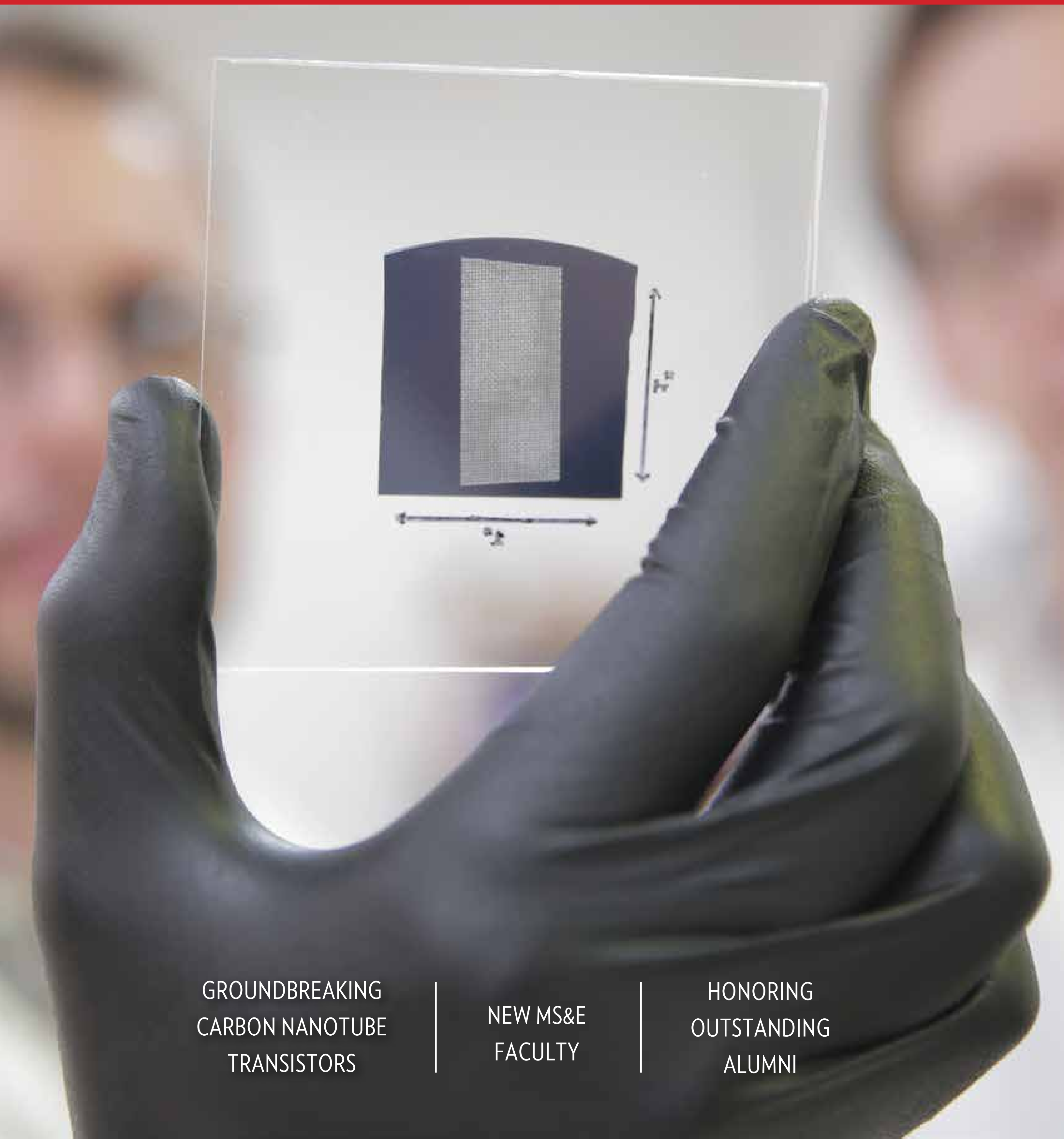
FALL 2016

MATERIALS SCIENCE AND ENGINEERING

UNIVERSITY OF WISCONSIN-MADISON



GROUNDBREAKING CARBON NANOTUBE TRANSISTORS

NEW MS&E FACULTY

HONORING OUTSTANDING ALUMNI

Paul Voyles

GREETINGS!

I was recently appointed faculty chair of the Department of Materials Science and Engineering, and I'd like to take this opportunity to introduce myself and share some department news with you.

I joined the department in 2002 as an assistant professor. My research is in the structure of materials, primarily in electron microscopy, covering metals, ceramics, and nanomaterials. My teaching is primarily in undergrad and graduate lab courses, and I really enjoy the many opportunities to interact with our outstanding students while teaching labs.

I'm pleased to announce that we've hired two new faculty members—Jason Kawasaki and Jiamian Hu. You can read about Jason's background and interests on page 5; look for a profile of Jiamian in a future newsletter. And the department is continuing to grow—we're looking to hire additional faculty members through the Grainger Institute for Engineering. Our undergraduate enrollment is also growing; our largest undergraduate class in decades started this fall. The department has done a great job generating interest in materials science and engineering, and we're excited by the opportunity to educate more students in the discipline.

Big and exciting changes are also now happening at the graduate level with the merger of the Materials Science Program and the materials engineering graduate programs. This merger presents an opportunity for us to build on the interdisciplinary character of the Materials Science Program combined with the rigor of the materials engineering degree. It rebrands the graduate materials experience at Wisconsin as solidly within the department, builds better connections between the graduate and undergraduate programs, and helps us with recruiting students and faculty.

As you'll read in this publication, we are accomplishing great things and it's an exciting time for the department. Your engagement and support will help us build on our successes and enhance our students' educational experience.

If you are ever in Madison, I invite you to stop by and say hello. I'd like to meet you, and (with a little advance notice) the department can arrange a tour of our labs, conversations with some of our undergraduates, or other activities that suit your interests. Lastly, support from our alumni makes a tremendous difference and is greatly appreciated. Please consider supporting your alma mater by making a gift online at **allwaysforward.org/giveto/mse**.

Thank you for your continued support of our department. ON, WISCONSIN!

Paul

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Longtime engineering dean passes away

As dean of the College of Engineering and a professor of materials science and engineering, Paul Peercy constantly sought ways to help students succeed in engineering. In ongoing efforts to educate "global" engineers, he focused on diverse and interdisciplinary experiences, innovations in teaching engineering, and on hands-on work that connected the technical aspects of engineering students' education with real challenges facing society. "Engineering is where science meets society," he said in a 2012 interview, referring to myriad global challenges, including energy needs and pollution. "These are problems that can't be solved without engineers and can't be solved by engineers alone."

Peercy, who served as dean from 1999 until his retirement 2013, died Oct. 20, 2016, after a lengthy illness.

Read more and learn how you can make a gift in Peercy's memory that helps carry on his commitment to undergraduate education here: **go.wisc.edu/peercy-passes-away**.

Stephanie Precourt

The UW–Madison engineers use a solution process to deposit aligned arrays of carbon nanotubes onto 1 inch by 1 inch substrates. The researchers used their scalable and rapid deposition process to coat the entire surface of this substrate with aligned carbon nanotubes in less than 5 minutes.

FOR THE FIRST TIME, CARBON NANOTUBE TRANSISTORS OUTPERFORM SILICON

For decades, scientists have tried to harness the unique properties of carbon nanotubes to create high-performance electronics that are faster or consume less power—resulting in longer battery life, faster wireless communication and faster processing speeds for devices like smartphones and laptops.

But a number of challenges have impeded the development of high-performance transistors made of carbon nanotubes, tiny cylinders made of carbon just one atom thick. Consequently, their performance has lagged far behind semiconductors such as silicon and gallium arsenide used in computer chips and personal electronics.

Now, for the first time, UW–Madison materials engineers have created carbon nanotube transistors that outperform state-of-the-art silicon transistors.

Led by Michael Arnold and Padma Gopalan, professors of materials science and engineering, the team's carbon nanotube transistors achieved current that's 1.9 times higher than silicon transistors. The researchers reported their advance in a paper published Sept. 2, 2016, in the journal *Science Advances*. "This achievement has been a dream of nanotechnology for the last 20 years," says Arnold. "Making carbon nanotube transistors that are better than silicon transistors is a big milestone. This breakthrough in carbon nanotube transistor performance is a critical advance toward exploiting carbon nanotubes in logic, high-speed communications, and other semiconductor electronics technologies."

This advance could pave the way for carbon nanotube transistors to replace silicon transistors and continue delivering the performance gains the computer industry relies on and that consumers demand. The new transistors are particularly promising for wireless communications technologies that require a lot of current flowing across a relatively small area. "In our research, we've shown that we can simultaneously overcome all of the big challenges of working with nanotubes, and that has allowed us to create these groundbreaking carbon nanotube transistors that surpass silicon and gallium arsenide transistors," says Arnold.

The researchers benchmarked their carbon nanotube transistor against a silicon transistor of the same size, geometry and leakage current in order to make an apples-to-apples comparison.

They are continuing to work on adapting their device to match the geometry used in silicon transistors, which get smaller with each new generation. Work is also underway to develop high-performance radio frequency amplifiers that may be able to boost a cellphone signal. While the researchers have already scaled their alignment and deposition process to 1 inch by 1 inch wafers, they're working on scaling the process up for commercial production.

Arnold says it's exciting to finally reach the point where researchers can exploit the nanotubes to attain performance gains in actual technologies.

"There has been a lot of hype about carbon nanotubes that hasn't been realized, and that has kind of soured many people's outlook," says Arnold. "But we think the hype is deserved. It has just taken decades of work for the materials science to catch up and allow us to effectively harness these materials."

Padma Gopalan

TWO MS&E ALUMS RECEIVED COLLEGE OF ENGINEERING AWARDS DURING THE ENGINEERS' DAY CELEBRATION NOV. 11, 2016

*Read even more about our recipients: **www.engr.wisc.edu/eday***

DISTINGUISHED ACHIEVEMENT AWARD

BOYD MUELLER

Vice President of Technology
Alcoa Power and Propulsion
MSMetE '83, PhDMetE '86
(BSMetE '82, Michigan Technological University)

How did you choose to attend college at UW-Madison?
I'm originally from Wisconsin; I was born a Badger. I attended Michigan Technological University in Houghton for my undergrad, and through some professors there I became aware of Professor Perepezko. Because of the reputation of the UW and John's reputation, that led me to select UW-Madison for my graduate studies.

What's your fondest memory of your time on campus?
It was a special time in my life in that I got married after my first year at UW-Madison. My wife and I both enjoyed living in Madison, taking bike rides and walks along the lake. That, and the freedom to conduct research and development in areas that fascinated me are both memories I have of my time at UW.

Why did you choose engineering as your major?
Coming out of high school, I thought I wanted to be a chemical engineer, but then some of the professors at Michigan Tech convinced me to go into materials, and I'm certainly glad I did. ... Materials engineering is an extremely diverse field, and it touches basically everything we use.

When you were a student, what was your favorite place to eat (or hang out) on campus?
Every time I get back on campus I still go to the Union and get ice cream.

Of what professional accomplishment are you most proud?
I would say there are two. First, in the early to mid part of my career I had the opportunity to work with a number of researchers from different companies, universities and also national labs on DARPA-funded programs. When I think back to those programs, they laid part of the foundation for things that are still going on today in the integrated computational materials engineering area. We took a number of theoretical models and databases, and integrated those into a software suite that we applied to solidification

EARLY CAREER AWARD

NICHOLAS BALSTER

Vice President of Industrial
Groom Energy Solutions
BSMS&E '00
(MBA '13, Babson College)

Who was your favorite UW-Madison engineering professor?
Frank Fronczak in mechanical engineering taught an introduction to engineering course my freshman year. He really confirmed that I was in the right program and got me excited about engineering. ... He encouraged us to think creatively and utilize some of the skills that we already had. The other favorite is the guy who nominated me for this award—John Perepezko. He taught a foundational course that solidified for me that materials science and engineering was the discipline I wanted to pursue. The course was a prerequisite for a lot of other courses. He was a very enthusiastic instructor.

What lesson learned as a student has benefited you most in your career?
One of the tenets that was drilled into me by a professor named Fred Bradley was the notion that in the course of a career, you're going to have to constantly change and figure things out, and figuring things out as a sort of mantra has been very true of my career path, and also one of the single most valuable lessons that I walked off campus with. Typically, engineers walk off campus with all sorts of problem-solving techniques and then get plopped into environments and have to figure out how a team functions and business works. Being able to handle that depends on figuring things out even if they're very murky in the beginning.

What was your favorite engineering class?
I studied abroad my junior year in Munich, and I took an elective with an awesome professor who I'm sure has passed away now. His name was Professor Tensi, and he taught a course on diffusion. The reason I loved this class was a combination of this guy and the material: Diffusion is a fundamental process in materials processing. I ended up taking two more courses from Professor Tensi because he just engaged in a really brilliant way with students.

Who played the greatest role in your achievements?
My parents. They have been a strong support team my entire life. They provided me with resources and opportunities to achieve most of what I have achieved in my life. They made sacrifices and worked very hard. Both deserve substantial credit.

What advice would you give students in your discipline today?
I would say innovate. There are some things that I learned in my career that I don't think there's a reason that students in the College of Engineering or other disciplines couldn't or

problems. It really moved us forward in the application of science to industrial engineering problems. These programs pulled together a very diverse group of research including university, national lab and industrial researchers to work together toward a common goal.

The other accomplishment is leading the research group at Alcoa Power and Propulsion to bring new technologies to the market—technologies that are used on the latest, most fuel-efficient and environmentally friendly aircraft engines for planes such as the Joint Strike Fighter, Airbus A320 NEO, Boeing 737 MAX, aircraft not yet in service such as the Boeing 777X and the Airbus A330 NEO, and also for land-based power-generation turbines. Seeing things that you work on have an impact at a global scale is very rewarding.

What are your hobbies/interests?

I enjoy spending time and traveling with my family, fishing and hiking. My daughter lives in Colorado and when we visit we hike the Rockies. We also very much enjoy traveling, especially to Europe—going there for the history and the different cultures.

shouldn't learn. It goes back to Fred Bradley and his "keep figuring things out" mantra. My read is that people who will be the most successful are those who can fail fast, move forward and never stop innovating in themselves and thinking. The level of innovation that occurs today versus when I was on campus is very different and students would do well to sort of accept and try to master a continuous innovation or improvement mindset.

What are your hobbies/interests?

I'm a big road bicyclist. I like general fitness and staying fit. I love spending time with my family and try to do as much free reading as I can. I read a pretty broad smattering of stuff. I don't read a ton of fiction. Traveling would be the other thing. I like traveling quite a bit. I just went to visit one of my friends in eastern China over the summer and I still love Munich. I think Munich is my favorite city on the planet.

Is there anything else you'd like to tell us about yourself?

I'd like to give a family shout-out to my wife and kids. I'm the fortunate husband of Ali and the proud father of Katie, Lyla and Jackson.

JASON KAWASAKI

Uncovering new phenomena in electronic materials

Jason Kawasaki grows and refines new functional electronic materials not only to uncover new and interesting properties, but also to observe how these properties can revolutionize practical devices.

Kawasaki, who joined UW-Madison as an assistant professor of materials science and engineering in fall 2016, uses a method called molecular beam epitaxy (MBE), which he likens to spray-painting with atoms, to grow Heusler compounds.

"Heuslers are a family of ternary alloys that display both metallic and insulating behavior, magnetism, superconductivity, shape-memory effect, topological states and large thermoelectric figures of merit," Kawasaki says. "These properties make the Heuslers an exciting playground for investigating novel phenomena, especially in artificially layered heterostructures in which layers of different functionality are combined, and new properties emerge at their interfaces."

MBE is the process through which high-purity elemental precursors undergo evaporation in an ultrahigh vacuum. Researchers can observe this process in real time, using tools such as electron diffraction to monitor growth dynamics at each atomic layer. Based on that information, Kawasaki and his group can refine the process by stabilizing certain phases of growth, therefore ultimately creating a more effective final product.

All of his group's tools and probes are aimed at studying the atomic and electronic structure of these materials and fine-tuning their properties.

"Much of our work is quite fundamental, learning ways to grow high quality crystalline films and expand their library of properties," Kawasaki says. "But we also have an eye for how these properties can be used to make devices—for example, thermoelectric modules and magnetic memory (the storage of data on a magnetized medium)."

Kawasaki began his education at Princeton University, from which he graduated in 2009 with a bachelor of science degree in mechanical engineering and a minor in materials science. Through his early research in crystal growth as an undergraduate, he became especially interested in epitaxial electronic materials. He received his PhD in materials science in 2014 from the University of California, Santa Barbara, where he conducted research on the growth of compound semiconductors and low dimensional metallic nanostructures for thermoelectric applications.

Before joining UW-Madison, Kawasaki was a postdoctoral fellow at the Kavli Institute for Nanoscale Science at Cornell University, working with oxide materials that have strong electron-electron correlations and spin-orbit coupling. He is now continuing his research and developing a lab in the College of Engineering.

"I was drawn to UW-Madison's long history of excellence in materials engineering and metallurgy, as well as the top-notch faculty, students and research facilities," he says. "I was impressed by the levels of collaboration in research, both within the Department of Materials Science and Engineering, and more broadly in engineering and the sciences, and I saw Madison as a great future home."

Kawasaki is also looking forward to educating the next generation of engineers, with an interest in not only graduate and undergraduate students, but K-12 students as well.

MOVE OVER SOLAR:

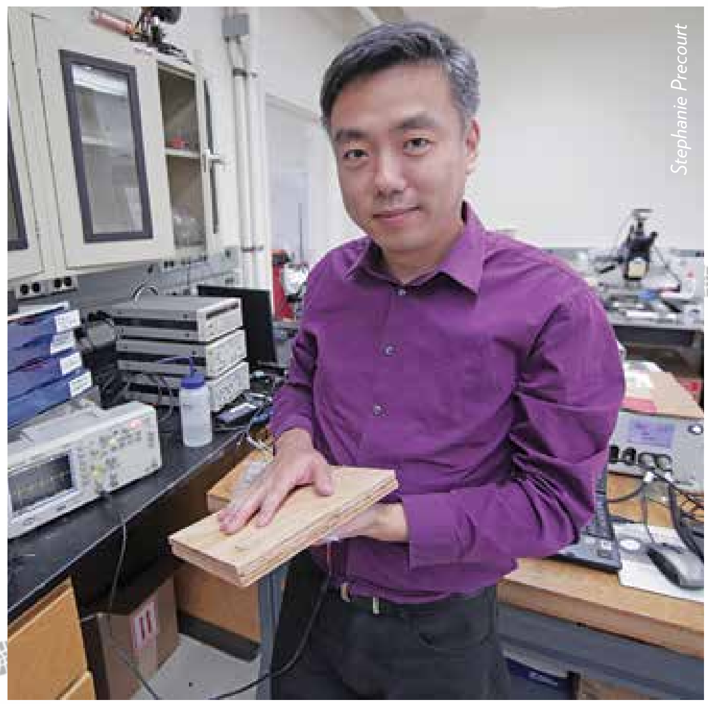
The next big renewable energy source could be right beneath your feet

Flooring can be made from any number of sustainable materials, making it an eco-friendly option in homes and businesses alike.

Now, however, flooring could be even more “green,” thanks to an inexpensive, simple method developed by UW-Madison materials engineers that allows them to convert footsteps on the flooring into usable electricity. Associate Profesor Xudong Wang, his graduate student Chunhua Yao and their collaborators published details of the advance on Sept. 24, 2016, in the journal *Nano Energy*.

The method puts to good use a common waste material: wood pulp. The pulp, which is already a common component of flooring, is partly made of cellulose nanofibers. They're tiny fibers that when chemically treated produce an electrical charge when they come into contact with untreated nanofibers. When the nano fibers are embedded within flooring, they're able to produce electricity that can be harnessed to power lights or charge batteries. And because wood pulp is a cheap, abundant and renewable waste product of several industries, flooring that incorporates the new technology could be as affordable as conventional materials.

While there are existing similar materials for harnessing footstep energy, they're costly, non-recyclable and impractical at a large scale.



Xudong Wang holds a prototype of the researchers' energy harvesting technology, which uses wood pulp and harnesses nano fibers. The technology could be incorporated into flooring and convert footsteps on the flooring into usable electricity.

Wang's research centers around using vibration to generate electricity. For years, he has been testing different materials in an effort to maximize the merits of a technology called a triboelectric nanogenerator (TENG). Triboelectricity is the same phenomenon that produces static electricity on clothing. Chemically treated cellulose nanofibers are a simple, low-cost and effective alternative for harnessing this broadly-existing mechanical energy source, Wang says.

The UW-Madison team's breakthrough is the latest advance in a green energy research field called “roadside energy harvesting” that could, in some settings, rival solar power—and it doesn't depend on fair weather. Researchers like Wang who study roadside energy harvesting methods see the ground as holding great renewable energy potential well beyond its limited fossil fuel reserves.

“Roadside energy harvesting requires thinking about the places where there is abundant energy we could be harvesting,” Wang says. “We've been working a lot on harvesting energy from human activities. One way is to build something to put on people, and another way is to build something that has constant access to people. The ground is the most-used place.”

Heavy traffic floors in hallways and places like stadiums and malls that incorporate the technology could produce significant amounts of energy, Wang says. Each functional portion inside such flooring has two differently charged materials—including the cellulose nano fibers, and would be a millimeter or less thick.

The floor could include several layers of the functional unit for higher energy output.

“So once we put these two materials together, electrons move from one to another based on their different electron affinity,” Wang says.

The electron transfer creates a charge imbalance that naturally wants to right itself; but as the electrons return, they pass through an external circuit. The energy that process creates is the end result of TENGs.

Wang says the TENG technology could be easily incorporated into all kinds of flooring once it's ready for the market. He is now optimizing the technology, and he hopes to build an educational prototype in a high-profile spot on the UW-Madison campus where he can demonstrate the concept. He already knows it would be cheap and durable.

“Our initial test in our lab shows that it works for millions of cycles without any problem,” Wang says. “We haven't converted those numbers into year of life for a floor yet, but I think with appropriate design it can definitely outlast the floor itself.”

The Wisconsin Alumni Research Foundation holds the patent to the technology. Other authors on the paper include Zhiyong Cai of the Forest Products Laboratory and UW-Madison graduate students Alberto Hernandez and Yanhao Yu. The Forest Products Laboratory and National Science Foundation provided funding for the research.

WHITE HOUSE PUTS MATERIALS INITIATIVE SPOTLIGHT ON UW-MADISON RESEARCH

Harvey D. Spangler Professor **Dane Morgan** joined researchers from around the country at the White House in August to celebrate five years of the Materials Genome Initiative (MGI).

President Barack Obama announced the Materials Genome Initiative in 2011 to help businesses discover, develop, and deploy new materials twice as fast, aiming to speed the path to lightweight cars, more efficient solar cells, tougher body armor and new spacecraft.

Federal agencies have invested more than $500 million in research and infrastructure to achieve that goal, creating both new materials and databases of materials for researchers to comb through in search of the properties that best fit their needs.

The White House Office of Science and Technology Policy featured successful research at MGI's anniversary meeting, including two initiative-funded projects at UW–Madison:

- Successfully combining computational modeling and experimentation helped a group led by **Chang-Beom Eom**, Theodore H. Geballe Professor and Harvey D. Spangler Distinguished Professor, to create a new crystalline material that both conducts electricity like a metal and impedes the flow of electrons like an insulator. Combining contradictory properties in one material will help make devices that perform simultaneous electrical, magnetic and optical functions. The work is supported by NSF and Department of Energy grants.

- **Morgan**'s Informatics Skunkworks, launched with an NSF grant, is teaching undergraduate engineering students how to use machine learning tools to extract information—for example, the factors controlling diffusion in solids or precipitation in irradiated materials—from vast pools of data. Skunkworks accelerates the educational experience by exposing undergraduates to research typically done by graduate students and to real-word problems offered up by industry partners.

Undergraduate carries on tradition of academic excellence

In 2015, Zach Jensen, a senior in materials science and engineering, received the William & Mary Dyrkacz Scholarship for his commitment to education and the materials science community, and now in 2016, he has earned two more scholarships.

Jensen received the The Minerals, Metals and Materials Society (TMS) 2017 Kaufman CALPHAD Scholarship, a competitive national scholarship that funds him to attend the annual TMS conference in San Diego. He also received the 2016 Ladish Co. Foundation Scholarship, which is awarded to a Wisconsin resident through the ASM Materials Education Foundation.

In addition to these scholarships, Jensen spent summer 2016 working at Oak Ridge National Laboratory as a part of the U.S. Department of Energy Science Undergraduate Laboratory Internship program, where he worked with laboratory scientists to synthesize electrolytes for fuel cells.

The new scholarships will support Jensen's metallurgy research. He works with amorphous aluminum alloys, modeling how they crystallize. There are several key benefits of amorphous aluminum alloys. "They have good corrosion resistance and higher strengths than crystalline aluminum," he explains.

Jensen chose UW-Madison because of its strong research programs

Corrosion resistance, for example, makes the alloys potentially useful in biological implants, while strength and lightness make them a valuable material to reduce weight and improve fuel efficiency in the automobile industry.

Jensen's goal is to optimize the crystallization temperatures of the alloys. Researchers in his lab cool the alloys down and then heat them, noting the temperatures at which they crystallize. Jensen then takes those crystallization data and runs machine-learning algorithms on them to create a model that predicts how amorphous alloys with varying relative compositions will behave. And after he creates a model, it's all about optimization—trying to get the highest crystallization temperature. In general, the higher the crystallization temperature, the more stable the alloy will be, Jensen explains.

Jensen chose UW-Madison because of its strong research programs and says that the scholarships have been particularly valuable because they have given him the opportunity to focus on school and research without having to take a second job. They have allowed him to cultivate relationships with faculty and peers that he otherwise would have been unable to cultivate. "The Department of Materials Science and Engineering is a smaller department, so you can really get to know all of the professors," Jensen says.

Jensen has cultivated relationships with Izabela Szlufarska and Dane Morgan, Harvey D. Spangler Professors in materials science and engineering. Szlufarska advises Jensen's primary research, while Morgan is the founder and advisor of Informatics Skunkworks, *(see story at left)*, which Jensen is a part of.

Jensen is on track to graduate in spring 2017 and is applying to graduate programs in materials science that emphasize renewable energy applications and computational materials science.

Throughout the University of Wisconsin System, there is a wealth of materials expertise, equipment and research facilities—but connecting those resources across campuses and between academia and industry often depends on serendipity and informally built connections.

"There are so many collaborations that come about because you met someone at a conference and they're doing something related to what you're doing or have capabilities you're looking for," says Gokul Gopal, an assistant professor of engineering physics at UW-Platteville. "It tends to happen through almost random encounters rather than a systematic portal that allows you to access information in a smoother manner."

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Connecting UW's materials resources with industry

Partners across the system are filling that void through the Regional Materials & Manufacturing Network (RM2N). On the network's website (wiscmat.org), academic and industrial partners from all over Wisconsin can list and search for the resources they have and need, to advance materials science and engineering through both academic research and the development of new products. The member campuses in the network are UW-Eau Claire, UW-La Crosse, UW-Madison, UW-Milwaukee, UW-Oshkosh, UW-Platteville, UW-Stevens Point, UW-Stout and UW-Whitewater.

While researchers on each UW System campus interact with different Wisconsin companies in different sectors of industry, the network can make all those partnerships more fruitful. "It's a way for us to help industry, for example, without saying, 'No, we can't help you because we don't have this certain type of instrument on campus,'" says Doug Dunham, director of the Materials Science Center at UW-Eau Claire. "We can still help even if it's not coming directly from us."

Thomas Kuech, the Milton J. & A. Maude Shoemaker Professor in chemical and biological engineering and MS&E, says he sees opportunities in particular for UW-Madison to share its resources and expertise more broadly, and for the partnership in general to benefit industrial partners such as those in the plastics and packaging industries."You want to make something that's more than just a bunch of parts," Kuech says. "If you follow the Wisconsin Idea, you want to provide communication and benefit to industry and the people of the state, and that's what we're trying to do with this network."

The RM2N holds meetings that feature academic and industrial speakers, and that offer opportunities for networking with materials and related manufacturing researchers in academic and industry, and students from campus affiliates. Join the RM2N email list and receive information about upcoming events here: **go.wisc.edu/rm2n-signup-info**.