

# MATERIALS SCIENCE AND ENGINEERING



UNIVERSITY OF WISCONSIN-MADISON

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**LEADERSHIP MATERIAL:  
MS&E STUDENTS AT THE  
CUTTING EDGE**



# CHAIR'S MESSAGE



## Hello from Madison!

A new academic year is already upon MS&E. We are excited to welcome our new undergraduate, MS and PhD students and also to reflect on advances we made during the 2018-2019 school year. It has been full of milestones! In the fall, our department debuted a one-year, non-thesis master of science degree program in nanomaterials and nanoengineering. The curriculum allows graduate students to advance their education and broaden their expertise in an accelerated manner. The program thrived in its inaugural year under the leadership of Professor Xudong Wang, who envisioned the curriculum and leads the program.

It has been a busy and exciting year for Xudong! His creative research in mechanical energy harvesting materials and their applications in devices that improve the human condition has been recognized by a Presidential Early Career Award for Scientists and Engineering (PECASE) Award from the U.S. Department of Health and Human Services. The PECASE Awards are conferred annually at the White House. They constitute the highest honor bestowed by the U.S. government on outstanding scientists and engineers at the beginning of their independent careers. Xudong's award illustrates how far innovations in material design reach and the underpinning role they play in advancing technologies that improve the human condition.

Professor Padma Gopalan was appointed a World Research Hub Professor for 2018-2020 at the prestigious Tokyo Institute of Technology, Japan. To the best of our knowledge, Padma is the first U.S. female scientist in a STEM field to be awarded this honor. Definitely take a moment to read a bit about Padma's experiences in Japan.

The achievements of our students are the pride of our department and we certainly had no lack of them this year! Just in 2019 alone, graduate students Mia Lenling and Tyler Dabney earned honors at the internationally attended Minerals, Metals and Materials

Society (TMS) Annual Meeting and Exhibition in San Antonio, Texas. Another PhD candidate, William Doniger, was invited to attend a prestigious consortium in the Netherlands as part of NuSTEM—the joint collaboration among UW-Madison, Texas A&M, and the University of California-Berkeley. Additionally, graduate student Laura Hasburgh was awarded the 2019 Margaret Law Award from the Society of Fire Protection Engineers. The list doesn't end there, so be sure to read all about the stellar accomplishments of all MS&E students within the pages of this newsletter.

Not to be forgotten are our hard-working bachelor candidates. We awarded the largest undergraduate class in department history their bachelor's of science degrees in materials science this last spring. Our alumni have now grown by 60! We could not be prouder of our recent graduates. What an exciting way to cap off the academic year!

As our alumni network gets bigger, so does our department faculty. In 2019, we welcomed Assistant Professor Dawei Feng. Dawei designs and synthesizes inorganic-organic hybrid solid state materials at the molecular level to develop novel materials with targeted chemical and physical properties. Currently he is developing metal-organic electronic materials for energy conversion, energy storage and electronic devices, as well as solid state ion conductors for rechargeable ion batteries.

Beyond the walls of our MS&E building, the city of Madison is one of the country's best places to be. Madison was named the nicest place to live by U.S. News and World report, confirming what most of us already know. Furthermore, it was named by *USA Today* as the #1 best city to live in after graduation. So, to all you recent MS&E grads, please stay in touch! Welcome to another great year, and ...

**ON, WISCONSIN!**

**Susan E. Babcock**

Professor and Department Chair  
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## Celebrating our distinguished alumni



Every fall, we honor the achievements of outstanding alumni at the Engineers' Day banquet.

Alum **Mark Hoffmeyer**, recipient of a 2019 distinguished achievement award, is a senior technical staff member at IBM Systems. His expertise has led to significant innovations in microelectronic devices in areas that include materials design, assembly, packaging and manufacturing.

## SUPPORT MS&E



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# GOPALAN SABBATICAL IN TOKYO INSPIRES LEADERS, SPARKS INNOVATION



There's an intrinsic level of "unique" when you are a world expert in the design and synthesis of never-before-made organic molecules and polymers.

But when you are the first U.S.

researcher—and the first woman in STEM—ever asked to participate in a prestigious tech initiative located halfway around the world, "unique" morphs into "elite."

That's the case for Professor Padma Gopalan. Her expertise earned her an invitation to join the world's top researchers as a specialty appointment professor at the Tokyo Tech World Research Hub Initiative in Japan.

Now made up of 234 researchers from across the globe, the initiative is a bold undertaking, designed to break down barriers between fields and countries so that the world's brightest minds can tackle the 21<sup>st</sup> century's toughest problems through interdisciplinary research.

During her year-long sabbatical from UW-Madison, Gopalan worked in the materials and devices division of the research hub. There, she continued ongoing research with Teruki Hayakawa, a professor in the School of Materials and Chemical Technology at Tokyo Tech, and also initiated new collaborations with scientists from around the world.

Among Gopalan's achievements while in Japan are developing a new class of coatings to enable block copolymer self-assembly in thin-films and creating degradable conjugated polymers that can sort semiconducting single-walled carbon nanotubes and assemble them in arrays, then subsequently be removed from devices to maximize performance.

Outside the lab, Gopalan immersed herself in Japanese culture, becoming conversant in the language and traveling around the country giving talks at institutions outside of Tokyo.

And while Gopalan learned a lot during her time in Japan, she also left quite an impression on her hosts.

"I did not realize that it is not a normal sight to see a female professor in a STEM field traveling around the country, giving talks in Japan," she says. "This has started meaningful discussions with administrators in different institutions in Japan that I have visited, as they see the extreme gender inequity in Japanese academia. I hope to use this appointment effectively to make a positive impact."

## FACULTY NEWS



**Mike Arnold** was appointed Beckwith-Bascom Professor in honor of his exceptional contributions to teaching, research and service on

the UW-Madison campus. Arnold, who joined MS&E in 2008, is a world expert in the fabrication of carbon nanotubes and in graphene synthesis. In addition to his research, Arnold is the associate chair for undergraduate studies in materials science and engineering and his group has developed and led multiple summer camps and outreach workshops for middle and high school students.

Arnold's research also earned recognition at the 2019 TechConnect World Innovation Conference and Expo, held June 17-19, 2019, in Boston. The event connects top applied research and early-stage innovations from universities, labs, and startups with industry end-users and prospectors. Arnold won an

innovation award for his method to make a dense, highly aligned film of semiconducting single-walled carbon nanotubes that could be incorporated in high performance field effect transistors and other devices including displays, sensors, biosensors and solar cells.



Professor **Sindo Kou** won the William Spraragen Award for the best research paper published in the *Welding Journal* research supplement. Kou is a world

expert in understanding and controlling cracking, segregation, microstructure and transport phenomena during welding, casting and crystal growth. He and graduate student Tayfun Soysal published a 2017 manuscript describing a simple test for susceptibility to solidification cracking, which is a serious weld defect. In the paper, Kou and Soysal outline a reproducible test for the defect with several

significant advantages over the current, most widely used method.



The International Society for Solid State Ionics bestowed a prestigious mid-career award upon Harvey D. Spangler Professor **Dane Morgan**. Presented

at the organization's annual meeting, held in Pyeongchang, South Korea, on June 20, 2019, the award recognizes Morgan's innovative and impactful research. Among his numerous contributions to the field, Morgan, a world expert in computational materials science, has revealed key insights into the properties of solid-state ionic conductors, which are key components of energy storage devices such as supercapacitors and solid oxide fuel cells.

# FUEL CELL ADVANCE A BREATH OF FRESH AIR FOR FUTURE POWER ALTERNATIVE

A promising alternative to conventional power plants, solid oxide fuel cells use electrochemical methods that can generate power more efficiently than existing combustion-based generators. But fuel cells tend to degrade too quickly, eating up any efficiency gains through increased cost.

“Fuel cells are exciting technologies with potentially disruptive capabilities,” says Professor Dane Morgan. “But degradation issues have been a major obstacle for the consumer market.”

One reason that fuel cells degrade is that the devices must operate at extremely high temperatures—in excess of 1,500 degrees Fahrenheit—to drive the chemical reactions that create electricity.

Fuel cells combine oxygen with an external fuel source, a similar process to the heat and light-yielding transformation that occurs in fire.

In order for oxygen to enter the cathode, the gas molecule must split into two atoms. Then each atom must encounter a vacancy. Understanding this process is difficult because it happens at the top atomic layers of the cathode, whose chemistry can be quite different from the bulk of the material.

“Measuring composition and vacancy chemistry at those top two layers is extremely challenging,” says Morgan.

That’s why he and colleagues turned to computer simulations. As leading experts in molecular modeling, they combined density functional theory and kinetic modeling to gain atomic-level insight into the reactions occurring on the top two layers of the cathode.

The team determined that oxygen splitting is not the rate-limiting step in the studied material. They learned that what is limiting fuel cell efficiency is the



Dane Morgan (left) and Yipeng Cao.

way in which oxygen atoms find and enter vacancies at the surface.

Material with more vacancies, therefore, could potentially make fuel cells much more efficient.

“This could allow for materials design in a way that was very hard to do before,” says Morgan.

## NOT SO DEFECTIVE, AFTER ALL

### Demystifying advanced quantum materials

Sometimes, flaws are what makes a thing special.

That is the case for materials called optical quantum emitters, which send out light in an exceptionally precise manner, one photon at a time, often due to tiny imperfections in the crystal structure.

Optical quantum emitters could become the backbones of ultrafast computers, super-high-resolution sensors and uncrackable long-range secure communication technologies.

Recently, buzz has been building about a newly discovered variety of quantum emitters consisting of two-dimensional materials (think flat sheets only as thick as a single molecule, similar to graphene). But there’s a hitch: No one truly understands the exact natures of the defects that cause these 2D materials to become optical quantum



emitters. And that’s been a major obstacle in obtaining these potentially useful materials.

“If we can understand the nature of the defects, the hope is to be able to control them,” says Assistant Professor Jason Kawasaki.

Kawasaki is one member of a team of engineers and physicists at UW-Madison that is combining expertise in materials synthesis and atomic-scale measurements in an effort to demystify those defects in two-dimensional materials. Ultimately, they hope to develop a reliable method for making optical quantum emitters.

“We’re interested in developing a base technology,” says Shimon Kolkowitz, an assistant professor of physics. “What’s needed are solid-state emitters, but we still don’t have high-output materials that produce a high rate of photons on demand.”

Currently, two main tactics exist to create the emitters: Engineers either bombard an existing sample with ions, or use a strategy called exfoliation, which is a fancy way to describe peeling off incredibly thin sheets of material using adhesive tape, and looking for defects at the edges. Both are rather “blind” processes; researchers still do not know the precise chemical nature of the defects.

To shine some light on the mystery, Kawasaki, Kolkowitz, and colleagues Victor Brar and Zongfu Yu will carefully examine samples of optical quantum emitters using a combination of structural analysis and energetic measurements.

“Measurement has been a challenge,” says Kawasaki. “There are techniques for studying the defect structure and separate techniques to measure the emission spectrum. The question is, how do you combine those two?”

Fortunately, Brar and Kolkowitz bring world leadership in a specialized combination measurement technique to the table. And once the team has a handle on the defects, they will begin growing materials from scratch. That’s where Kawasaki comes in.

“It’s a project that spans our campus, which is pretty exciting,” says Kolkowitz.

# TARGET ACQUIRED

## Using magnets to help medicines deliver a more powerful punch



Chang-Beom Eom



Jiamian Hu

When you take a pill, the drug passes through your system—but its healing effects can come a cost: Along the way to its intended location, the drug can dose, and harm, healthy tissues, too. Materials scientists at UW-Madison hope to reduce the

side effects of medicines and boost their efficacy by delivering them only to their intended targets within the body.

And they have laid out the theoretical basis for a drug-delivery system that uses the power of magnets to release therapeutic molecules right where they're needed.

"This is on-demand control of drug release," says Jiamian Hu, an assistant professor and fellow of the Grainger Institute for Engineering.

Hu, an expert in computational theoretical modeling, and colleague Chang-Beom Eom, a world leader in materials synthesis, described their concept for a magnetic drug delivery system in a paper published in April 2019 in the journal *Applied Physics Letters*. The paper was also selected as an editor's highlight in the issue.

On-demand drug release has long been a goal for clinicians around the world.

Imagine a future where cancer patients would no longer experience the ravaging side effects of chemotherapy because the toxic chemicals that kill cancer cells only exert their lethal effects inside tumors, bypassing healthy tissues.

Targeted drug delivery could also open up new frontiers for treating neurological conditions such as multiple sclerosis and Alzheimer's disease. Currently, very few existing medicines are able to cross the protective

structure called the blood-brain barrier.

Biologists have been working on specialized packaging systems that release medicines on cue for several years—some methods use small spherical containers made out of fat called liposomes, while others hinge on artificial nanostructures comprised of DNA.

Hu and Eom looked to a less organic material for their drug delivery system.

"We are materials scientists," says Hu. "We are taking a different approach."

The researchers realized that many drug molecules, including some commonly used chemotherapies like cisplatin, carry a partial electric charge. In other words, they're polar.

Polar molecules can be coaxed to "stick" to a surface under the influence of a magnetic field. And some specialized ferromagnets have the ability to alter the strength of their magnetism under the influence of an externally applied field.

Hu and Eom hit upon the notion of using surface-functionalized ferromagnetic materials to capture drug molecules. They envision therapies consisting of small ferromagnetic particles coated with drugs. The medicines would not be active until clinicians applied an external magnetic field to release drug payloads from the particles' surfaces. As a bonus, doctors could even use external magnets to manipulate the particles inside patients' bodies.

"You can use magnets to guide the small particles to the places where you need to release the drug, then change the magnetic field condition to release it," says Hu.

But not just any old refrigerator magnet will do. Hu designed precisely composed

stacks of thin layers of ferromagnetic materials and other coating materials.

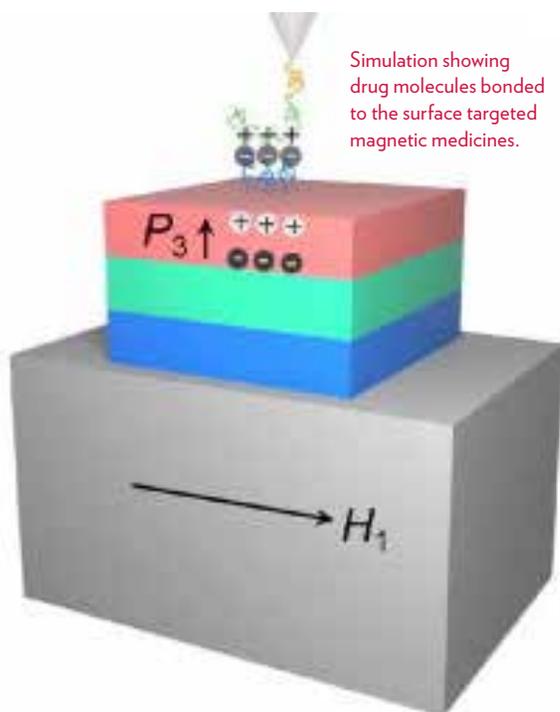
"It's theoretical work," says Hu. "We drew from two well established theories from different fields and took it one step forward."

Crucially, Hu consulted with Eom—a world expert in growing never-before-seen materials one atomic layer at a time—to determine if the stacks that he designed would be feasible to synthesize in the real world. Not surprisingly, Eom has grown similarly complex multilayered materials in the past.

"It's very beneficial to talk with experimentalists," says Hu. "We needed to know our stacks could really be fabricated."

Currently, the researchers are taking steps toward doing just that. That initial step will allow them to begin experiments, in the lab, using real drugs.

"This is all preliminary work; nobody has thought about this before," says Hu. "It's one small step, but it's progress as long as at every step, we produce something."



# ‘CADILLAC’ OF FELLOWSHIPS HELPS GRAD STUDENT DRIVE NUCLEAR RESEARCH FORWARD

Master’s student Tyler Dabney has earned a highly competitive and prestigious fellowship from the Department of Energy Nuclear Energy University Program.

With three years of full funding and support, Dabney will work on developing protective coatings for the fuel rods inside nuclear reactors using a solid-state additive manufacturing technology called cold spray.

Those coatings could help reactors withstand unforeseen events. “If an accident occurs, the coatings should allow fuel rods to survive longer so engineers can restabilize the reactor core,” says Dabney, whose advisor is Distinguished Research Professor Kumar Sridharan, an expert in cold-spray coatings.

Cold spray is attractive for nuclear applications because it allows engineers to lay

down a protective coating without melting the material. That means very little oxygen gets incorporated into the coatings and there’s no opportunity for defects to arise during solidification, making them long-lived, tough and resistant to oxidation.

Additionally, cold spray is high-throughput, allowing coatings to be produced much faster than other techniques offer.

Dabney began his work as an undergraduate during his junior year, and he stayed on working as a research intern in Sridharan’s lab after commencement in 2017.

His cold spray research has already earned him international attention: In March 2019, he took home first place for a poster in the additive manufacturing for energy applications poster competition at the TMS

annual meeting—the most widely attended conference in the field of metallurgy, minerals and materials.

He’ll continue that work, and the fellowship will allow him to fully immerse himself in the project.

“It’s a nice burden lifted and I’ll be able to really focus on the research,” he says.



Mia Lenling and Tyler Dabney.

## COLD SPRAY IS A HOT TOPIC FOR GRAD STUDENT

Grad student Mia Lenling spent two days in April 2019 hobnobbing with some of the brightest talents in the nation at the GE Research technology nucleus located in Niskayuna, New York.

The all-expense-paid trip was Lenling’s reward for being selected from a nationwide pool of applicants to GE Research’s *Innovate* program, which aims to bolster participation in science, technology, engineering and math disciplines among women and underrepresented minority students.

“The most valuable aspect of the experience was networking, not only with GE employees, but also with other attendees from all across the country,” says Lenling, who also is advised by Sridharan.

While in upstate New York, Lenling had the opportunity to tour state-of-the-art lab spaces featuring the latest robotics and artificial intelligence, now housed in the same buildings where X-ray technology got its start.

Of particular interest to Lenling was the additive manufacturing equipment at the facility, as her research focuses on cold spray.

Lenling uses cold spray to fabricate free-standing nanostructured steel tubes (called “cladding”) that coat nuclear fuel rods. Her approach to creating the tubes that surround the radioactive rods is much quicker and more efficient than the multi-step extrusion processes used today.

Lenling’s cladding research not only nabbed her a trip to Niskayuna, but she also earned second prize in March 2019 for her poster at the annual meeting of TMS.

At the meeting, Lenling received great feedback on her research, including some suggestions for new techniques to improve the cladding tubes.

After Lenling graduates, she hopes to pursue a research and development position in industry. While she’s interested in nuclear energy, Lenling is open to branching out into other fields—yet she aspires to continue working on cold spray technology.

“My research has mostly focused on nuclear, but there are many other applications where cold spray could be beneficial,” says Lenling.

### MS&E STUDENT WINS AWARD FOR MOLTEN SALT RESEARCH

William Doniger, a materials science and engineering PhD student advised by Sridharan, received second place for his poster presentation on molten salt corrosion and electrochemistry at a major international meeting in the Netherlands, July 4-5, 2019. The conference was the final gathering of a multi-year, multi-institution initiative called Safety Assessment of the Molten Salt Fast Reactor, which is working to find alternative coolants to water for nuclear power plants.

## WHERE ARE THEY NOW?

# MS&E ALUMNI MAKE THEIR MARKS AROUND THE WORLD

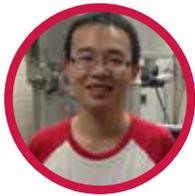
Since the department's early days as a mining and metallurgy program, materials science and engineering at UW-Madison has forged leaders.

Now, the outstanding people who studied here over time have made their mark in academia, industry and research labs around the country. Here's a snapshot featuring just a few alumni.



Most recently, **Xin Wang**, a postdoctoral scholar in Professor Dane Morgan's computational

materials research group, accepted an assistant professorship at Penn State University.



Also in 2019, **Congli Sun**, who completed his PhD under Professor Paul Voyles, became an assistant professor in

the Nanostructure Research Center at the Wuhan University of Technology in Hubei Province, China.



On the mid-career faculty alumni front, among those who recently received tenure are **Jian Shi**, now an associate professor at

Rensselaer Polytechnic Institute in Troy, New York. Shi was a graduate student in Professor Xudong Wang's group from 2009-2012. And **Yifei Mo**, an alumnus of Morgan's computational materials group, was promoted to associate professor at the University of Maryland in May 2019.

MS&E alumni also excel outside of academia.



For example, **Lizhen Tan**, who completed his master's degree in 2001 and his PhD in 2003 under Professor Wendy Crone, is

currently team lead of the nuclear structural alloys group at Oak Ridge National Laboratory.



**Maria del Carmen Lopez Garcia**, who finished her PhD in 2009 under Professor David Bebee, works in corporate research

at Kimberly Clark, and is listed on several patents for the company's leak-proof diaper technology.



Another of Crone's former students, **Max Salick**, who defended his PhD dissertation in 2014, was a recipient of

STAT Wunderkind Award in 2017 for his groundbreaking work on building artificial brains using stem cells to better understand diseases like epilepsy. He's currently a scientist with Insitro, where he's continuing his work on using stem cells for disease modeling and drug discovery.

## Malcom Clark earns Erroll B. Davis award from Alliant Energy

For Malcom Clark, dedication to his engineering research has paid off—and his 2019 Alliant



Energy/Erroll B. Davis, Jr. Academic Achievement Award recognizes his hard work.

Clark, a 22-year-old Madison native, is one of two UW-Madison College of Engineering students to win the award. The awards are given each year to recognize the academic and community service from engineering and business students from traditionally underrepresented groups at UW-Madison and UW-Platteville.

"It means a lot," says Clark, who is going into his fifth year at UW-Madison. "It's nice to be rewarded for working so hard for a while and still being able to support yourself."

He's most recently been conducting research under Kumar Sridharan, a distinguished research professor in engineering physics and MS&E, to study how high-temperature alloys handle the stresses presented in nuclear reactors.

The research team heats pins and disks in a furnace to study how they react in certain environments, such as in a reactor. That testing can be done in conjunction with an array of surface treatments such as kolsterising—a process that diffuses carbon into a metal's surface to harden it.

The upshot of the work, Clark says, is to find ways to create stronger, more stable materials for enhanced performance in nuclear reactors.

Clark says he's looking forward to getting his engineering career started once he graduates and wants to use what he's learned to work with renewable energy.

"I'm really interested in the energy sector," he says. "Especially solar energy, just because I'm really interested in renewable energy. I want to, if I can, merge the two together and use what I know to move into that field."





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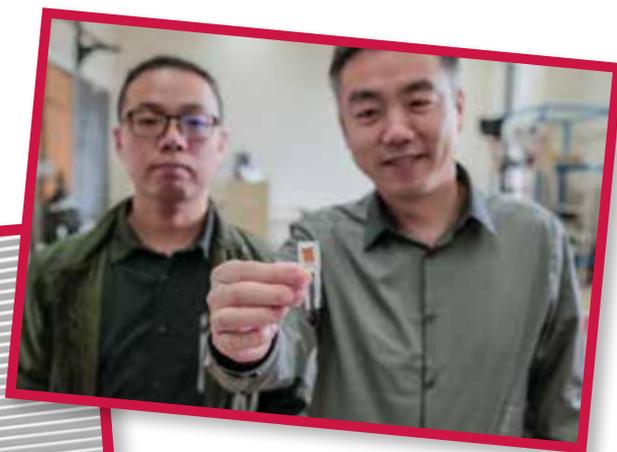
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## CONGRATULATIONS XUDONG WANG!

Professor Xudong Wang earned one of the highest honors for early-stage researchers given by the U.S. government: the Presidential Early Career Award for Scientists and Engineers. Nominated by the Department of Health and Human Services, Wang won for his research on developing small generators that harvest energy from the movement of the human body to power biomedical devices to monitor vital signs and apply treatment.



Xudong Wang with his students, demonstrating some of the energy-harvesting devices he has developed.