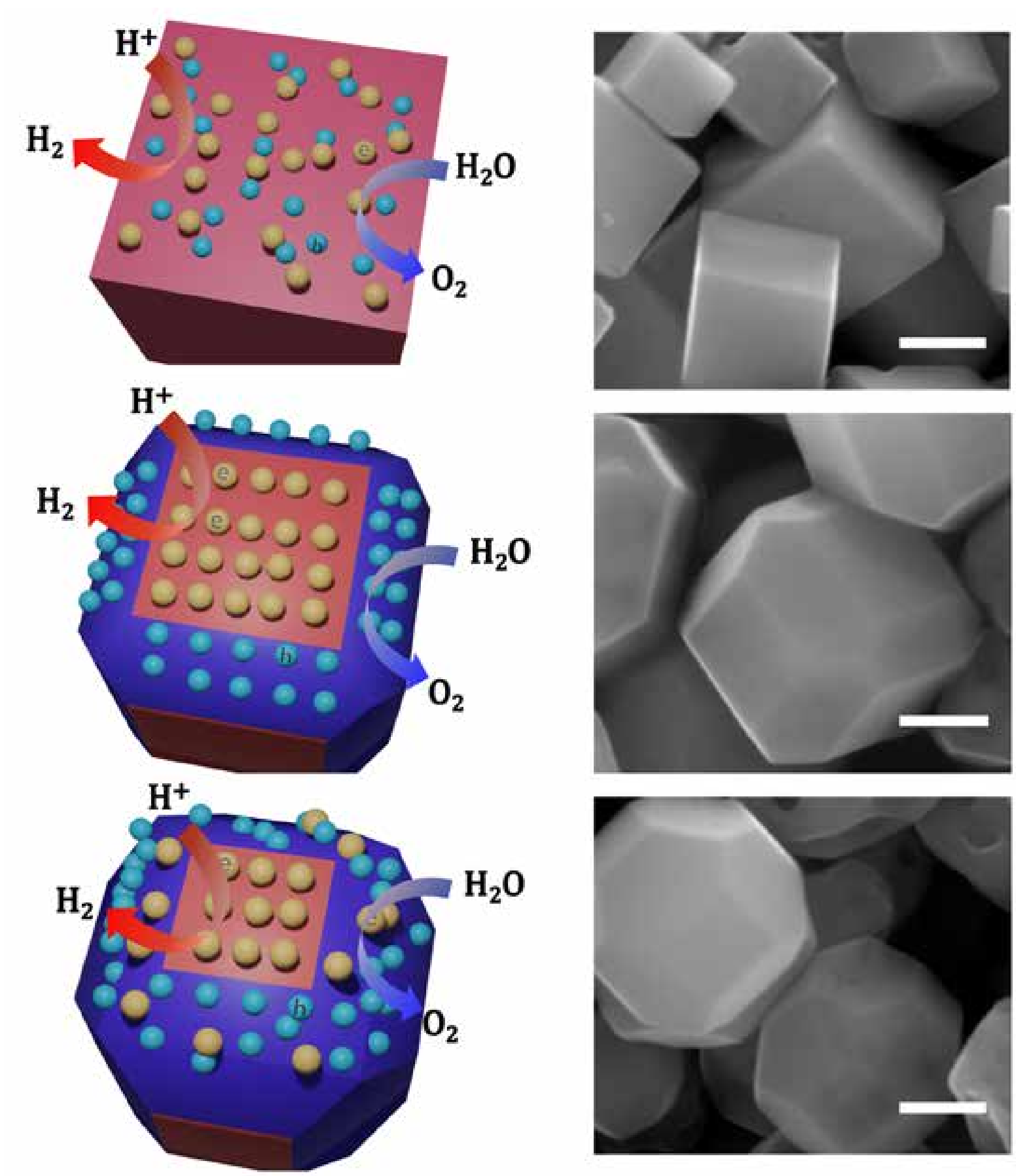
MSE NEWS

MATERIALS SCIENCE AND ENGINEERING

SPRING 2021

Carnegie Mellon University



Attacking Climate Change via New Materials

See story on page 4

A NOTE FROM THE DEPARTMENT HEAD
Elizabeth Dickey

Dear MSE friends,

It is a true honor to be writing you as the newest Head of the Department of Materials Science and Engineering at Carnegie Mellon University. Over the past two months, I've had the pleasure of getting to know many of our undergraduate and graduate students, while learning from and working with our fabulous staff and faculty. I have also been able to connect with several of our MSE alumni, but I have many, many more to meet and look forward to those opportunities to engage with our broader MSE community. I am immensely proud to be part of the Tartan family.

I want to acknowledge the leadership that **Professor Greg Rohrer** provided this Department as its prior Head over the past 15 years. As you may already appreciate, in addition to being an adept academic leader, Greg is a true scholar. He is an international leader in the understanding of oxide surface structure and reactivity, and he has pioneered the measurement and statistical representation of surface and grain boundary properties as a function of interface crystallography. I have no doubt that his most creative days as a scientist and educator are yet to come! I hope you enjoy learning more about his current research activities in this edition of our newsletter and, when circumstances permit, we will properly celebrate, as an MSE community, his professional career and many contributions to this Department.

As the Department moves into its next chapter, I aim to build from the rich and distinguished history that has positioned us as a global leader in materials research and education. I hope to share with you throughout the year my primary areas of emphasis for expanding the Department's impact in education, research, and technology development. Connecting and engaging with our alumni will be essential for developing and implementing that vision to its fullest potential. In that respect, I encourage you to reach out to me; I want to get to know you and hopefully identify ways for you to more fully interact with our Department and students.

Be assured that during these challenging times, our faculty and staff are working harder than ever to ensure that our students continue to receive the world-class education that is a hallmark of Carnegie Mellon University. We highly value the interactive learning that underpins a great engineering education, but we have, of course, had to create and integrate new teaching methods.

As you will see in this newsletter, our graduate students have been safely working in their laboratories since last summer, while our undergraduate students are participating in computational and experimental laboratories and conducting undergraduate research. There is no doubt that we are learning both positive and negative lessons from our new teaching and communication modalities, we more fully appreciate the value of (and miss) human interactions, and we will ultimately emerge as stronger educators on the other side. I look forward to our continued communications and, yes, human interactions as we go through this transition and toward an even brighter future for our MSE community.

Sincerely,
Beth Dickey
Teddy and Wilton Hawkins Distinguished Professor and Head,
Department of Materials Science and Engineering

Gregory S. Rohrer: A Material Impact on the Department

Rohrer's Impact by the Numbers, 2005-2020:

- Undergraduate MSE class increased from 65 to 120 students.
- The number of masters students grew from 2 to 50, plus an additional 35 ESTP MS students.
- Ph.D. students increased from 58 to nearly 100.
- Full-time faculty expanded from 16 to 21.
- Research expenditures grew from $4 million to $7.9 million.

In January, **Professor Gregory S. Rohrer** stepped down as Department Head after leading MSE for 15 years. During his tenure, MSE improved the quality of its physical space, expanded the instrumentation for materials research, increased collaboration with other departments, and grew its global reputation. Equally important, Rohrer led the expansion of MSE's research and curricula to include new, exciting areas such as biomaterials, computational materials science, and additive manufacturing (AM). Following are just some of the highlights of Rohrer's 15 years at the helm of MSE.

2005 MSE began a complete revision of the doctoral recruiting and education plan. These changes led to growth in enrollment, a reduced time-to-degree, and an increase in the number of publications resulting from graduate research.

2007 The Department began a $1 million renovation of its Wean Hall facilities, including a complete renovation of MSE's laboratories for soft materials research and the creation of a new electronic materials laboratory.

2008 The Department began a Masters of Materials Science program by admitting three students. Over the next several years, enrollment in the program increased to more than 50 students.

2010 The MSE Department developed the interdisciplinary Masters degree in Energy Science, Technology, and Policy (ESTP). The degree is an MSE-led collaboration among the other academic units in the College of Engineering. The 96-unit curriculum focuses on a wide range of issues — from the harvesting and conversion of energy to its distribution, demand, and usage.

2011 President Barack Obama visited CMU and announced the Materials Genome Initiative, aimed at helping businesses discover, develop, and deploy new materials twice as fast. MSE responded with changes in its research emphasis by hiring new faculty in computational materials science. Computation was introduced throughout the core and elective curriculum, and specific courses were added on the topic of computational materials science.

2012 MSE completed a $4.5 million renovation of its facilities in Doherty Hall. The renovation included an expanded laboratory for undergraduate education and research, office space for graduate students and researchers, an undergraduate student lounge, an expanded classroom, and office space for the masters program in ESTP.

2016 MSE launched the Next Manufacturing Center, a new initiative focused on additive manufacturing, or 3D printing. It is one of the world's leading research centers for AM, leveraging knowledge from across disciplines to develop an entirely new approach to AM: design optimization, materials selection and characterization, process parameter mapping, software development, final part inspection, and qualification.

2018 The ESTP masters program was a true force within the College, enrolling 47 students and producing nearly 200 alumni in its first eight graduating classes. Graduates had accepted positions in leading companies including Alcoa, Boeing, and Consol Energy, as well as government agencies such as NASA, NETL, and NIST.

2019 Two new center-level research activities were established in MSE, funded by government agencies. NASA sponsored a new University Leadership Initiative in AM to reduce the cost and increase the speed of mass-producing aircraft. The Air Force Research Laboratory sponsored a Center of Excellence focused on integrating machine intelligence into materials research to address problems relevant to the aerospace industry.

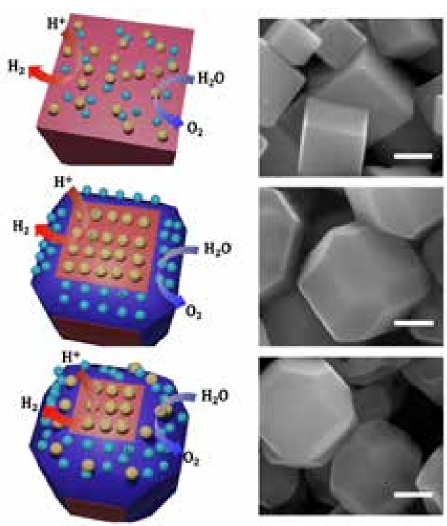
Attacking Climate Change via New Materials

Professor Gregory S. Rohrer's research lab is determined to reduce the costs, and environmental impacts, of energy production

The energy needed to power the modern world is still mostly derived from fossil fuels, which supply about 80% of the total energy consumed in the United States. The remainder of US energy needs are met by nuclear (8%), biomass (5%), hydroelectric (3.5%), and renewable (3.5%) power sources.

Predictably, the United States' reliance on fossil fuels has increased the concentration of CO_2 in the atmosphere, which impacts the climate and global ecosystems. Because the net impacts of climate change are projected to be negative, there is a need for additional energy sources that don't contribute additional CO_2 to the atmosphere. While contributions from renewable sources such as solar photovoltaic and wind are increasing, there's a persistent need for fuels that can be stored and/or transported before being used to supply energy.

Hydrogen, created by catalyzed solar water splitting, is one possible path to a renewable solar fuel that doesn't increase the concentration of atmospheric CO_2. However, this technology is materials-limited, because currently available water-splitting catalysts can't produce hydrogen at a cost that's competitive with fossil-fuel energy sources.



ON THE COVER

Control of reactivity by particle shape. The rates at which Al-doped $SrTiO_3$ particles split water depend on the particle shape, and the figure shows schematic (left) and real (right) catalyst particles. Top: cube shaped crystals force the oxidation and reduction reactions to occur exclusively on the {100} faces. Middle: introducing {110} faces, blue, provides preferred sites for the oxidation reaction. Bottom: if there is not enough {100} area (red), then the reduction reaction can limit the overall rate. The crystal shape shown in the middle is most reactive. The scale bar in the SEM images is 100 nm.

EXPLORING THE POTENTIAL OF LOW-COST POWDERED CATALYSTS

While there are several potential technologies capable of splitting water, one promising route is using relatively low-cost powdered oxide catalysts. Appropriate powders can be manufactured by currently available technologies — and the reactor can be as simple as a water/catalyst slurry, placed in a plastic bag, lying in the sun. The H_2 and O_2 will be recovered in a circulating gas flow and separated using standard methods such as pressure swing absorption, currently used to separate H_2 produced by steam reforming.

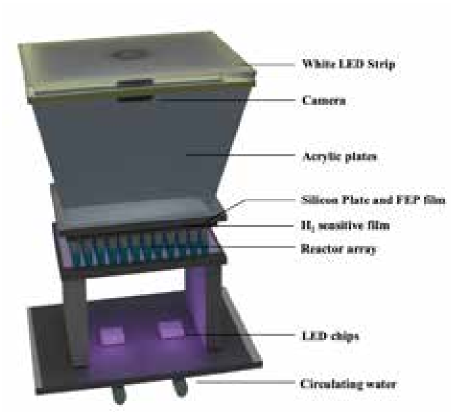
This sounds simple, but the major challenge is that powdered catalysts have relatively low efficiency for hydrogen production. Problems arise because the surface of the same small crystal is required to perform two very opposite functions: promoting the photocathodic reduction of water with electrons, and performing the photoanodic oxidation of water with holes.

Professor Gregory S. Rohrer — W.W. Mullins Professor and Former Department Head of MSE — is leading an effort to solve this challenge and commercialize the use of low-cost powdered catalysts for large-scale energy production. Rohrer's research group is designing particles that can separate charge to specific crystal surfaces to promote the oxidation and reduction reaction at separate locations, increasing efficiency by reducing the back reaction and electron-hole recombination.

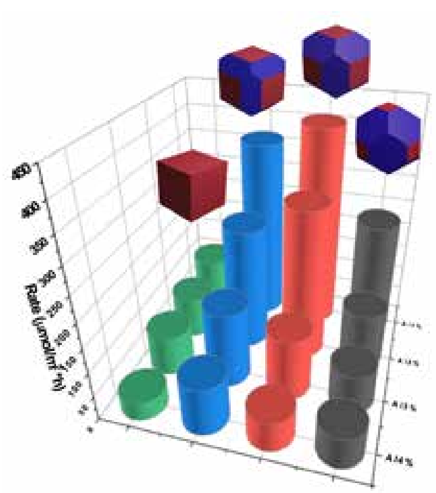
IMPROVING CATALYST PERFORMANCE VIA A NEW TOOL

Catalyst performance is strongly coupled to the material's characteristics, including particle composition, defects, size, and shape. In the past, exploring the effect of these parameters in a systematic way was a challenge.

The main problem was the time required for analysis. The conventional method used to measure the rate of H_2 evolution from a catalyst relies on a sealed photochemical reactor and a gas chromatograph to measure the amount of H_2 produced. Using this method, it takes one person an entire day to evaluate the H_2 yield from a single catalyst. If multiple reactors and gas chromatographs were installed and automated, then the number of catalysts screened could scale with the number of instruments, up to the limit of available laboratory space. However, if researchers wanted to compare the H_2 yield from catalysts prepared at four different temperatures, with four different doping concentrations, and in solutions with 12 different pHs, the number of required experiments would quickly reach the hundreds.



Schematic illustration of the parallelized and automated photochemical reactor (PAPCR) for the high-throughput measurement of hydrogen production. The apparatus sits on bench top.



The hydrogen production rate from catalysts with four different shapes, and four different dopant concentrations. The maximum rate occurs for particle shape "C" with the smallest added concentration of Al.

This situation led to the development of the parallelized and automated photochemical reactor (PAPCR) for the high-throughput measurement of H_2 production. This instrument, developed by CMU Chemistry Professor Stefan Bernhard and his research group, makes it possible to measure the H_2 yield from 108 different catalysts in a single day.

Professor Rohrer's research group is using this reactor to investigate how different combinations of materials parameters influence photochemical reactions. This information is being used to develop improved water-splitting photocatalysts.

The PAPCR, illustrated schematically in the graphic at left, consists of 108 1.1 ml glass shell vials whose headspaces are covered with a hydrogen-sensitive material that darkens in proportion to the amount of hydrogen to which it's exposed. When the relationship between the amount of hydrogen in the headspace and the appearance of the hydrogen-sensitive material is calibrated, optical images of the hydrogen-sensitive material can be used to determine the amount of hydrogen produced by up to 108 different catalysts in a single experiment. Light is provided from below by two 100 W LED chips adjusted to provide a uniform light intensity across all the vials. These sources are available with a variety of wavelengths. The experiment is completely computer controlled and determines the amount of hydrogen in each vial every six minutes.

A 100X ACCELERATION IN CATALYST ANALYSIS TIME

Researchers in Rohrer's group have demonstrated the power of this innovative tool: they can measure the rate of hydrogen evolution from 100 catalysts in the time it used to take to measure a single catalyst.

An example is illustrated in the figure at left, which shows the hydrogen yield from $SrTiO_3$ catalysts with different shapes and different concentrations of aluminum dopants. The different $SrTiO_3$ particles are bounded by different relative areas of (red) photocathodic {100} and (blue) photoanodic {110} surfaces. The particles that have a balance of the two surfaces (B & C) simultaneously promote the oxidation and reduction half reactions and perform better than particles dominated by one of the two surfaces (A & D).

Another advantage of a highly parallel experiment, enabled by the PAPCR, is that Rohrer's team can use several duplicate catalysts in the same experiments to quantify uncertainty in the measured hydrogen rates for that catalyst. Researchers can also include standard samples across many analyses, comparing results from experiment to experiment.

COMBATTING GLOBAL WARMING WITH PARTICLE SCIENCE

Leveraging this new reactor, Rohrer and his team are systematically determining the influence of particle shape, particle size, dopants, charged surface domains, protective coatings, co-catalysts, and many other catalyst characteristics on the ultimate hydrogen production rate.

Their experiments will produce a database of calibrated hydrogen production rates from thousands of catalytic materials based on strontium, barium, lead, and iron titanate, as well as some solid solutions of these compounds. The structure-performance relationships developed from this data are the basis for the development of improved catalysts.

Professor Rohrer's ultimate goal is to develop improved oxide photocatalysts for water splitting. These can be used to produce a sustainable solar fuel source whose combustion does not contribute carbon dioxide to the atmosphere — helping to attack the problem of climate change.

*This research is a collaboration between doctoral students **Mingyi Zhang** and **Wenjia Song**. They are advised by MSE faculty members **Paul Salvador** and Greg Rohrer. The group thanks CMU Chemistry Professor Stefan Bernhard for the development of the PAPCR and NSF DMR 2016267 for funding.*

Warren Garrison Retires After 36 Years

Decades of students pay tribute to a long-time teacher, mentor, and inspiration

A faculty member in the MSE Department for more than 36 years, **Professor Warren M. Garrison** recently retired and has been named Professor Emeritus. After earning a bachelors degree in Physics from UC Berkeley, a masters degree in Physics from UC Davis, and a Ph.D. in Materials Science and Engineering from UC Berkeley, Garrison joined the MSE faculty in 1984.

Garrison taught many classes, but is especially well known for teaching thermodynamics to generations of MSE students across multiple decades. Upon learning of Professor Garrison's retirement, former students from around the world shared their thoughts. Following are just a sampling of the notes they sent him.

"It's a strange thing to write. but your description of the second law of thermodynamics is something I think about almost daily. I hope in your retirement you're able to reflect on how your impact continues to reverberate out into the world. Thank you."
JAMES ROGERS, *B.S. 2007*

"I truly enjoyed your class and your teaching style. You always made time for your students. Congratulations on a well-deserved retirement."
JEAN GROPP PUGLIA, *B.S. 1987*

"Even though I didn't like the Mechanical Behavior class, I like your humor and your light-hearted personality, it is more inspiring than anything else! Proud to let you know that your class has prevented a battery company wasting multiple million dollars on a stupid idea and saved them tons of time!"
HUI DU, *M.S. 2006, Ph.D. 2009*

"Congratulations on your retirement after an inspiring career. As a student and later as a TA for your classes, I saw firsthand your commitment and dedication towards education. I really appreciate your valuable feedback and guidance throughout my time at CMU."
SUDIPTO MANDAL, *Ph.D. 2017*

"I will always remember your 8:30 am Thermodynamics classes in Hamburg Hall. Your patience with us students in grasping the material and getting through problem sets continues to be a fond memory. Your guidance and approachability was so needed in a place where things could feel overwhelming at times. Thank you."
JACKIE MILHANS, *B.S. 2006*

"Thanks for being a wonderful teacher; I've kept my Thermodynamics notes for reference! Your dedication and willingness to constantly support your students was always apparent."
ELLEN TWORKOSKI, *B.S. 2011*

"Thank you so much for all your effort pounding thermodynamics into my head back in the '90s. I swear it wasn't in vain! Your teaching style was refreshing and made a topic such as thermo so much more palatable."
MIKE GINGRAS, *B.S. 1999*

"You remain one of my all-time favorite professors."
JOHN KMETZ, *B.S. 1985*

"I have three memories of you dating back to 1985:
- *Only prof in the department who wore flip flops and jeans*
- *Tousled hair and sleepy eyes, as if you had been up all night prepping for a Thermo lecture (which was actually the case)*
- *Gracious approach to those of us not heading to grad school*

It meant a lot to have a professor who related so well to the undergrads. You made a memorable encouraging comment to me in 1988, which I still remember — thanks!"
DOUG TYGER, *B.S. 1989*

Making Materials Research More Inclusive

Robert Heard's studio-based learning experience makes materials science accessible for nontraditional students

Julita Przybylska, a senior in CMU's School of Architecture, made a purse from celery fibers as part of her 2020 SURF project, under the guidance of Heard. Przybylska created a sheet material, about 1 mm in thickness, that could be cut, sewn, heat sealed, bent, and worn. The biodegradable purse can be used as a fertilizer or seed planter once it reaches the end of its life cycle.

Since joining the Department of Materials Science and Engineering in 2004, **Professor Robert Heard** has been working to make materials science topics more accessible and easier to understand.

Heard's popular course, "Exploration in Everyday Materials," has introduced a range of non-engineering students from across CMU to materials concepts such as manufacturability and durability, demonstrating how these topics might impact applications in their own discipline. Design, architecture, business, and fine arts students have benefited from Heard's efforts to teach materials science, and lead materials research, in a non-technical, inclusive manner.

"Students enrolled outside engineering or technical programs at CMU have limited opportunities to study materials science as it relates to their field. And they might be hesitant to enroll in a highly technical MSE course because they feel intimidated," notes Heard. "My goal is to broaden the topic of materials science so that it's more relevant to the needs of non-engineering students who are involved with materials — whether that means building infrastructures, sewing garments, or constructing theatrical sets."

IMUR: SUPPORTING NONTRADITIONAL RESEARCH APPROACHES

Today, Heard is benefiting from a new program at CMU that shares his goal of research inclusiveness. The Innovative Models for Undergraduate Research (IMUR) Faculty Fellows Program was recently launched by CMU's Eberly Center for Teaching Excellence and Educational Innovation, in partnership with the Undergraduate Research Office. This initiative invites faculty members from across CMU to develop new models for supporting undergrad research.

"The IMUR Faculty Fellows Program is designed to support CMU faculty who want to 'think outside the box' about what undergraduate research or creative inquiry could look like in their discipline, particularly how it can scale and how it can better support underrepresented students," says Jacqui Stimson, Teaching Consultant at the Eberly Center.

Heard is supporting IMUR's objective via a new summer component of "Exploration in Everyday Materials" that will help students accomplish materials research projects funded under the Summer Undergraduate Research Fellowships (SURF) and Small Undergraduate Research Grants (SURG) programs.

"In the past, support for SURF and SURG researchers has varied greatly across the University," Heard points out. "Now IMUR is helping create customized, but scalable approaches that allow student researchers to work independently and creatively, but with clear faculty guidance and well defined outcomes. IMUR complements my own interests in making materials research more welcoming and inclusive."

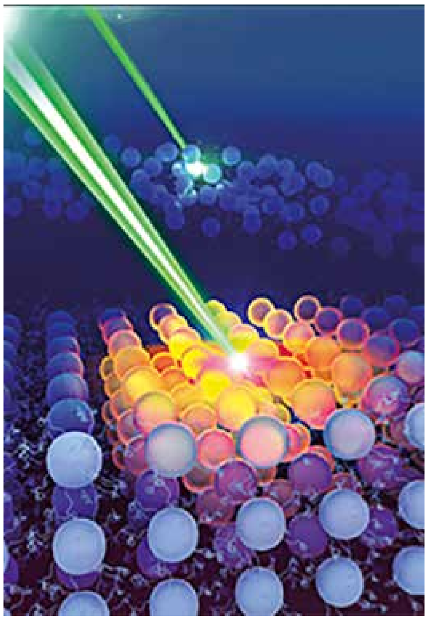
Heard's new summer extension of "Exploration in Everyday Materials" will feature hands-on learning about materials in a studio environment. Under Heard's mentorship, students will define and implement an exploratory design project that meets the goals of their SURF or SURG proposal. Students will be given both creative freedom and structure, as they submit weekly reports and a final portfolio that demonstrates their research outcome.

Like Heard's existing course, the new summer studio will be open to students from across CMU — and it will feature nontraditional topics. "Not only will students examine technical issues such as the durability of their chosen materials, but they will also examine the social, economic, and other impacts of their choices," explains Heard. "The objective is really to broaden the meaning of 'materials science,' while also broadening its audience."

Faculty News Briefs

FEINBERG ELECTED TO AIMBE COLLEGE OF FELLOWS

Professor Adam Feinberg, who holds a joint appointment in MSE and Biomedical Engineering, has been elected to the American Institute for Medical and Biological Engineering's (AIMBE) College of Fellows, Class of 2021. AIMBE Fellows are nominated by their peers and represent the top 2% of the medical and biological engineering community. According to AIMBE, these outstanding bioengineers in academia, industry, clinical practice, and government have distinguished themselves through their contributions in research, industrial practice, or education. Feinberg's research centers on developing materials-based, regenerative strategies that enable various cell types to self-organize and self-assemble into tissue structures.



Artist rendering by Katharina Maisenbacher, Max Planck Institute for Polymer Research

BOCKSTALLER AND COLLABORATORS PUBLISH IN ADVANCED MATERIALS

Professor Michael Bockstaller and his former graduate research student **Jaejun Lee** *(Ph.D. 2019)* are among the co-authors of a paper published in November in *Advanced Materials*. Called "Transparent Hybrid Opals with Unexpected Strong Resonance-Enhanced Energy Conversion," the paper focuses on research they conducted with Professor Krzysztof Matyjaszewski and postdoctoral researcher Jiajun Yan of CMU's Chemistry Department, as well as researchers at Max Planck Institute for Polymer Research in Mainz, Germany. The team's collaborative work has demonstrated an order-of-magnitude amplification of optical absorption in opals formed by the self-assembly of polymer-tethered nanoparticles. This research points to novel opportunities for tailoring light-matter interactions in hybrid materials by deliberate engineering of the molecular structure of polymer chains at interfaces.

DICKEY APPOINTED TEDDY AND WILTON HAWKINS DISTINGUISHED PROFESSOR

MSE Department Head Elizabeth Dickey has been appointed the Teddy and Wilton Hawkins Distinguished Professor. This professorship, established through the estate of Wilton A. Hawkins in 2000, supports a faculty member in the College of Engineering who is engaged in materials research. Dickey's research is focused on developing processing-structure-property relationships for materials in which the macroscopic physical properties are governed by point defects, grain boundaries, or internal interfaces.

STARTUP CO-FOUNDED BY MCHENRY WINS PRIZE

CorePower Magnetics — a startup company co-founded by **Professor Michael McHenry**, adjunct faculty member **Paul Ohodnicki**, *(M.S. 2006, Ph.D. 2008)*, and Michael Anness — recently won the top prize at West Virginia University's Transtech Energy Business Development Program Conference. The first-place award includes $10,000 in funding, which will go toward establishing the company's first manufacturing line and expenses associated with customer discovery. CorePower Magnetics was founded to leverage both McHenry's research in MSE and Ohodnicki's lab at the University of Pittsburgh — where he is an Associate Professor in Swanson Engineering — to produce new high-frequency magnetic materials and component technologies. Ohodnicki first became involved with this work when he was a graduate student at MSE in Professor McHenry's lab. Since then, their collaborative research has resulted in 22 patents and patent applications.

Noa Marom received the Ladd Research Award from Engineering Dean Bill Sanders at her home.

MAROM RECEIVES LADD RESEARCH AWARD

Professor Noa Marom has been recognized with the 2020 George Tallman Ladd Award. This award is made to a faculty member within Carnegie Mellon's College of Engineering in recognition of outstanding research and professional accomplishments and potential. The award is in the form of a memento and an honorarium. Marom's research in MSE is focused on combining quantum mechanical simulations with machine learning and optimization algorithms to computationally design materials with desired properties for various applications.

ROLLETT DELIVERS IAAM AWARD LECTURE

Last August, P**rofessor Anthony Rollett** delivered the International Association of Advanced Materials (IAAM) Award Lecture as part of the Association's Advanced Materials Lecture Series 2020. This lecture series is aimed at promoting open, informed discussions on issues pertaining to advanced materials science, engineering, and technology. According to the Association, the IAAM Award Lecture is a prestigious and coveted lecture that is delivered by a select few individuals. Via the lecture, "The IAAM recognizes worthy and deserving researchers to commend their years of hard work and perseverance." Rollett's research focuses on microstructural evolution and microstructure-property relationships in 3D, using both experiments and simulations.

HOLM RECEIVES DISTINGUISHED SERVICE AWARD FROM TMS

Professor Elizabeth Holm is the recipient of the 2020 Alexander Scott Distinguished Service Award from The Minerals, Metals and Materials Society (TMS). This award honors a member's outstanding contributions to TMS, as exhibited by an exceptional devotion of time, effort, thought, and action toward furthering the Society's mission through administrative and functional activities. The award is typically presented to an individual for 10 or more years of TMS service. Holm was also featured in a July 2020 article in *U.S. News & World Report* called "What to Do with a Materials Engineering Degree." Holm explained the concepts underlying material science and professional applications, such as product development, that are related to these concepts. In her research, Professor Holm uses the tools of computational materials science to study a variety of materials systems and phenomena.

WEBLER FEATURED IN WIRED ARTICLE

Professor Bryan Webler was quoted in an August 2020 article in *Wired* called "Why Do Razor Blades Get Dull So Quickly?" The article examined how human hairs can cause fracturing and chipping of razor blades made of a hardened steel-carbide alloy. Over time, these defects of the blade decrease their ability to effectively cut hair. Webler remarked, "The identification of a failure mechanism opens up new opportunities to engineer blade material composition or processing to create microstructures that will resist this type of failure." He added, "This could be done by reducing microscopic rough edges on the blade edge or thinking about ways to form a more uniform micro-structure." Webler's research interests are in the reactions between metals and their environment, both during processing and in-service.

Making Waves

MSE alum Jason Harman has been named the US Navy's chief nuclear materials engineer

Jason Harman *(B.S. 1995, M.S. 1996)* attended Carnegie Mellon as a member of the US Navy's Reserve Officers Training Corps, balancing his MSE coursework with 6:00 a.m. training exercises, military classes, and afternoon marches on campus. Twenty-five years later, Harman has been named Director of Reactor Materials for the Navy's Nuclear Engineering Program — making him the Navy's chief nuclear materials engineer.

In this role, Harman is responsible for the development of all materials used in the US Navy's nuclear reactors and propulsion plants, as well as its quality assurance programs. Currently the Navy operates 79 nuclear-powered ships, including 68 submarines and 11 aircraft carriers. These vessels account for about 40% of the Navy's fleet.

"One of the Navy's biggest engineering challenges has been understanding the long-term effects of radiation on materials — efforts that have been key to the Navy developing nuclear reactors that now operate for as much as 35 or 40 years of service. We also need to maintain and invest in the unique facilities required for this critical research and development," says Harman.

"Equally important," he adds, "we need to focus on advanced materials research that drives innovation. We need to explore new materials and processes that will support the next generation of nuclear power."

Harman is the first trained materials scientist to serve as Director of Reactor Materials in 25 years, overseeing various research and development, testing, inspections, and characterization activities.

"My MSE professors taught me to rationalize decisions, analyze problems, and think logically. Those have been invaluable skills."

CHARTING A COURSE FOR SUCCESS

Harman admits he initially saw his involvement in the Navy Reserve Officers Training Corps (ROTC) as a means to an end. "My uncle, a Navy commodore, encouraged me to join ROTC to finance my education," Harman recalls. "When I visited Carnegie Mellon, I was impressed by both the quality of the engineering school and the ROTC program. It seemed like a great opportunity."

Following graduation, Harman fulfilled his five-year active duty commitment to the Navy as a staff engineer in the Naval Reactors Program. "I tackled real-life engineering challenges on subs and ships," notes Harman. "It was gratifying to make an impact on our country's naval readiness and national security."

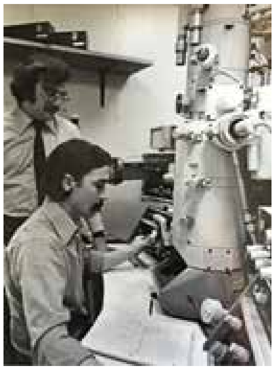
Harman enjoyed his work for the Navy so much that, following his military commitment, he stayed on as a civilian employee. He gradually rose through the ranks of the Navy's nuclear engineering organization, including positions managing shipyard maintenance, component research and development, and two technical laboratories.

Throughout his career, Harman has relied on his MSE training. "My time at CMU gave me the technical knowledge I need to pursue foundational engineering questions and get answers," he says. "My MSE professors taught me to rationalize decisions, analyze problems, and think logically. Those have been invaluable skills."

Harman's professional success has been matched by an equal measure of personal happiness. He met his wife, Dr. Kathryn Beers (*M.S. Polymer Science, Ph.D. Chemistry*) when they worked together at CMU's student-run radio station, WRCT. Today the couple lives in Washington, DC, where Beers is a Program Manager for the National Institutes of Standards and Technology (NIST). They have two children, Bernard, 14, and Penelope, 12. looking back, Harman is grateful that he joined Carnegie Mellon's ROTC program and then stayed on beyond his original service commitment. "My work with the US Navy is important and makes a genuine difference in the world. I can't ask for a better job than that," he concludes.

Nuhfer Retires After 52 Years at MSE

Last July, the Department of Materials Science and Engineering bid a fond farewell to **Tom Nuhfer**, the Founding Director of MSE's Materials Characterization Facility. Nuhfer retired from MSE after more than 52 years with the Department. He joined Carnegie Mellon's Metallurgy Department as a Technician in 1967, then was promoted to a Technical Engineer and Senior Scientist before becoming Director of the Materials Characterization Facility.



In reflecting back on his career, Nuhfer notes the significant changes in the field of materials science and engineering. "Our work has changed as the Department has evolved," Nuhfer says. "We've gone from metals in the Metallurgy Department to a Materials Science Department focused on composite materials, nano-materials, biomaterials, polymers, and nanotubes. But image resolution has always been a critical issue."

Nuhfer helped build the Materials Characterization Facility into a world-class electron microscopy teaching and research laboratory, where engineers can identify the structures of a material down to the atomic scale. Located in Roberts Engineering Hall, the Materials Characterization Facility is filled with high-powered technology, including X-ray machines, computing equipment, and ultra-sensitive microscopes.

"I love electron microscopy and the technique of characterization. It became quite the passion, and I wanted to build the Facility into something special to leave behind," explains Nuhfer. "My hope is that the Facility will maintain and grow when I retire."

IN MEMORIAM

With sadness, the MSE Department announces the loss of **Harold W. Paxton** on March 8. Paxton was the U.S. Steel University Professor (Emeritus) of Metallurgy and Materials Science at MSE. He joined Carnegie Mellon (then Carnegie Tech) in 1953 as Assistant Professor of Metallurgical Engineering. Paxton became Head of the Department of Metallurgy and Materials Science, as well as Director of the Metals Research Laboratory, in 1966. He retired from active teaching in 1994, and was named a University Professor soon after. The title of University Professor is the highest designation a faculty member can receive at CMU. The MSE Department expresses its deepest sympathy to Professor Paxton's family. Watch for a longer tribute to him in the Fall 2021 edition of *MSE News*.

The Department is also sorry to announce the passing of **George Dieter** *(Ph.D. 1953)* on December 12, 2020. Dieter was more than an alumnus; he was a longtime supporter of MSE, serving on Department advisory panels and making generous donations. Dieter wrote two seminal books: *Mechanical Metallurgy*, now in its third edition and a standard textbook, and *Engineering Design*, coauthored with Linda C. Schmidt, now in its sixth edition. In 1993, he was elected to the National Academy of Engineering for "contributions to engineering education in the areas of materials design and processing." Dieter had a long and successful career as a faculty member in the Mechanical Engineering Department at the University of Maryland, and served as Dean of the A. James Clark School of Engineering from 1977 to 1994. The University of Maryland has prepared a video to honor Dieter's memory which can be viewed at https://youtu.be/4VmzxGksLl0. The CMU MSE community sends its most sincere condolences to Gorge Dieter's family.

Dieter's Memory

Applying New Energy

MSE students tackle complex materials problems related to energy conversion, transmission, and storage

Elizabeth Favela, Ziyi Xu, and Jacob Steele (left to right) are gaining hands-on research experience in the lab of Professor Lisa Porter.

As global energy demands increase exponentially, materials scientists face a number of pressing challenges.

"How can materials enable smaller, higher-power electronics? How can we store and transmit energy, in huge volumes, efficiently? These are just a couple questions we need to address to make electric vehicles, a sustainable power grid, and other innovations possible," says **Professor Lisa Porter**.

Porter's lab in MSE is exploring new methods for fabricating, processing, and characterizing the materials at the heart of energy conversion, storage, and transmission. Currently she is focusing on a new material, gallium oxide, that holds promise as a wide-bandgap semiconductor — and a potential replacement for the industry standard, silicon. Its high breakdown voltage, coupled with a low power loss, seem to make gallium oxide ideal for balancing skyrocketing power demands with stable performance.

"Gallium oxide may be a solution for fabricating semiconductor devices that enable maximum energy transmission, but that's just the beginning," Porter emphasizes. "Developing this new, highly promising electronic material could impact electric vehicles, power grids, the aerospace industry — the sky is really the limit."

LEVERAGING THE POWER OF STUDENT RESEARCHERS

As evidenced by the recent, well-publicized failures of public power grids, solving the energy transmission and storage problem is critical. This means Porter must make rapid progress in proving the feasibility of gallium oxide. Three MSE student researchers — **Elizabeth Favela, Jacob Steele**, and **Ziyi Xu** — are helping her.

"I'm fortunate to have these incredibly smart students accelerating my work," notes Porter. "At the same time, they're gaining valuable, hands-on experience in fabricating and testing next-generation materials. MSE's commitment to engaging both undergraduate and graduate students as researchers is a real strength of the Department."

A third-year Ph.D. student, Favela is depositing electrical metal contacts onto thin layers of gallium oxide, then exposing them to 300-degree Celsius temperatures in a vacuum furnace. "While there's been a ton of materials research on silicon, I'm really working at the cutting edge and exploring an emerging material," she explains. "Every day I learn something new. As a researcher, there's nothing as exciting as making new scientific discoveries." Favela's work with Porter has increased her interest in a research career post-graduation, perhaps at a national laboratory.

An MSE senior, Steele had never considered the possibility of doing undergraduate research until he took Porter's "Transport in Materials" class in his sophomore year. His work is aimed at identifying how gallium oxide schottky contacts behave at elevated temperatures. "I agreed to work with Professor Porter on gallium oxide on the spur of the moment, because I loved her class," notes Steele. "And it's literally changed my life." Following graduation in May, Steele will join a gallium oxide research team at Cornell University as a doctoral student.

Xu, who will earn an integrated masters/bachelors (IMB) degree in May, is studying innovative layered contact structures as a way to enhance the performance of gallium oxide. In addition to supporting Porter's research, he's working on a Senior Capstone project with **Professor Jay Whitacre** on more efficient lithium-ion battery technologies. "Designing better high-power electronics, batteries, and semiconductors is critical to addressing the energy crisis," Xu points out. "And advanced materials are the solution. The work I'm doing in MSE has the potential to impact the everyday quality of life for billions of people."

Taking Care of Business

Ph.D. student Spencer Matonis is MSE's first Swartz Entrepreneurial Fellow

First-year doctoral student **Spencer Matonis** has been named a James R. Swartz Entrepreneurial Fellow by CMU — the first MSE student to earn this honor. Given to students who are passionate about technology entrepreneurship, the Fellowship develops each student's entrepreneurial potential and leadership skills through hands-on experiences, networking, mentoring, and coursework.

Matonis' interest in technology commercialization began when he was a high school student working on an independent research project. A self-described "marine biology nerd," Matonis recognized that a "self-healing" filament used by marine mollusks to attach themselves to rocks might have applications for suturing wounds. "That's when I discovered the concept of materials science," recalls Matonis. "I simultaneously realized that this field has a name — and that I love the work."

At the University of Connecticut, Matonis earned a B.S. in materials science while participating in R&D internships at II-VI Inc., ASML, and IBM Research. In his sophomore year, he launched his first startup — an online platform to help labs connect with new researchers and collaborate in digital workspaces.

Following graduation, Matonis worked as a Materials Engineer at NASA's Marshall Space Flight Center, where he focused on printable, flexible electronics for space exploration. He had initially resisted the stereotypical reputation of Ph.D. studies, but came around to the idea after reflecting on the experience he had engineered for himself during his time at UConn. Matonis' confidence in his decision only grew on meeting **Professor Christopher Bettinger**, a researcher he highly respects, who shares his vision for bringing ambitious innovations to the public domain. Their current work together seeks to reimagine bioelectronic interfaces through a novel gastrointestinal signal pathway and fully edible device.

"I'm passionate about identifying the utility in materials and realizing an exploratory vision in something anyone can get excited about," says Matonis. "Research cannot exist in a vacuum, it should be shared, experienced, and celebrated. I'm grateful to be in a place where I have all the resources I need to pursue my scientific and entrepreneurial goals."

Advocating for Diversity, Equity, and Inclusion

In July 2020, as issues of social justice captured the attention of the country, eight graduate students in the MSE Department formed a working group within the Graduate Student Advisory Council (GSAC) focused on issues of Diversity, Equity, and Inclusion (DEI). The mission of the group is to improve representation within the MSE community, increase support for students belonging to underrepresented groups, and normalize and facilitate discussions and dialogue on challenging topics. One of the first major actions by the group was founding a Graduate Application Support Program (GrASP), aimed at reducing the barriers that are often acutely felt by underrepresented scholars. GrASP included a series of webinars open to all prospective applicants, as well as a one-on-one mentorship opportunity for applicants to receive feedback on their applications from current students. In its inaugural year, GrASP served about 50 students through the webinars and matched nearly 25 applicants with current students, with 11 of them receiving admission to our program. It is the goal of the group to grow GrASP in the following application cycle with more targeted advertising and increased current student participation. The founding members of the GSAC DEI working group include **Gaurav Balakrishnan**, **Adrian Johnson**, **Katelyn Jones**, **Michael Kitcher**, **Venkatesh Krishnamurthy**, and **Katrina Ramirez-Meyers**. Contact the group via email at mse-grad-dei@andrew.cmu.edu with suggestions, feedback, or comments.

Student News Briefs

Seniors **Stefanie McMillan** and **Nicole Shi** represent MSE as 2020-2021 Andrew Carnegie Society (ACS) Scholars. ACS Scholars embody CMU's high standards of academic excellence, volunteerism, leadership, and involvement in student organizations, athletics, or the arts. McMillan has a dual major in MSE and Biomedical Engineering, while Shi has a dual major in MSE and Engineering & Public Policy.

Luke Lyle, a recent Ph.D. graduate, received The Minerals, Metals, and Materials Society (TMS) 2021 Functional Materials Division JEM Best Paper Award. Lyle's paper is titled "Characterization of Epitaxial (Al,Ga,In) O-Based Films and Applications as UV Photo-detector." This award recognizes outstanding contributions to the *Journal of Electronic Materials (JEM)*. Lyle received the award during the 150th TMS Annual Meeting, held virtually March 15-18.

A poster created by MSE Ph.D. candidate **Michael Kitcher** won Best Poster at the 2020 Magnetism & Magnetic Materials (MMM) Conference. The poster is titled "Energetics, Equilibrium Shape, and Vorticity of Skyrmions and Antiskyrmions Stabilized by the Anisotropic Dzyaloshinskii-Moriya Interaction in Thin Films with C2v Symmetry." The MMM conference was held virtually November 2-6.

MSE senior **Anna Park** has been awarded a George A. Roberts Scholarship from the ASM Materials Education Foundation. Established through a contribution from Dr. George A. Roberts, ASM Past President and retired CEO of Teledyne, these awards recognize juniors or seniors who demonstrate exemplary academic and personal achievements, and interest and potential in metallurgy or MSE. With a minor in electronic materials, Park plans to continue her focus on semiconductor research and pursue a Ph.D.

Andrea Hwang, an MSE senior with a minor in electronic materials, has been awarded a Tau Beta Pi Scholarship. A researcher in **Professor Noa Marom's** group, Hwang focuses on computational materials science. Hwang plans to pursue a Ph.D. and hopes to be a professor, conducting research while educating the next generation of engineers. Tau Beta Pi Scholarships, given by the national engineering honor society, support tuition during the senior year of study.

Seven Students Receive CMU Engineering Fellowships

CMU's College of Engineering has awarded fellowships to six MSE students. Created through the generosity of Engineering alumni and friends, these fellowships recognize students' accomplishments and potential for continued success. The seven recipients are:

- **Siyu Gao** received the ATK-Nick G. Vlahakis Graduate Fellowship, which supports the masters-level studies of highly deserving students in Mechanical Engineering, Electrical and Computer Engineering, or MSE, or joint MBA/MS students in the same departments.
- **Andrew Huck** was awarded the Presidential Fellowship, which provides financial support to recruit and retain outstanding graduate students, enabling CMU to remain an international leader in graduate education and research.
- **Kunyao Jiang** and **Yue Zhai** received the Neil and Jo Bushnell Fellowship in Engineering, which provides funds to students pursuing doctoral degrees in nanotechnology or electronic materials.
- **Michael Kitcher** received the Bradford and Diane Smith Graduate Fellowship in Engineering, established to support the graduate studies of highly deserving students.
- **Daniel San Roman** received the Phillips and Huang Family Fellowship in Energy, designated for highly deserving Ph.D. students whose research impacts renewable energy and energy efficiency.
- **Ziheng Wu** was awarded the Liang Ji-Dian Graduate Fellowship, created to support the graduate studies of highly deserving Ph.D. students of Chinese heritage.

MSE Celebrates Commencement 2020, Virtually

The Department of Materials Science and Engineering's Class of 2020 included 36 B.S. graduates, 50 M.S. graduates, and 14 Ph.D. graduates. Many of these 100 students found their last months in MSE profoundly disrupted by the COVID-19 pandemic.

Following weeks of uncertainty, Carnegie Mellon University was forced to cancel the in-person May 2020 commencement ceremony — and subsequently, all department diploma ceremonies — due to ongoing public health concerns and state mandates. For the first time in Carnegie Mellon's history, the University hosted a virtual conferral of degrees, and each department was tasked with creating its own virtual celebration.

MSE staff members found themselves in unchartered territory, but were determined to find an appropriate way to honor the graduating students who had worked so hard to get to that pivotal point in their academic careers.

By working together, MSE's staff was able put together a celebratory, entertaining event that included the Department's own videotaped version of students "walking" for graduation, heartfelt and also humorous words of encouragement from the faculty, and a special staff video that included 1001 handmade origami scotty dogs! To watch a video about the meaning of the origami dogs, visit https://youtu.be/Hzy1ZSp4oBs.

The following awards were presented during the virtual 2020 Commencement ceremony:

- *Award for Research Excellence in the Masters Program*
  Recipient: **Kunyao Jiang**
- *Award for Academic Excellence in the Masters Program*
  Recipient: **Dongye Liu**
- *The William T. Lankford Jr. Memorial Scholarship*
  Recipient: **Emmalyn Lindsey**
- *The William W. Mullins Undergraduate Award*
  Recipient: **Jingxi Cai**
- *The Hubert I. Aaronson Undergraduate Award*
  Recipient: **Xining Gao**
- *The James W. Kirkpatrick & Jean Kirpatrick Keelan Award*
  Recipient: **Gwendolyn Wright**
- *The 2020 Paxton Award for Best Doctoral Dissertation Materials Science & Engineering*
  Recipient: **Jonathan Goodwill**
- *The 2020 Krivobok Brooks Award for Excellence in Graduate Metallography*
  Recipients (tie): **Ian Chesser and Megan DeBari**
- *The 2020 Krivobok Brooks Award for Excellence in Undergraduate Metallography*
  Recipient: **Yukun Liu**

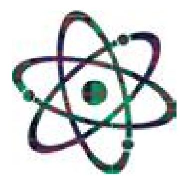
Keith Kozlosky, B.S., is shown with Priscilla Chung, B.S. in MSE and EPP

https://www.cmu.edu/epp/

Gwendolyn Wright, B.S., received the Paxton Award

Amy Coronado, B.S., is shown with Priscilla Chung

Make an impact in MSE today!
Visit giving.cmu.edu/mse



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