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MATERIALS SCIENCE AND ENGINEERING

UNIVERSITY OF WISCONSIN-MADISON

HUNTING FOR NEW PROPERTIES IN UNCONVENTIONAL MATERIALS

Paul Voyles

HELLO,

and thank you for reading this edition of our department newsletter. In the following pages, you'll find an introduction to a new faculty member in the department, Assistant Professor Jiamian Hu. His research specialty is mesoscale computational modeling of materials, especially phase field methods applied to functional and ferroic materials. You can also read about the recent successes of our undergraduate students, like Malcolm Clark, who participated in the University Research Scholars Program and won the Ian M. and Victoria R. Robertson Engineering Scholarship; our graduate students, like Laz German, who has won a fellowship from 3M Inc.; and our alumni, like Chia-Hong Jan, who was made a fellow of IEEE this year. The success of the members of the UW-Madison MS&E community is a point of great pride for me and the rest of the faculty, so please contact me if you have news to share.

I'd like to tell you about our new senior design website at projects.msae.wisc.edu. The site shows highlights of our current student design projects. This academic year we have several challenging materials science projects, including a project sponsored by Thermo Fisher Inc. to investigate electron backscattered diffraction of the microstructure and phases in welds, and a project sponsored by the Forest Products Lab to investigate using cellulosic nanomaterials to enhance the properties of epoxy nanocomposites. The website has a short video on the impact of senior design on our students, and an archive of past design projects.

The site has two ways that you can get involved with senior design in MS&E. The first is to submit an idea for a project you could sponsor. As a sponsor, a team of undergraduate students will work closely with you developing and executing a statement of work, use of research laboratory facilities, and conducting design of experiments. In the last newsletter, I discussed the enormous increase in undergraduate MS&E enrollment. It's great to have so many excellent students, but we need more interesting, engaging and practical design projects for them to work on! If your company, lab, or practice could sponsor an engineering design project, please consider submitting an idea through projects.msae.wisc.edu. There is no obligation associated with submitting an idea, but we will contact you if there is a good match between a project you submit and the interests of our students. We recently had a sponsored project that involved a multidisciplinary engineering team, so don't worry if your project requires mechanical, electrical, biomedical or other engineering fields besides materials—we can do that!

The other way to get involved is to make a donation to the newly created MS&E Design Course Fund. The design fund helps us to provide the margin of excellence that is the hallmark of a UW-Madison MS&E degree. It supports things like access to specialized, fee-for-use instrumentation; purchase of new equipment and capabilities for design projects; and events, both on campus and off campus, to enhance the design experience for our students.

There's a link at the top of the projects.msae.wisc.edu page to make a donation, or you can go right to the donation page via **go.wisc.edu/mse-design-course-fund**.

Thank you for your continued support of the department, and I hope you enjoy the rest of the newsletter.

ON, WISCONSIN!

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The Division of Continuing Studies, which manages UW-Madison's Advance Your Career portal, has launched a new campaign to promote 21 online and accelerated engineering degrees. These expanded offerings enable us to better serve both traditional and adult students.

LEARN MORE: advanceyourcareer.wisc.edu/engineering/

JIAMIAN HU: USING COMPUTER MODELS TO IMPROVE MATERIALS FOR MANY APPLICATIONS

For materials scientist Jiamian Hu, the culture of interdisciplinary research collaboration at the UW-Madison is a major selling point for the university.

"That's actually one of the very important reasons that I wanted to come to Wisconsin," says Hu, who is joining the MS&E faculty. "I found that the collaboration barrier here is very low. It's a very interdisciplinary culture here within the college and across the entire university."

That low barrier for collaboration is especially attractive for Hu because his research centers on computational modeling, and in that field: "Collaboration is basically everything to us," Hu says.

Computational models need to be validated by experiments, and in return, modeling can provide guidance to experiments on how to achieve or optimize a desirable property or functionality.

An award-winning researcher of inorganic materials, Hu was hired through the college's Grainger Institute for Engineering. He comes from Tsinghua University in China via a post-doctoral stint at Penn State.

Hu primarily studies the properties of inorganic materials using the computational modeling method known as the "phase-field" method. He models the evolutional microstructure of materials—structures that are larger than the atomic scale but small enough that the naked eye cannot discern them.

"We call it the mesoscale. It typically ranges from nanometers to microns," says Hu. "Through computer modeling, we find how you can arrange a microstructure in such a way that a material will have the functionalities or properties you need. So basically, we are trying to make existing materials much better."

Those materials include everything from metals to polymers, and from soft materials to ceramics.

Hu is especially excited about the prospect of collaborating with current MS&E faculty like Professor Dane Morgan and Professor Izabela Szlufarska, who also do computational modeling, but on different time and spatial scales than Hu's microstructure-focused models.

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"I'm excited to see if we can collaborate and do some multi-scale modeling of materials," says Hu.

To date, most of Hu's phase-field method research has modeled the magnetoelectric properties of materials that are a combination of magnets and ferroelectric materials. Hu says these materials have unique properties that open up new opportunities for electronics.

"Addressing these materials almost does not require any electric currents, which means the heat production is minimal," Hu says. "That enables us to potentially produce many different types of energy-efficient devices that could eventually save a large amount of energy for our industry."

Additionally, the materials offer a method for converting magnetic fields into electric fields, and vice versa, for all sorts of potential applications. These range from new and much less cumbersome medical imaging equipment to smaller, more powerful and more energy-efficient electronic devices.

Hu plans to continue pursuing his research into magnetoelectric materials, but he also plans to expand his computational modeling methods to other materials and applications while at UW-Madison.

"In the future I'm planning not to limit myself into a specific area because I'm treating my phase-field model as a tool," Hu says. "The tool can describe a microstructure and its evolution dynamics in any material system."

In addition to his research, Hu may teach thermodynamics and kinetics of materials. He says he's excited to share his knowledge and experience on a wide variety of topics with students.

"Hopefully I can teach other courses eventually, as well," he says. "Teaching is the best way to learn, and Wisconsin also has a lot of resources for teaching and designing courses. It's very cool how many resources Wisconsin has for teaching, learning and research."

HUNTING FOR NEW PROPERTIES IN UNCONVENTIONAL MATERIALS

Graduate student Estiaque Shourov *(left)* installs an effusion cell, which is essentially a furnace for evaporating (or sublimating) ultrahigh purity elements, as graduate student Patrick Strohbeen *(center)* and Jason Kawasaki look on.

For the microelectronics industry, ferroelectric materials are attractive for a variety of applications, including making computer memory.

Random access memory (RAM) made out of ferroelectric materials—materials that have a spontaneous electric polarization that can be switched by applying an electric field—is able to retain its information when the power is turned off, allowing for long-term data storage.

“With most of the computer RAM today, you have to constantly apply power to the device, and as soon as you remove the power, you lose the information,” says Assistant Professor Jason Kawasaki. “Ferroelectric materials provide a way to make a nonvolatile memory element, meaning you don’t have to apply power to retain a stored bit.”

The vast majority of materials that display ferroelectricity are oxide-based materials, and Kawasaki says researchers have therefore narrowly focused on oxide materials in their search for ferroelectrics since they align with the conventional wisdom of what’s required for a material to be ferroelectric.

However, Kawasaki is challenging convention in his search for new ferroelectric materials. With funding from the Army Research Office Young Investigator Program, Kawasaki will look for ferroelectric properties in material classes beyond the oxides—specifically in a class of intermetallic compounds called hexagonal Heusler compounds.

“Our work will investigate new classes of potentially ferroelectric materials that we can use for nonvolatile, low-energy-consumption, fast-switching memory applications,” Kawasaki says. “The mechanisms for ferroelectricity are predicted to be quite different in Heuslers than in oxides. Demonstration of a ferroelectric Heusler would enhance our understanding of ferroelectricity in general, and enable smaller, faster, and more energy-

Jason Kawasaki transfers a sample into the molecular beam epitaxy system for film growth.

Photos: Stephanie Precourt

efficient devices than are possible with current materials."

Researchers have conducted calculations that suggest Heusler compounds could have ferroelectric properties. But, so far, scientists have failed to experimentally demonstrate ferroelectricity in these compounds due to the challenges involved in synthesizing and stabilizing them.

"In some cases the materials we want simply can't be found in nature. They aren't stable. For the ones that are stable, controlling the composition and crystalline defects are big challenges," Kawasaki says.

Kawasaki will attempt to overcome these challenges by using a technique called molecular beam epitaxy, which he likens to spray-painting with atoms, to grow Heusler compounds.

Kawasaki is particularly interested in new phenomena that crop up in artificially layered heterostructures in which layers of different functionality are combined, and new properties emerge at their interfaces.

"Once you grow a crystal with a very desirable property, the really interesting properties emerge when you start mixing and matching layers with different functionality," he says.

Kawasaki says a prime example is the case of the oxide materials strontium titanate and lanthanum aluminate. Separately these two materials are insulators, but when sandwiched together they form a two-dimensional metal at their interface that even becomes superconducting at low temperature. Kawasaki is searching for similar phenomena in Heusler compounds.

"One of the holy grails in the oxide community has been finding multiferroic materials, materials that are simultaneously magnetic and ferroelectric, and working with Heusler compounds might be another system where we could potentially find these novel counterposed properties," he says.

Undergraduate research experience fuels student's SUCCESS

While in high school at Madison West, Malcolm Clark first learned about the field of materials science and was intrigued by the potential applications of new and improved materials.

As he was exploring engineering majors at UW-Madison, Clark says meeting Professor Paul Voyles and other faculty members and learning about opportunities in the department cemented his decision to major in materials science and engineering.

And Clark didn't waste any time taking advantage of research opportunities. Through the Undergraduate Research Scholars Program, he began working in Voyles' lab as a freshman. "It was really great to be able to get early research experience in my field of study," Clark says. "It gave me hands-on learning experiences as well as the chance to explore different aspects of materials science to see what areas I may want to pursue."

Working with a graduate student, Clark used a vapor deposition method to grow thin films. He used a scanning electron microscope to study the films, and investigated ways to create ultra-stable thin films.

Clark explains his research experiences gave him a deeper understanding of concepts from his classes. "It was nice to see how the things I was learning about in class applied to the hands-on work I was doing and to real-world applications," he says.

And his hands-on learning experiences went beyond the research itself. The deposition system Clark was using for the research needed various equipment upgrades and repairs, and he ended up spending a lot of time in the machine shop, where he produced new parts for the system while learning machining on the fly.

"I actually got a lot of my passes in the machine shop for this research project," he says. "I'm going to be able to use machining in a lot of engineering areas, so it was helpful to get ahead in those skills as well."

Clark, who is a sophomore, recently received the Ian M. and Victoria L. Robertson Engineering Scholarship, which awarded him $3,000 to help fund his education.

Clark says the scholarship is a big help, especially since he has a twin brother who attends UW-Stevens Point. He says that because his parents weren't able to save a lot of money for two college funds, the scholarship helps ease some of the financial burden. "It helps knowing my parents can help my brother out with money and not have to worry as much about me," he says. "And it takes a burden off me, allowing me to just focus on my education, and I'm very grateful for that."

Stephanie Precourt

FELLOWSHIP GIVES STUDENT FREEDOM TO EXPLORE RESEARCH INTERESTS

Graduate student Laz German has been awarded a 3M Fellowship. The three-year fellowship, which is funded by 3M and selected by the department's graduate committee, gives German financial freedom to pursue research that he is most excited about. And in the lab of his advisor, Associate Professor Xudong Wang, there is a lot that German is excited about.

German's research deals with photoelectrochemical devices, which are the interfaces between two materials of dissimilar composition at which electrochemical reactions take place. The electrochemical differences between the materials at these interfaces creates potential energy.

German uses software to create predictive models of energy-harnessing experiments and then investigates how those models match up with results from existing theories. In doing so, he informs how to capture energy more efficiently so that it can be used to as a renewable fuel source.

German also works on piezoelectric devices, which convert the mechanical energy from pressure into electricity. These devices have the potential to harness the mechanical energy from body movement, low-speed wind, and low-level vibrations such as sound waves so that it can be used in other applications ranging from wearable technologies to power-generating sidewalks.

Besides research, German juggles class and teaching. The support he receives from the 3M Fellowship for his work in Wang's lab allows German to hone his understanding of the fundamentals of solid state physics and electrochemical systems. "I can apply what I've learned in class and independently, which helps me in the lab and in my teaching," says German.

He has yet to solidify his career goals, but he is confident that the work he is doing will allow him to be professionally malleable.

The 3M fellowship allows German to explore different options that can help narrow down what he might want to do professionally. It's an opportunity to discover his interest and find his passion. "It's about the journey," says German.

Photos: Stephanie Precourt

Laz German uses a potentiostat to control the voltage between two electrodes in an electrochemical experiment.

Sindo Kou wins TMS award for best paper

Professor Sindo Kou won the 2016 TMS Light Metals Magnesium Best Paper—Application award. The award recognizes the individual excellence of a paper in the area of application of science in solving a practical problem, published in the preceding year's volume of Magnesium Technology. Kou co-authored the winning paper, "Effect of filler wires on cracking along edages of magnesium welds," with Tao Tuan of Tianjin University and Xiao Chai, of Novelis Global Research and Technology Center. Kuo received his award at the Magnesium Keynote Session on Feb. 27, 2017, at the 146th TMS Annual Meeting in San Diego, California.

ARNOLD RECEIVES ROMNES FACULTY FELLOWSHIP

Associate Professor Michael Arnold is among the 11 promising young members of the UW–Madison faculty who have been honored with Romnes Faculty Fellowships in 2017.

Romnes awards recognize exceptional faculty members who have earned tenure within the last six years. The awards are supported by the Wisconsin Alumni Research Foundation (WARF).

The award is named for the late H.I. Romnes, former chairman of the board of AT&T and former president of the WARF Board of Trustees.

Arnold's research interests include overcoming longstanding challenges in the synthesis and integration of electronic nanomaterials (particularly semiconducting carbon nanotubes and graphene), with promise for extending Moore's law; developing faster, more energy efficient computer chips; and creating higher-bandwidth cellular communication, Wi-Fi, and Internet of Things devices. Arnold teaches fundamental courses in materials transport phenomena and electronic properties of materials.

In 2016, Arnold and his collaborators achieved a major milestone in nanotechnology by making carbon nanotube transistors that, for the first time, surpassed state-of-the-art silicon transistors.

THREE GRAD STUDENTS WIN M&M SCHOLAR AWARDS FOR OUTSTANDING PAPERS

The Microscopy Society of America and the Microanalysis Society recognized three graduate students for contributing outstanding papers for the 2017 Microscopy & Microanalysis (M&M) meeting. Congli Sun, Chenyu Zhang and Pei Zhang, all members of Professor Paul Voyles' research group, each received M&M student scholar awards.

Sun was honored for his paper, "Identification and quantification of boron dopant sites in antiferromagnetic chromium(III) oxide films by electron energy loss spectroscopy." His research aims to identify and quantify boron dopants in possible lattice positions of chromium(III) oxide that potentially increase the magnetic ordering temperature of chromium(III) oxide.

Chenyu Zhang won the award for his paper, "Joint denoising and distortion correction for atomic column detection in scanning transmission electron microscopy images." In this research, he focuses on applying Bayesian method to directly identify atom positions from noisy scanning transmission electron microscopy images, which enables a higher precision level in image analysis and lower electron dose during image acquisition.

Pei Zhang won the award for her paper, "Atomic-scale relaxation dynamics in the supercooled liquid state of a metallic glass nanowire by electron correlation microscopy." In this research, she reports a visualization of the heterogeneous relaxation at atomic scale in the supercooled liquid state of Pt-based metallic glass nanowire via a time-resolved coherent electron scattering. This finding is important to understanding the dynamics when cooling from an equilibrium liquid state towards a non-equilibrium glassy state.

The award includes complimentary student registration for the full M&M 2017 meeting and financial support of up to $1,000 to help defray expenses to attend the meeting.

Congli Sun

Chenyu Zhang

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Alumnus Chia-Hong Jan elected fellow of IEEE

The Institute of Electrical and Electronics Engineers (IEEE) has named Chia-Hong Jan (MSMS&E '88, PhDMS&E '91) among its 2017 class of fellows. The honor recognizes Jan for his leadership in developing low power logic technologies for system-on-chip (SoC).

Jan, of Portland, Oregon, is an Intel senior fellow and the director of high-performance computing and SoC technology integration for the Technology and Manufacturing Group at Intel Corporation. He is responsible for Intel's most advanced process technology development for next-generation CPUs used in high-performance and SoC product segments, including data center, cloud server, desktop, laptop, notebook, tablet, smartphone, application-specific integrated circuits, field-programmable gate arrays and wireless communication products.

Jan holds more than 60 patents worldwide in the fields of semiconductor manufacturing process and integration. He has published more than 40 technical papers related to CMOS processing technology. Jan has received three Intel Achievement Awards and was honored with the UW-Madison College of Engineering's Distinguished Achievement Award in 2008.

The IEEE is the world's foremost professional association for advancing technology for humanity. With more than 400,000 members from 160 countries, the association is a leading authority on a wide variety of areas ranging from aerospace systems, computers and telecommunications to biomedical engineering, electric power and consumer electronics.

IEEE fellows comprise top one-tenth of one-percent of the total membership, an honor bestowed by the Board of Directors only to researchers with outstanding records of accomplishment.

Photo courtesy of Chia-Hong Jan