubleshooting experiments or just encouraging my growth as a scientist," Schlorff said. "My senior thesis, using X-ray techniques to characterize stress in materials, was the most independent project I've taken on, and Nichole was with me every step of the way."

Similarly, the 2D Crystal Consortium – Materials Innovation Platform (2DCC-MIP) integrates undergraduate students into research focused on two-dimensional chalcogenide materials. By working within this national user facility, students gain vital experience in material growth and characterization, contributing to innovative discoveries in electronics, energy storage, and beyond.

The MRI Undergraduate Fellowship Program further emphasizes facility access by providing on-site training for students to become certified equipment operators. This experience not only prepares them for their research tasks but also gives them a competitive edge when pursuing future careers in science and engineering.

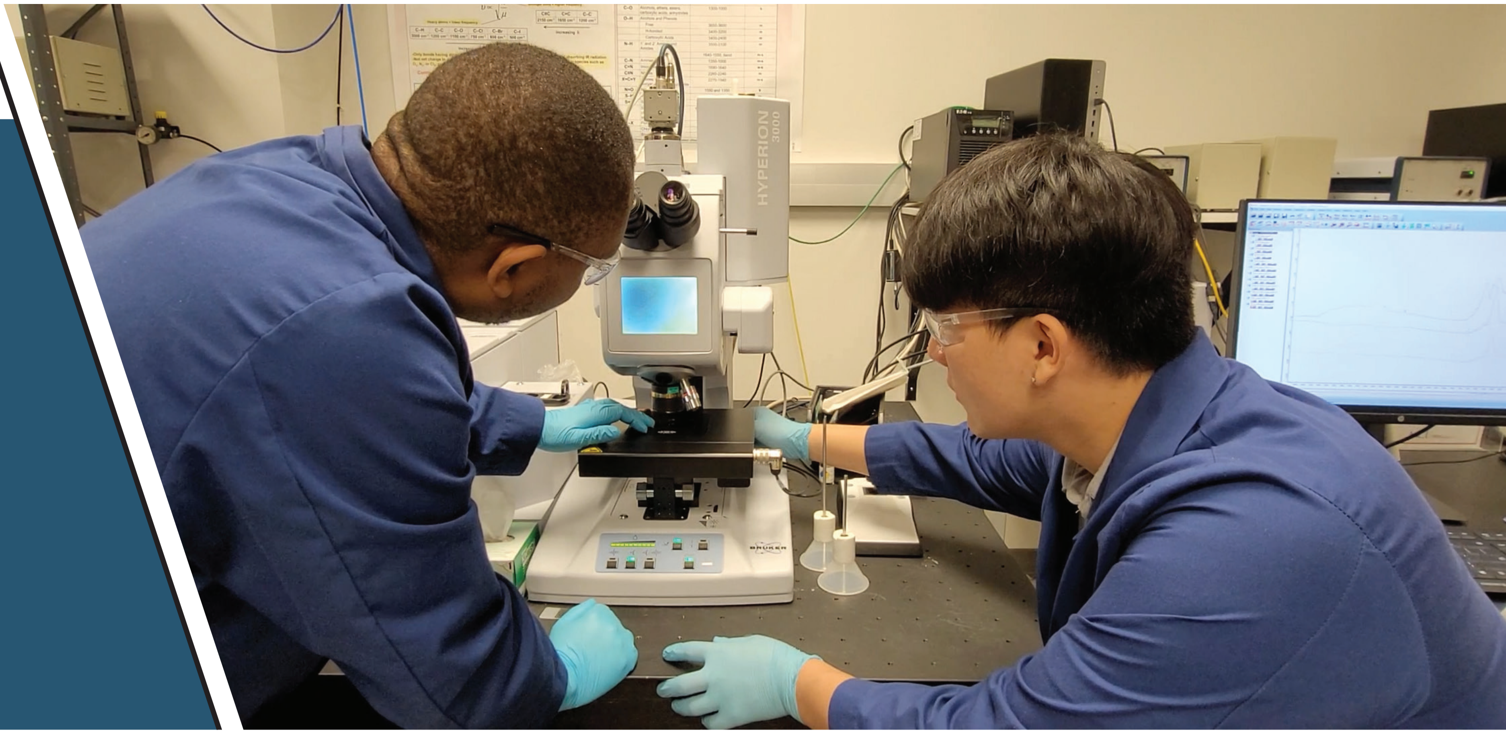
Building Skills for Future Success

By participating in MRI's undergraduate programs, students gain far more than technical knowledge. They develop skills in teamwork, communication, and problem-solving while building professional relationships with faculty and industry experts.

"The MRI and MCL community are so welcoming and supportive," said Schlorff. "Even if it feels intimidating at first, it's worth it. I've learned more than I ever imagined when I first started."

Penn State's Materials Research Institute continues to uphold its commitment to fostering educational opportunities that merge academic growth with practical experience. For undergraduates, these programs serve as a vital gateway to discovery, innovation, and meaningful contributions to the scientific community. ■

Credit: Corey Beasley



Credit: Seana Wood/Penn State MRI

The lab as classroom

How MRI research facilities powers education at Penn State and beyond

When most people think of cutting-edge scientific research, they imagine white-coated scientists, gleaming labs, and futuristic technologies.

But at Penn State's Materials Research Institute (MRI), the work goes deeper and reaches further. Here, research is not just a pipeline for innovation. It's a dynamic engine of education, preparing students with hands-on experience, cultivating a future-ready workforce, and fulfilling the university's land-grant mission.

MRI is often recognized for its world-class research in semiconductors, advanced materials, and nanotechnology. But behind the scenes, its core facilities including the Materials Characterization Lab (MCL), the Nanofabrication Lab, the Two-Dimensional Crystal Consortium- Materials Innovation Platform (2DCC-MIP) and others are constantly buzzing with student activity. Graduate students, undergrads, and postdocs don't just observe experiments; they plan and execute them.

"Core facilities serve a dual, synergistic purpose of education and research where the two domains are one in the same, the act of doing cutting-edge research on state of the art tools is education," said Kevin Dressler, affiliate assistant professor of civil engineering and operations and user facilities director of the 2DCC-MIP.

Dressler, along with Josh Stapleton, associate research professor and the director of the MCL, help to oversee two of MRI's state-of-the-art facilities, where students from undergraduates to postdocs learn by using the same high-powered instruments relied on by global industry. These experiences not only support Penn State's scientific mission but also fulfill its land-grant commitment to workforce development and public service.

Stapleton sees that impact firsthand.

> "I think the part that is most frequently overlooked is the story that sits right in front of us, which is a workforce development story," he said. "There are a bunch of students who put impressive bullet points on their CV because they worked in the MCL, 2DCC-MIP, or NanoFab, and that ends up being what gets them a job."

Sometimes that job comes directly through connections forged in the lab. Jeff Shallenberger, associate research director of MCL and assistant research professor, recalled working with a senior figure from a Pennsylvania semiconductor company who was looking to hire.

"I said, 'There's a student I work with who sounds like what you're looking for,'" Shallenberger said. "They met in the XPS lab and that student's been working there for five years now."

These connections are no accident. MRI's collaborative ecosystem brings together faculty, students, staff, and industry in shared spaces where research and learning happen side-by-side. That hands-on experience translates into a workforce ready to tackle the nation's biggest challenges.

Joan Redwing, distinguished professor of materials science and engineering and director of the 2DCC-MIP, has trained more than 25 doctoral students at Penn State.

"Many of my students have been hired by Intel or other semiconductor companies," Redwing said. "They have the skills that these companies need."

Redwing's group specializes in growing and studying semiconductor materials like gallium nitride, which is a key component in LED lighting and modern display screens.

> "Semiconductors are not just in your laptop," Redwing said. "They are quickly becoming the source of all lighting applications because they're more energy efficient and they last longer."

The value of MRI's research-education model is also evident in economic initiatives like the onsemi Silicon Carbide Crystal Center (SiC3) at Penn State. Led by Penn State and industry partners, SCIA supports semiconductor development for energy intense and national security applications while training students in high-value manufacturing techniques and crystal science.

Joshua Robinson, professor of materials science and engineering and director of the onsemi SiC3 at Penn State, emphasized the dual focus on innovation and talent.

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Haley Jones

Graduate Research Assistant
Materials Science and Engineering

What is your research focus?

My research is focused on nondestructive evaluation and characterization of bulk electroceramics using ultrasound. My current work is focused on evaluating internal damage and degradation in multilayer ceramic capacitors with ultrasonic attenuation.

How do the facilities help you do your research, and can you give a few examples of this?

The MRI facilities have been an essential part of my research. Aside from the ultrasonic measurements, all other characterization techniques used for my work are in Millennium Science Complex. For example, the electrical characterization lab is vital for electrically degrading my materials which I then characterize using ultrasound. The SEM and TEM capabilities in the Materials Characterization Lab allow for further characterization of samples at the micro- and nanoscale which establish structural degradation effects and help draw correlations with my ultrasound measurements.

How might you apply what you have learned here using our facilities that you might apply in your career once you get your graduate degree?

My career goal is to remain in academia as a professor focused on teaching and fundamental research. I plan to utilize my skills with the many characterization techniques that I have learned as an MRI facilities user to conduct fundamental research in the field of materials science as well as disseminate that knowledge to future students of mine.

What are the potential societal impacts of your research?

Capacitors are ubiquitous in electrical circuits, with around 1000 in any smart phone and more than 10,000 in an electric vehicle. Their reliability is essential to all electronic devices, but requires a deep understanding of interconnected, multi-scale phenomena in physics and materials science. Through utilizing ultrasonic nondestructive evaluation to understand these multi-scale phenomena, we are bridging the length scale gap in characterization of degradation phenomena which could prevent critical electrical circuit failures.

Credit: Seana Wood/Penn State MRI

“We want everyone in the nation to be able to come here to innovate in an open platform, and to train the next generation in silicon carbide crystal manufacturing,” Robinson said while addressing attendees at the alliance’s first industry advisory board meeting in March.

Credit: Jennifer M. McCann/Penn State MRI

For Dressler, the connection between education and research is fundamental—and deeply aligned with Penn State’s identity.

“We are the land-grant university of Pennsylvania,” he said. “This is what we were founded to do.”

In the end, MRI is not just a research powerhouse. It’s a training ground, a launchpad, and a bridge between learning and doing. Whether it’s a student mastering an electron microscope, a company solving a complex materials problem, or a doctoral program grad landing a job in industry, the impact of MRI extends far beyond the lab, and into classrooms, communities, and careers across the Commonwealth. ■

Credit: Jennifer M. McCann/Penn State MRI

At MRI, industry partners find more than just equipment

By partnering with Materials Research Institute (MRI), industry leaders are finding more than access to high-end laboratories: They're discovering lasting partnerships that drive innovation, accelerate research, and train the next generation of scientific leaders.

With more than 100 industry collaborators, MRI has become a hub for companies seeking not only tools, but talent and expertise. From start-ups to global corporations, partners say MRI's people and resources are essential to advancing their work.

"We're not just renting equipment here, we're embedded in a world-class research culture," said Bruce Rayner, principal scientist for atomic layer deposition (ALD) at the Kurt J. Lesker Company. "Back in the 2012-2013 time-frame, Penn State purchased multiple ALD systems from us. One of the mutual benefits of this purchase was a close collaboration between KJLC and Penn State, especially considering our combined interest in electronics. Shortly thereafter, the decision was made to move one of our own ALD systems to Penn State to really kick-start this collaboration."

Rayner later relocated to State College to strengthen the relationship.

"Partnering and working closely with Penn State gives us direct daily access to the talent pool, as well as a culture of scientific and engineering excellence," he said. "Moreover, being physically located at Penn State gives us direct daily access to world-class metrology, including one of the best nanofab facilities in the US."

Rayner said the partnership has led to significant technical advancements. This includes two current projects the two entities are working together on.

> "This partnership has played a direct role in the development of our unique ultra-high purity process capability for ALD techniques, as well as associated intellectual property," he said. "KJLC and Penn State currently have two joint publications based on this technology. It is also the basis for our current work on wurtzite-based ferroelectric materials."

Shared Goals, Shared Success

MRI's collaborations extend across fields—from glass science to semiconductors—offering companies access to world-class resources and research expertise.

Credit: Jennifer M. McCann/Penn State MRI

Nick Smith, a principal research scientist at Corning and a Penn State alumnus, highlighted the many ways Corning engages with MRI.

"Corning interacts with Penn State and MRI in many different ways," Smith said. "For example, we're a regular user of the Materials Characterization Lab facilities. That allows us to access several unique tools, get help with challenging problems, or sometimes manage overflow or downtime on our own equipment."

Smith works onsite at MRI through a special in-residence arrangement, giving him direct, daily access to tools, collaborators, and expertise. His office puts him right in the middle of the action in the Millennium Science Complex.

"Being here allows us to move faster," Smith said. "Even with the world-class research capabilities at Corning, long lead times for new equipment are sometimes difficult to avoid. Having the ability to work with universities where you can access state-of-the-art equipment, as well as the expertise that goes along with it, is really beneficial to help us move faster."

Smith emphasized that while Corning has a strong track record of independent product development, partnerships like those at MRI are key to help address fundamental scientific challenges.

"It's quite powerful when we can partner with academic institutions to help solve the grand scientific challenges that are underpinning our next generation of products" he said. "That brings long-term impact because we can address those bigger questions, uncover fundamental material science, and that paves the way for us to innovate faster."

Recruiting the Next Generation

For Morgan Advanced Materials, MRI's value lies in both its cutting-edge research capabilities and its people. The UK-based company, which specializes in technical ceramics, carbon, graphite materials, and thermal ceramics opened its Carbon Science Centre of Excellence at Penn State's Innovation Park in 2018.

"When Morgan was looking for a home for their Carbon Science Centre of Excellence, a lot of metrics were looked at and Penn State started to stick out," said Joe Abrahamson, who leads the center. "I have a bias—I'm a Penn State alum. I like to say that carbon science was born at Penn State around the 1950s due to the father of carbon science, Penn State Professor Phil Walker, Jr."

Abrahamson emphasized that one of the biggest benefits is workforce development. Abrahamson has echoed what many of MRI's industry partners have said about the University's preparation of its students for life after graduation.

"Maybe one of the main benefits is just staying well plugged in to some of the programs and professors, so we know what students are doing well," he said. "I don't conduct a 30-minute interview and try to gauge if someone's going to be a good employee. I know these people. I know when they're going to graduate, and I'm going to want to hire them."

He added that MRI's facilities make a real difference for companies like Morgan.

"We don't have to buy super expensive characterization tools. We can go down there and use them," Abrahamson said. "In my opinion, the MCL works best when you are a user. If you're trained to use the equipment, then it's fantastic."

A Launchpad for Innovation

For some companies, Penn State has been the birthplace of not just projects, but entire businesses. Mark Granahan, CEO and co-founder of Ideal Semiconductor, credits his company's very existence to his early work at MRI.

"I knew Penn State from my prior experience, and I knew that they had a fair amount of materials characterization capabilities," Granahan said. "I was looking for a place that I could do some research on my idea and that also had the technological capabilities.. I ended up basically engaging with the NanoFab as well as MCL."

He hired researchers who were approved to work inside MRI's facilities and spent two years running experiments. In that time, Granahan said they reached their goals.

"The result was significant in that we were able to get the device to ultimately work conceptually," Granahan said. "And that triggered funding of my current company, which is Ideal Semiconductor."

Granahan said Penn State's flexible industry engagement model played a critical role.

"At the time, any of the intellectual property that was created was owned by me. That was an important detail for me, because if I was going to spend money at the nanofab and start a company, it was critical for me to own the IP," he said. "Otherwise, I wouldn't have been able to attract capital funding."

Today, Ideal Semiconductor continues to work with MRI on an as-needed basis. This enables a flexible, on-call relationship when they need MRI's assistance.

> "We have used MCL to do some of the more advanced microelectronics imaging, for instance, FIB-TEM," Granahan said. "Those are two capabilities that we don't have as a company, and once again, based on my relationship with the university as well as the talent that they have in MCL, we were able to image key device features, quite frankly, I wasn't able to get done anywhere else."

Granahan also praised the University's approach to collaboration. "They gave me an office in the NanoFab, and they gave the people that I hired office space too," he said. "The ease of doing business, the economics of it, and the capabilities—all of it was important. It enabled very advanced research in power semiconductors."

A Model for Industry-Academic Partnerships

Across all four companies, a clear theme emerges: MRI's combination of top-tier facilities, expert staff, and strong relationship-building creates a rare environment where industry and academia drive real-world innovation together.

As Rayner put it, having access to facilities and expertise on a daily basis is not just helpful, it's essential. And for Smith, Abrahamson, and Granahan, the partnerships forged at Penn State have led to new technologies, stronger companies, and a pipeline of well-trained future scientists and engineers.

In a time when the country faces challenges in education, research funding, and innovation leadership, MRI stands as a powerful example of how universities and industry can work together to build a stronger, more resilient future. ■

Andrew Graves
Assistant Research Professor,
Thin Films - MOCVD

What is your research focus?

At the Two-Dimensional Crystal Consortium (2DCC-MIP), I work on synthesis techniques for 2D materials—specifically, wafer-scale synthesis of transition metal dichalcogenides (TMDs) using metal-organic chemical vapor deposition (MOCVD). My focus is on improving film quality and performance through innovative doping methods.

How do Penn State's facilities support your research?

There are three main reasons. First, the Millennium Science Complex building was designed to support our MOCVD systems and their specialized requirements. Second, the co-location of 2DCC, MCL, and the nanofab enables seamless synthesis, characterization, and device integration. We can go from growing a material to testing it in a real device within hours. That level of iteration is a game changer. Third is the sheer density of expertise. If I run into a challenge, I can walk down the hall and get expert input almost instantly. This environment dramatically accelerates discovery.

What role did facilities play in your decision to come to Penn State?

They were the deciding factor. I turned down a national lab offer to join Joan Redwing's group because it was clear Penn State had built a unique ecosystem for materials discovery. When I visited, I saw researchers synthesizing, characterizing, and testing devices all in one space; it was like nothing I'd ever seen.

What are the societal benefits of your research?

Graves: Our work could enable next-generation electronics far beyond what silicon can achieve—faster, smaller, more energy-efficient. This has massive implications for everything from smartphones to AI and quantum computing. Whoever leads in these materials will shape the future of technology. We're working to make sure the U.S. stays in that lead.

Behind the scenes at the Millennium Science Complex

Running a large research complex requires variety of skills

At first glance, the Millennium Science Complex (MSC) at Penn State is a striking architectural feat, its angular design and vast expanse evoking comparisons to a giant brick spaceship.

But beyond its impressive facade, the building houses some of the most advanced scientific research facilities in the world. In these facilities, dedicated researchers produce work that has enabled the Materials Research Institute (MRI) to be part of the effort that has led to Penn State recently ranked nationally first in materials science and second in materials engineering by the National Science Foundation's Higher Education Research and Development rankings, which measures research strength and capacity across disciplines.

Ensuring that everything runs smoothly—so that researchers can focus on their work without interruption—is a massive responsibility. And that responsibility falls, in part, to Sarah Eichfeld.

As the facilities manager for the MRI within MSC, Eichfeld oversees critical infrastructure that keeps research moving forward. She is the key point of support for MRI's three main facilities, the Materials Characterization Laboratory (MCL), the Nanofabrication Laboratory, and the Two-Dimensional Crystal Consortium, a U.S. National Science Foundation Materials Innovation Platform and national user facility (2DCC-MIP).

"The job of facilities is a bit challenging to define," she notes. "It can be anything from assisting a laboratory with modifying equipment to helping hook up, install, and maintain research tools."

The building Eichfeld manages stands out not just at Penn State, but among research facilities nationwide. Designed with scientific precision in mind, it includes specialized "quiet labs" in the basement, which minimize vibrations and electromagnetic interference—crucial for high-resolution microscopy and nanoscale experiments.

"The design of the building and how it functions, combined with preventative maintenance, is what allows us to maintain such high standards," Eichfeld explains. "We're 13 to 14 years into the building, and some of our more sensitive tools still meet today's design specifications for vibration minimization."

The impact of this careful design is evident. Eichfeld recalls giving a tour to NASA representatives who were evaluating MSC as a model for their own research facilities. During the tour, one of the visitors stopped inside a quiet lab and told his colleagues to be silent. After a moment, he asked, 'Do you hear that?' When they responded that they heard nothing, he simply said, 'Exactly. I want a room just like this for my microscopes.'"

To maintain this level of quality, Eichfeld and her team work behind the scenes to ensure that MSC's complex network of building support systems—such as air, water, and nitrogen—operate seamlessly. Her team includes MRI Technicians Jake Lyons, Nathan Dotts, and Damian Richards, along with Bruce Walker, who runs receiving building services in the MSC. They play a crucial role in supporting the facilities and meeting the needs of researchers by collaborating closely with Sarah to gather data on building performance and researcher requirements, then work together to find the best solutions. This involves understanding the capabilities and limitations of the building's support systems, such as air, water, and nitrogen supply, and applying that knowledge to address the researchers' needs. The team's efforts ensure the building's specialized features, like the quiet labs and vibration minimization, continue to meet the design specifications that enable cutting-edge research to be conducted in the Millennium Science Complex. In addition, they serve as a bridge between researchers and Penn State's Office of Physical Plant (OPP) to ensure the building's infrastructure supports high-level scientific endeavors.

Every day in Eichfeld's role presents new, often unpredictable challenges for her and her team. Anticipating and responding to these unexpected situations is a key part of the job.

"You never know what each day is going to hold," she explains. "You can have a day full of meetings planned, but then suddenly, you're on the phone troubleshooting a building issue with staff in the Nanofab."

One of the main challenges is maintaining MSC's specialized research environments. With sensitive scientific instruments in use—some requiring extreme levels of environmental control—even minor disturbances can affect experimental results.

From left to right Damian Richards, Jake Lyons, Sarah Eichfeld, Bruce Walker and Nathan Dotts Credit: Jennifer M. McCann Penn State/MRI

> "It's really about gathering data," Eichfeld says. "Just like our researchers do, we collect facility data and researcher input to solve problems in the quickest and most efficient way possible."

Eichfeld's deep understanding of research gives her a unique advantage in her role. Holding a doctoral degree in materials science, she conducted her doctoral research with fellow MSC resident Joan Redwing, distinguished professor of materials science and engineering and director of the 2DCC-MIP, before transitioning into facilities management.

"Having done research, it helps to understand the challenges researchers face because I've been there," Eichfeld said.

This dual perspective makes Eichfeld a vital liaison between researchers and OPP, ensuring that the infrastructure supports scientific advancements without unnecessary roadblocks. Her job involves project management, budgeting, and, most importantly, communicating with all stakeholders to align building capabilities with research needs.

MSC continues to evolve to support cutting-edge research. One of the most significant upcoming projects is the cleanroom expansion, which will increase its size by approximately 20%.

"With the huge push in semiconductor manufacturing research, this expansion will be critical," Eichfeld notes. "What's really impressive is that the cleanroom will remain operational throughout the renovations, so research won't be interrupted."

Another major upgrade is the expansion of the building's nitrogen generation system.

"Several years ago, we installed a second nitrogen generator to reduce our reliance on liquid nitrogen," Eichfeld explains. "With the expansion and new equipment coming in, we're further increasing capacity to support the building's needs."

As Penn State's research footprint grows, Eichfeld and her team remain committed to ensuring that MSC remains a world-class facility. Whether troubleshooting building systems, collaborating with researchers, or guiding major infrastructure projects, their behind-the-scenes work is essential to the breakthroughs happening inside.

"In the end, it's all about enabling the research," Eichfeld says. "That's what makes this job so rewarding—knowing that what we do helps scientists focus on their discoveries that have real impact on our society, without having to worry about the facilities supporting them." ■

PennState
Materials Research
Institute