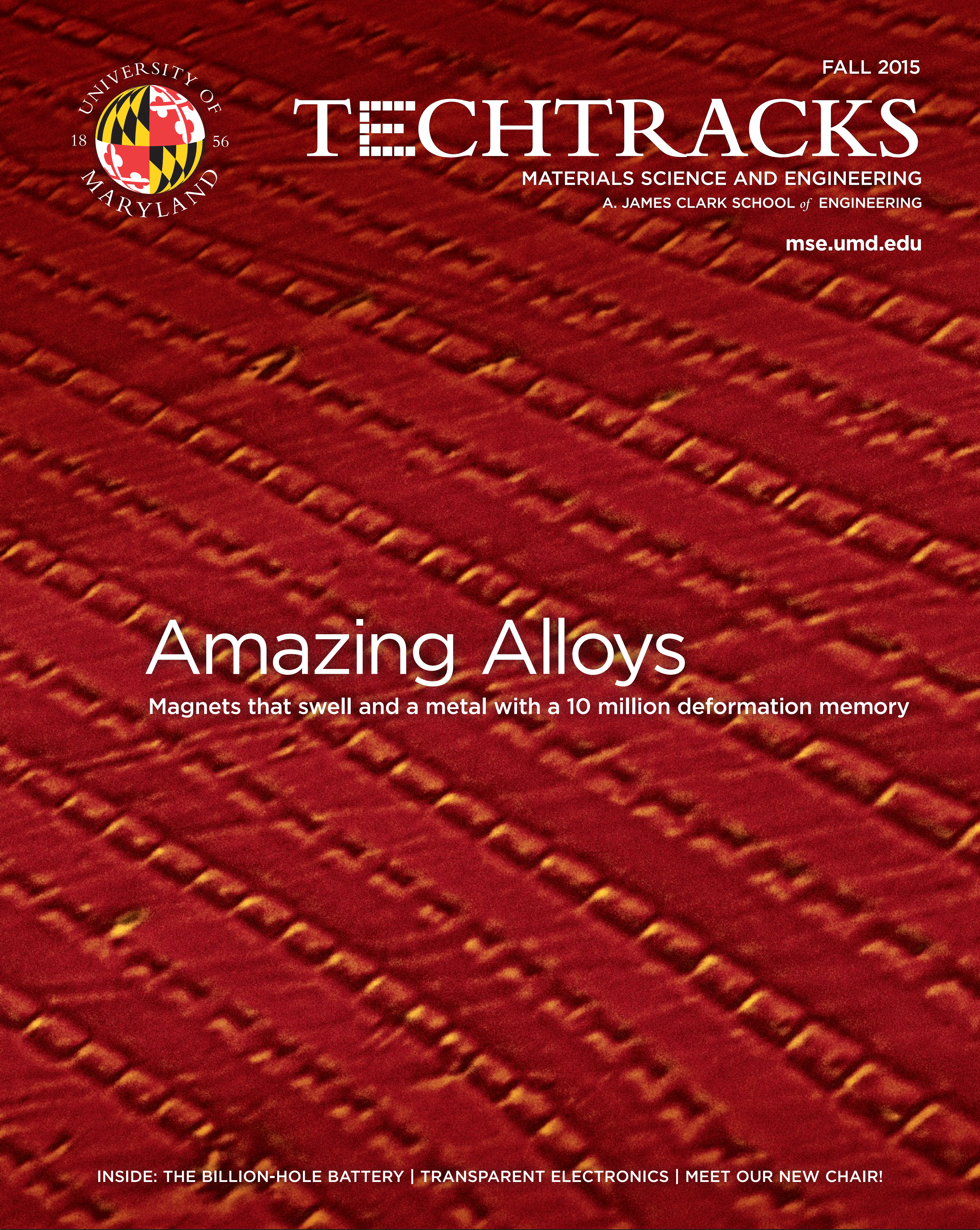


FALL 2015

TECHTRACKS

MATERIALS SCIENCE AND ENGINEERING
A. JAMES CLARK SCHOOL *of* ENGINEERING

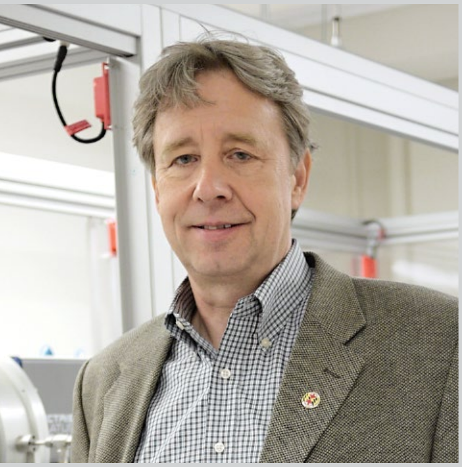
mse.umd.edu

Amazing Alloys

Magnets that swell and a metal with a 10 million deformation memory

INSIDE: THE BILLION-HOLE BATTERY | TRANSPARENT ELECTRONICS | MEET OUR NEW CHAIR!

chair's MESSAGE



IT'S BEEN A WONDERFUL 12 YEARS AS CHAIR OF THE MSE DEPARTMENT AT THE UNIVERSITY OF MARYLAND.

I stepped down this past July and have taken the position of Associate Dean for Research here in the A. James Clark School of Engineering. I look forward to remaining a faculty member in addition to tackling my new role.

When I started as Chair in July of 2003, the Department had just completed a reorganization and officially changed its name from the Department of Materials and Nuclear Engineering to the Department of Materials Science and Engineering. We had 13 professors on our faculty and about 35 undergraduates in the program. We now have 19 faculty members and 150 undergraduates. Our research expenditures have more than doubled to about $11 million per year, putting us 12th in the nation among materials departments.

"We are a unified department with a vision and a supportive environment for education and research."

Thinking back, the thing I am most proud of is the sense of community among the students, faculty and staff that we have built in the Department, all with the shared goal of teaching and knowledge creation in the field of materials. We are a unified department with a vision and a supportive environment for education and research.

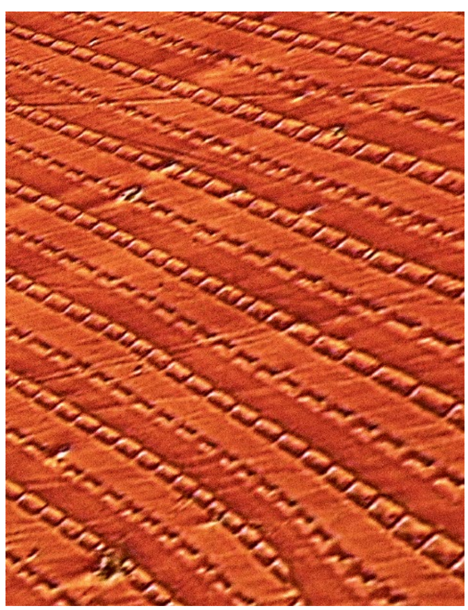
Professor **Ray Phaneuf**, who has previously served as our Graduate Program Director, has taken on the role of Interim Department Chair. I am confident that he will steer MSE toward even greater accomplishments.

As always—if you're an alumnus or alumna, you can share great news about your life and career by joining the "MSEUMD" group on Facebook, connecting with us on LinkedIn, or e-mailing us at **mse@umd.edu**. You can get the latest MSE news at any time by visiting **mse.umd.edu/news**.

Sincerely,

Robert M. Briber
Professor and Past Chair, MSE

IN THIS ISSUE:



ON THE COVER:

Never-before-seen, highly periodic magnetic 'cells' or 'domains' in an iron-gallium alloy responsible for non-Joulian magnetism. This new class of magnets, which expand in volume when placed in a magnetic field and generate negligible amounts of waste heat during energy harvesting, was discovered by MSE professor **Manfred Wuttig** and **Harsh Deep Chopra** (Ph.D. '93). Wuttig has also developed another remarkable material: a shape memory alloy so tough it withstands being bent and heated over ten million times. The discoveries were published in *Nature* and *Science,* respectively. For the story, see page 4. *Image courtesy of Harsh Deep Chopra.*

MSE.UMD.EDU | FACEBOOK.COM/MSEUMD | YOUTUBE.COM/MATERIALSATUMD

IT'S AN EXCITING TIME TO BE INVOLVED IN MATERIALS SCIENCE AND ENGINEERING—indeed many of the Grand Challenges facing society are materials-related, including alternative energy, sustainability, and engineering the tools for scientific discovery.

At the same time, our Department is on a very successful trajectory, with a number of recent noteworthy awards, grants, and high profile publications.

> "My goal as Interim Chair is to keep our department growing, and to increase our presence in strategic areas including energy, computational materials science, and technology for sustainability."

Our undergraduate students continue to show that they are among the best in the country, having won the ASM national capstone competition. Graduate student **Amy Marquardt** won the international Three Minute Thesis video competition, sweeping both the judges' prize and the Peoples' Choice. (See page 12 for the story.)

Our Department of Energy Nanostructures for Electrical Energy Storage Research Center, led by MSE Professor **Gary Rubloff**, was renewed for another four years, while a group from the University of Maryland Energy Research Center, led by MSE Professor **Eric Wachsman** and including Assistant Professor **Bing Hu**, was selected by NASA to spearhead a high profile effort to develop a new class of batteries for extreme environments.

This success is thanks to the efforts of our talented faculty and students, our dedicated staff, and the vision and commitment of our outgoing Chair, **Rob Briber**.

My goal as Interim Chair is to keep our Department on its fast-growing trajectory, and to increase our presence in strategic areas including energy, computational materials, and technology for sustainability.

Until next time,

Raymond J. Phaneuf
Professor and Interim Chair, MSE

A Billion Holes Can Make a Battery

Martha Heil and Ted Knight contributed to this story.

MSE professor and Maryland NanoCenter director **Gary Rubloff** and his colleagues have invented a tiny structure that includes all of the components of a battery, which they say could bring about the ultimate miniaturization of energy storage devices. The battery, which exhibits high energy density and excellent capacity retention, is confined to a single nanoscale pore in a thin sheet of anodic aluminum oxide.

The "nanopore" battery contains an electrolyte used to carry the electrical charge between nanotubular electrodes at either end. Rubloff and his team believe it shows promise for higher energy availability for a given power density due to a large surface area and short transport time for the ions in the electrode material.

Millions–even a billion–of these consistently shaped pores can be packed together to create a larger battery the size of a postage stamp. Their collected volume is so small that it could contain no more than a grain of sand.

MSE graduate student **Chanyuan Liu**, the first author of a paper on the work that appeared in *Nature Nanotechnology,* says that although the device is a proof of concept, it performs well. It can be fully charged in 12 minutes and recharged thousands of times. Now that the team has it working, she adds, they have also identified improvements that could make the next version ten times more powerful, and are working on mass production strategies to make it commercially viable.

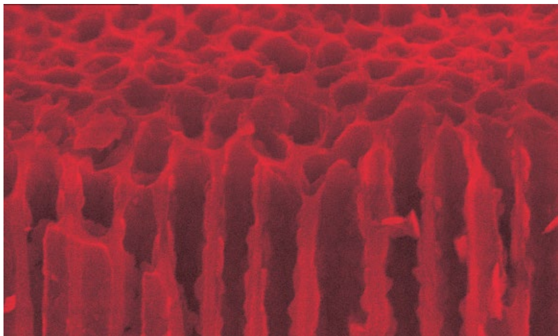
In 2015, the University of Maryland's Office of Technology Commercialization named the nanopore battery its Physical Sciences Invention of the Year.

Rubloff and Liu's collaborators included Professor **Sang Bok Lee** and graduate student **Eleanor Gillette** from the Department of Chemistry and Biochemistry, and past and present MSE graduate students **Xinyi Chen** (Ph.D. '13), **Alexander Pearse**, **Alexander Kozen** (Ph.D. '15), **Marshall Schroeder** (Ph.D. '15), and **Keith Gregorczyk** (Ph.D. '13).

This research was supported by Nanostructures for Electrical Energy Storage II, an Energy Frontier Research Center funded by the U.S. Department of Energy's Office of Science.

For More Information:

Liu et al. "An all-in-one nanopore battery array." *Nature Nanotechnology* 9, 1031–1039 (2014)



COVERstory

In 2015, Professor **Manfred Wuttig** and his colleagues introduced two transformative materials discoveries: a class of magnets that changes the way we think about a 175 year-old rule and a shape memory alloy tough enough to withstand millions of deformations. These breakthroughs have the potential to displace existing technologies and create altogether new applications due to their unusual properties.

Amazing Alloys

Magnets that swell and a metal with a 10 million-deformation memory

SWELLING MAGNETS TO ENERGIZE THE WORLD

Wuttig and his former Ph.D. student **Harsh Deep Chopra** (Ph.D. '93), now professor and chair of mechanical engineering at Temple University, discovered a new class of magnets that expand their volume when placed in a magnetic field and generate negligible amounts of wasteful heat during energy harvesting. The pair published their work, "Non-Joulian Magnetostriction," in the May 21st issue of the journal *Nature.*

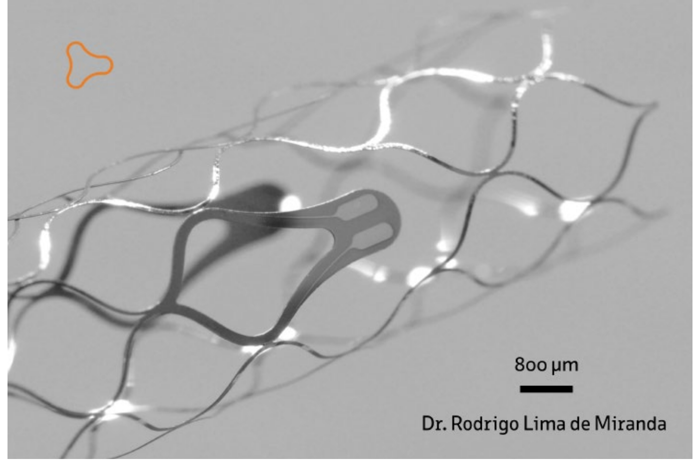
"Our findings fundamentally change the way we think about a certain type of magnetism that has been in place since 1841," says Chopra.

In the 1840s, physicist **James Prescott Joule** discovered that iron-based magnetic materials changed their shape but not their volume when placed in a magnetic field. This phenomenon is referred to as "Joule Magnetostriction," and since its discovery 175 years ago all magnets have been characterized on this basis.

"We have discovered a new class of magnets, which we call 'non-Joulian magnets,' that show a large volume change in magnetic fields," says Chopra. "These non-Joulian magnets also possess the remarkable ability to harvest or convert energy with minimal heat loss."

"The response of these magnets differs fundamentally from that likely envisioned by Joule," says Wuttig. "He must have thought that magnets respond in a uniform fashion."

Chopra and Wuttig discovered that when they heated certain iron-based alloys in a furnace at approximately 760 degrees Celsius for 30 minutes, then rapidly cooled them to room temperature, the materials exhibited the non-Joulian behavior. They also found the thermally-treated materials contained a never before seen microscopic cell-like structure whose response to a magnetic field is at the heart of non-Joulian magnetostriction.



AN IMPLANTABLE, 65µM-THICK NITINOL STENT WITH INTEGRATED FUNCTIONALITY, MADE WITH WUTTIG'S NiTiCu SHAPE MEMORY ALLOY. INTEGRATED FUNCTIONALITY ENABLES INCREASED DEVICE MINIATURIZATION BY STRUCTURING CIRCUITS ON TOP OF A FLEXIBLE, NITINOL THIN FILM. THE CIRCUITS ARE ISOLATED AGAINST THE NITINOL AND COVERED WITH A NON-CONDUCTIVE OXIDE. THIS STENT IS PRODUCED BY ACQUANDAS GmbH, A BIOMEDICAL DEVICE COMPANY LOCATED IN KIEL, GERMANY. (FOR MORE INFO, SEE ACQUANDAS.COM.)

"Knowing about this unique structure will enable researchers to develop new materials with similarly attractive properties," says Wuttig. For example, conventional magnets can only be used as actuators for exerting forces or causing displacements in one direction since they are limited by Joule magnetostriction. Actuation, even in two directions, requires bulky stacks or composites, which increase the size and reduce efficiency. Adding actuation in a third direction is even more cumbersome. Since non-Joulian magnets spontaneously expand in all directions, compact omnidirectional actuators can now be easily realized.

The magnets' energy efficient characteristics can be used to create a new generation of sensors and actuators with vanishingly small heat signatures. Since 99% of all energy conversion requires magnetism of one form or another, these magnets could find applications in energy harvesting devices; compact micro-actuators for aerospace, automobile, biomedical, space and robotics applications; and ultra-low thermal signature actuators for sonar and defense applications. Since they are free of rare earth elements, they could also replace existing rare earth-based magnetostriction alloys, which are both expensive and mechanically inferior.

"The impact of this discovery may be best summarized by Nobel lauriate **Herbert Kromer**'s criterion for transformative technologies," says Wutting. "'The principal applications of any sufficiently new and innovative technology always have been — and will continue to be — applications created by that technology.'"

HIGHEST-PERFORMING SHAPE MEMORY ALLOY TO DATE

Wuttig and his collaborators at the University of Kiel, Germany produced a new shape memory alloy so tough it returns to its original shape even after being bent and heated over ten million times. The new material, described in *Science* and profiled by BBC News, could be used to create and improve products ranging from robotics to refrigerators, and is already being used to develop biomedical devices in Europe *(see image above).*

Lightweight and elastic, shape memory alloys are found in a wide variety of products, such stents that open blocked arteries, fire protection systems, eyeglass frames, actuators, surgical tools, orthodontic wires, aerospace components, and even underwire bras. Eventually, all shape memory alloys wear out, which so far has made them unsuitable for long-term use.

Wuttig's alloy, a mixture of titanium, nickel and copper, has been shown capable of withstanding ten million cycles of deformation, making it a candidate for "high cycle" applications such as artificial heart valves and solid state air conditioners. In contrast, the previous highest-performing shape memory alloy could be deformed approximately 16,000 times before it succumbed to fatigue. In an editorial published in the same issue of *Science,* that material's inventor, Professor **Richard D. James** (University of Minnesota), described Wuttig's as "a breathtaking development."

All shape memory alloys are phase-changing materials, meaning they can shift into different molecular configurations; for example, from water into ice. The new alloy's transition can be "activated" by heat in one of its forms, and by a release of tension in another. Wuttig and his team discovered that the key to the

Professor **Manfred Wuttig** reveals "breathtaking" and "game-changing" materials in *Science* and *Nature.*

alloy's durability was the presence of a small impurity, a precipitate composed of titanium and copper (Ti_2Cu). These particles were compatible with both of the alloy's phases, allowing it to mediate millions of complete and reproducible transformations while reducing fatigue.

Wuttig and Chopra's Non-Joulian magnetostriction research was supported by the Metals and the Condensed Matter Physics programs of the National Science Foundation's Division of Materials Research.

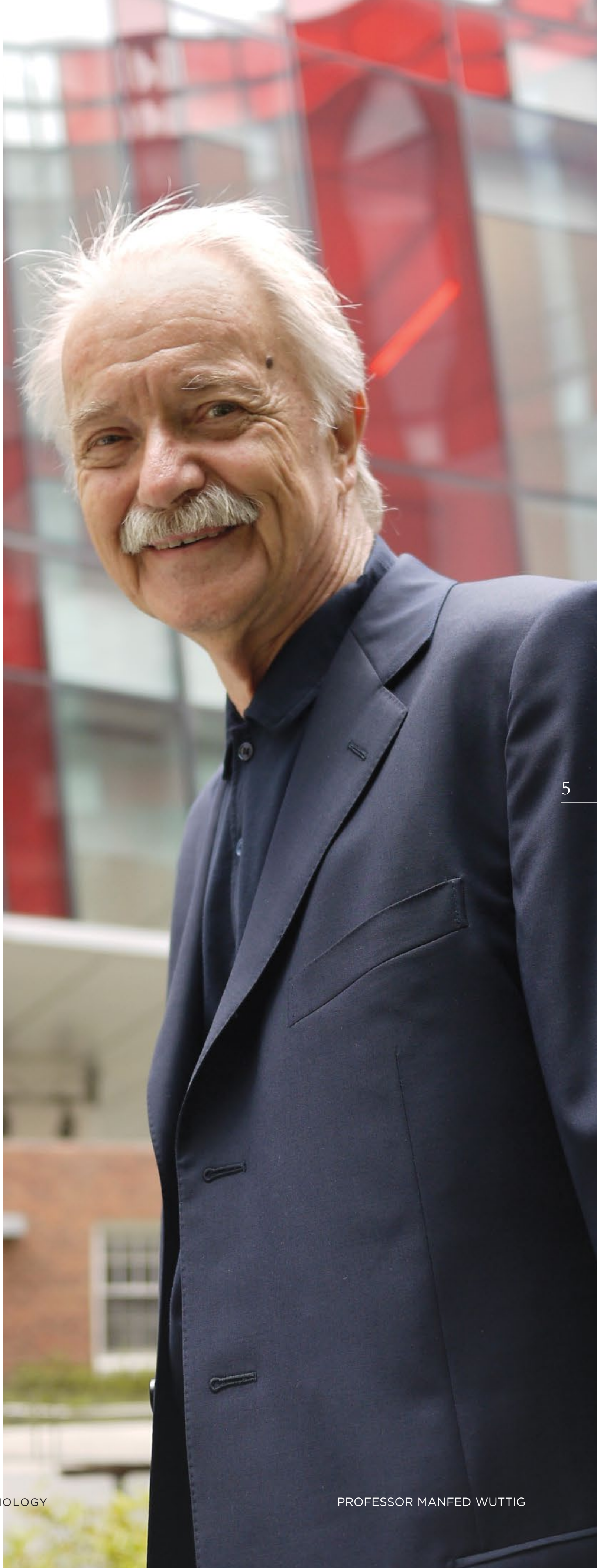
For More Information:

Harsh Deep Chopra and Manfred Wuttig. "Non-Joulian magnetostriction." *Nature,* 521, 340–343. 21 May 2015.

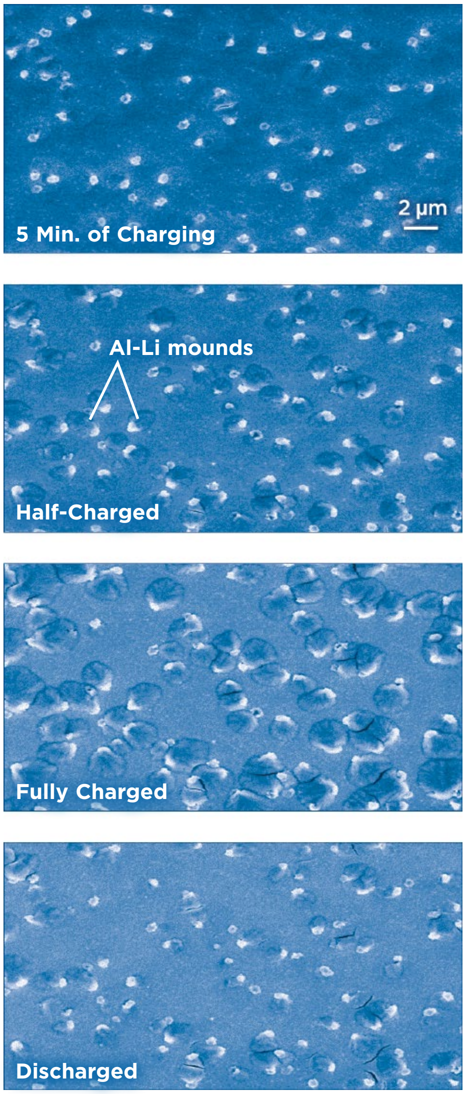
Christoph Chluba, Wenwei Ge, Rodrigo Lima de Miranda, Julian Strobel, Lorenz Kienle, Eckhard Quandt, Manfred Wuttig. "Ultralow-fatigue shape memory alloy films." *Science,* 348(6238), 1004-1007. 29 May 2015.

Richard D. James. "Taming the temperamental metal transformation." *Science,* 348(6238), 968-969. 29 May 2015.

Jonathan Webb. "Memory alloy bounces back into shape 10 million times." BBC News. **go.umd.edu/wuttigbbc**



Understanding Battery Failure in Realtime, at the Nanoscale



PLAN VIEW SCANNING ELECTRON MICROSCOPY IMAGES SHOWING THE MORPHOLOGY EVOLUTION OF AN ALUMINUM ANODE IN AN ALL-SOLID-STATE LITHIUM-ION BATTERY AS IT IS CHARGED AND DISCHARGED. INCREASING THE CHARGING CURRENT INCREASES THE DENSITY OF CLUSTERS, INDICATING THAT THE ALUMINUM-LITHIUM ALLOY FORMATION IS A KINETICALLY DRIVEN PROCESS. EVEN AFTER THE BATTERY IS COMPLETELY DISCHARGED, THE "MOUNDS" REMAIN, BUILDING UP AFTER EACH CYCLE UNTIL IT CAN NO LONGER FUNCTION.

Aluminum has many qualities that should make it a suitable material for use in ultra-light and on-chip batteries: it has a high melting point, high conductivity, and low cost.

"It would be a great anode for lithium-ion batteries," says MSE and Institute for Research in Applied Physics assistant professor **Marina Leite**, "if only we could stop it from reacting with lithium ions in a way that quickly ruins them. If we want to solve this problem, we need to understand why and how aluminum anodes fail."

Leite is part of a team that created a new way to probe the degradation of an entire aluminum anode, in realtime and at nanoscale resolution, using a combination of electron microscopy techniques. What she and her colleagues discovered could give battery developers the insight they need for future success.

All solid-state lithium-ion (Li-ion) batteries require anodes, positively charged electrodes that attract lithium ions during the charging process. These anodes have a "breathing" mechanism: their volume expands due to the addition of lithium ions as the battery is being charged, a process called lithiation, then contracts as the ions diffuse back to the positive electrode during discharge, or delithiation process. The anodes must remain stable and able to withstand repeated cycles of charging and discharging without being pulverized in the process.

Prior studies that attempted to explain aluminum anode failure suggested that they either crumbled, which has been observed in other anode materials, or that high strain caused the formation of a stiff aluminum-lithium alloy (AlLi) in the aluminum's matrix, which ruined its ability to expand and contract properly. Leite and her colleagues devised a way to find out if either of these theories were correct.

"The usual procedure is to take microscopy 'snapshots' of the anode material before and after cycling the battery," she explains. "We used a scanning electron microscope to image the changes taking place at the anode while charging and discharging the battery, which established a direct correlation between the structural changes in the material and the electrochemistry."

Using the new observation technique, Leite and her team discovered that aluminum anode failure is actually caused by lithium reacting with aluminum to form tiny "mounds" on the surface of the aluminum. These structures both permanently trap lithium and block still-free lithium ions from participating in the charge/discharge cycle. The anode's surface compounded the problem.

"The main challenge of working with aluminum is that a thin layer of aluminum oxide naturally forms on its surface," says Leite. "In our case, it plays a critical role in the degradation of the battery. When it reacts with the lithium, it forms a very stable alloy, aluminum lithium oxide. The alloy surrounds the mounds, like a prison wall around locked cells. Ultimately, this creates a tough barrier for any remaining lithium ions."

Without sufficient lithiation and delithiation, the battery's performance is limited, and since lithium diffuses through aluminum very quickly at room temperature, it doesn't take long for all these reactions to take place.

Leite's group is now exploring ways to address these problems, such as developing conductive thin films that will, when applied to surface of an aluminum anode, reduce oxidation and boost the battery's capacity. The team also hopes to test their observation technique on other battery materials.

A paper describing the methodology and results of the study was published in the *Journal of Materials Chemistry A,* where it was also featured on the publication's inside cover.

For More Information:

Marina S. Leite, Dmitry Ruzmetov, Zhipeng Li, Leonid A. Bendersky, Norman C. Bartelt, Andrei Kolmakov and A. Alec Talin. "Insights into capacity loss mechanisms of all-solid-state Li-ion batteries with Al anodes." *J. Mater. Chem. A,* 2014, 2, 20552.

Creating Transparent Electronic Networks with Graphene-Based Ink

Researchers from UMD's Department of Materials Science and Engineering (MSE) were the first to report that intercalating (embedding) sodium ions in a reduced graphene oxide (RGO) network printed with graphene oxide (GO) ink can significantly improve its performance as a transparent conductor in displays, solar cells and electronic devices. A paper describing the new technology, developed by MSE assistant professor **Liangbing Hu**'s group at the University of Maryland Energy Research Center, was published in *Nano Letters.*

The work builds on the group's previous development of nearly transparent, highly conductive ultrathin graphite sheets that can be used to create more efficient solar cells and highly sensitive touchscreens. Hu and his colleagues were the first to accomplish this by intercalating lithium between flakes of graphene.

MSE graduate student and Hu group member **Jiayu Wan**, the paper's first author, explains that while the sheets were a success, they would be difficult to produce at an affordable, commercial scale. He and his team decided to explore how they could achieve similar results with more cost-effective materials and production techniques. They swapped graphene flakes for graphene oxide ink and expensive lithium for sodium, a far more abundant natural resource.

The result, he says, is a highly scalable printed electronics system that produces cheaper and more stable conductors than the group's lithium intercalated graphene sheets. The group theorizes the increased stability is due to the natural oxidation of sodium along the edges of the printed networks – something like a crust on a piece of bread – which forms a barrier that prevents ion loss. Networks printed with the ink exhibit up to 79 percent optical transmittance and 311 Ohms per square of sheet resistance.

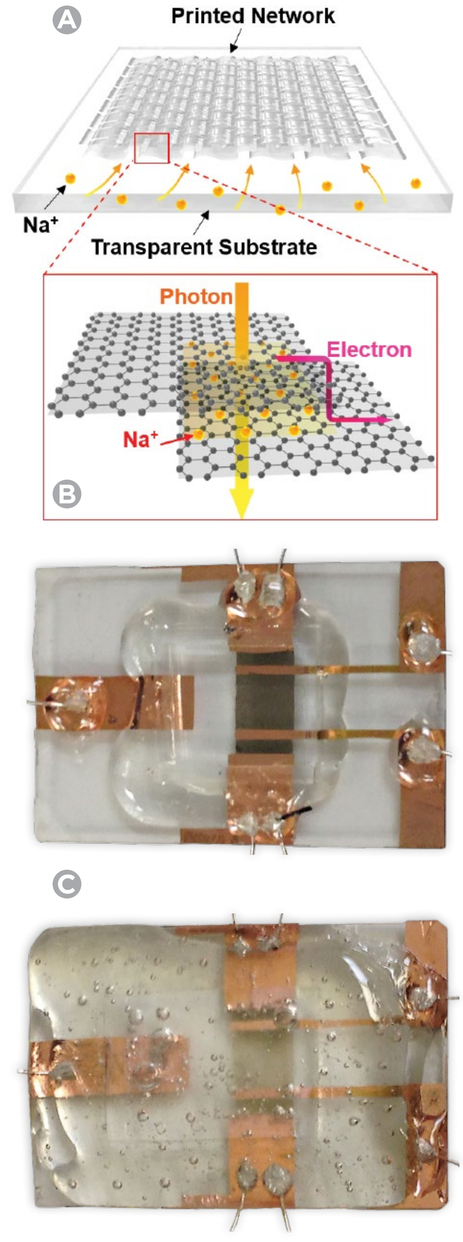
The process begins with the creation of specially formulated ink containing graphene oxide (GO), which is applied evenly to a thin glass slide, called a substrate, using a tiny roller. The coated slide is heated and dried to evaporate the ink solution, leaving a thin, semitransparent layer of GO behind. It is then subjected to a second heat treatment at 300 degrees Celsius, which converts the GO to reduced graphene oxide (RGO). The process is repeated up to six times. Wan then uses a tiny blade to cut and scrape away excess RGO, leaving behind a layered network. After adding thin film electrodes, he moves the device into a glovebox – a chamber with an inert atmosphere – where he is able to add electrolytes and intercalate the sodium ions without the risk of unwanted chemical reactions. As the ions are inserted into the space between each layer of RGO, the network becomes more transparent and more conductive. Finally, after sealing the device, Wan is able to remove it from the glovebox to characterize its optical and conductive properties.

"This technology is a few steps closer to commercial application than our lithium-graphene product," says Wan. "Large-scale production of solution-based, printed transparent conductors are potentially much lower in cost and can be used to create a range of electronic devices including solar cells, displays, and organic light-emitting diodes."

Wan's co-first authors on the paper are MSE graduate student **Feng Gu** and postdoctoral research associate Dr. **Wenzhong Bao**, who are also members of Hu's research group.

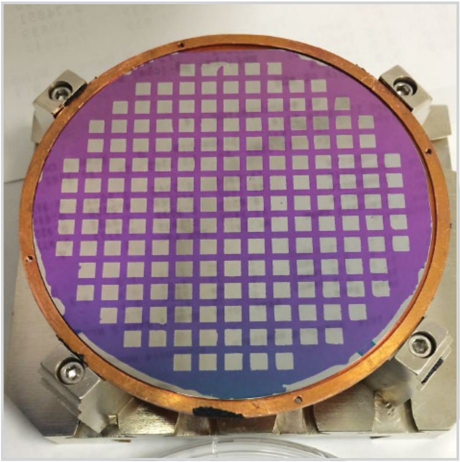
For More Information:

Jiayu Wan, Feng Gu, Wenzhong Bao, Jiaqi Dai, Fei Shen, Wei Luo, Xiaogang Han, Daniel Urban, and Liangbing Hu. "Sodium-Ion Intercalated Transparent Conductors with Printed Reduced Graphene Oxide Networks." *Nano Letters,* 2015, 15 (6), 3763–3769.



(A) SCHEMATIC OF Na-ION INTERCALATION BETWEEN TWO RGO SHEETS, SIMUTANEOUSLY ENHANCING THEIR OPTICAL TRANSMITTANCE AND ELECTRICAL CONDUCTIVITY. (B) SCHEMATIC OF Na-ION INTERCALATION IN PRINTED RGO NETWORK ON TRANSPARENT SUBSTRATE. (C) ABOVE: RGO NETWORK BEFORE Na INTERCALATION. BELOW: RGO NETWORK AFTER Na INTERCALATION.

ONR Funds Instrumentation for Materials Discovery



MSE professor **Ichiro Takeuchi** received a two-year, $215,000 grant from the Office of Naval Research's (ONR) Defense University Research Instrumentation Program (DURIP) to support the development of new high-throughput characterization equipment used to identify materials with unique and valuable properties.

Takeuchi, a member of the Maryland NanoCenter, directs the university's Combinatorial Synthesis Lab, which houses one of the largest collections of tools in the world for rapid exploration of novel functional materials.

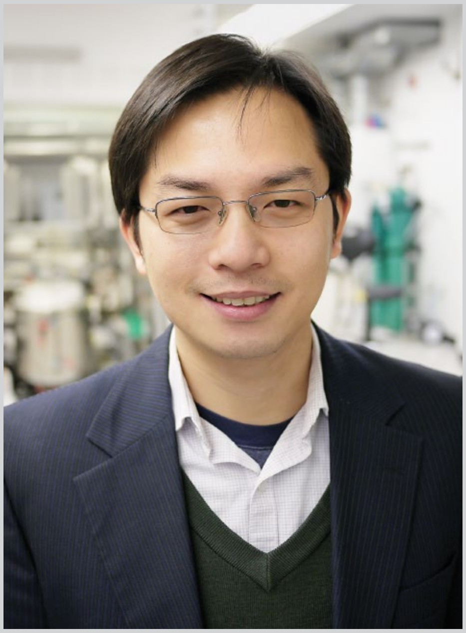
The DURIP grant augments an existing ONR Multidisciplinary University Research Initiative (MURI) program, called Topological Decompositions and Spectral Sampling Algorithms for Element Substitution in Critical Technologies. The team, headed by **Stefano Curtarolo** (Duke University), develops new algorithmic and theoretical approaches to designing and developing advanced materials for a variety of technological areas. The group is particularly focused on materials that could replace expensive elements with limited availability, such as indium and dysprosium.

Some of the materials the team is working on include transparent conductors to be used in future smart phones, and topological insulators, which are predicted to play an important role in quantum computation. One of Takeuchi's key contributions to the project is his use of the combinatorial synthesis strategy to carry out rapid experimental validation of materials predicted with computational modeling.

According to Takeuchi, the new instrumentation will allow automated measurements of a large number of devices fabricated on combinatorial thin film libraries.

"This equipment will substantially enhance the overall capabilities of the Combinatorial Synthesis Lab," he says, "and it will allow us to extend the scope of our investigation to many new areas, including energy materials."

Hu, Leite Named Maryland Academy of Science's Outstanding Young Engineer and Scientist of the Year



LIANGBING (BING) HU

MSE assistant professors **Liangbing Hu** and **Marina Leite** were named Maryland Outstanding Young Engineer (OYE) and Maryland Outstanding Young Scientist (OYS) in the academic sector, respectively, by the Maryland Science Center. Both awards are sponsored by the Maryland Academy of Sciences. Hu and Leite, who were chosen for their development of technology for solar energy, batteries and electronics, were honored at an awards ceremony at the center, where Hu was presented with the OYE award's Allan C. Davis medal and a $2500 cash prize, and Leite received the OYS award's Alexander M. Haig, Jr. medal and a $2500 cash prize.

Hu, a member of the University of Maryland Energy Research Center (UMERC) and the Maryland NanoCenter, received his Ph.D. from UCLA in 2007. His research group develops and studies nanomaterials and nanostructures for use in energy storage (batteries), energy conversion, solar cells, printed and flexible electronics, wearable devices, and transparent paper. *(See related story, p. 7.)* His work on a "battery made of wood" has been featured on National Public Radio, and a solid state lithium-ion battery he created with Professor **Eric Wachsman** (MSE/UMERC) was named the physical sciences Invention of the Year by the university's Office of Technology Commercialization. Hu was nominated for the OYE award by MSE professor and past chair **Robert M. Briber**.

"Bing is an incredibly creative and collaborative researcher who works with other engineers and scientists from across campus and around the world," says Briber. "Since joining the faculty, he has had tremendous

Two FIBs Now Available in NanoCenter's AIM Lab

Two new focused ion beam (FIB) instruments will accelerate the Maryland NanoCenter's growth and ability to serve industry, principal investigators and research faculty with the latest nanoscale imaging, creation and analysis techniques. The equipment has been installed in the Advanced Imaging and Microscopy Laboratory (AIM Lab; formerly known as the Nanoscale Imaging Spectroscopy and Properties Lab).

Work with the transmission electron microscope (TEM), one of the NanoCenter's most popular instruments, will be enhanced by the FIBs because they help users prepare the extremely thin samples needed for TEM imaging.

Users can more easily create semiconductor chip prototypes thanks to the FIBs' milling, etch and deposition capabilities. Micro- and nanomachines' operation can be fine-tuned to a meticulous level, correcting and creating tiny working parts. The FIBs can precisely cut dissimilar materials that are joined together, allowing novel combinations of materials to be used in nanomachines.

A scanning ion mass spectrometer will extend the FIBs' capabilities to conduct fine-grained sample analysis, providing an extra perspective for complete detail on a sample.

The new FIB power is doubled by dual beam imaging (scanning electron microscopy and FIB) for images of the surface of and deeper into a material's layers. The two new instruments have complementary abilities: a gallium beam for extremely detailed, high resolution work; and a xenon beam for fast, heavy-duty nanoscale slicing and ablation.

The lab's space was redesigned to create a central location that makes it easier for users to access expert NanoCenter staff and transfer between instruments.

MSE GRADUATE STUDENT **JOSHUA TAILLON** AND MSE PROFESSOR **LOURDES SALAMANCA-RIBA** WITH ONE OF THE NEW INSTRUMENTS.

impact, with numerous awards, high profile journal publications, media coverage of his work, and outreach to students. He is an outstanding engineer and his work has great promise for revolutionizing energy storage and conversion in batteries and solar cells."

Leite, who is jointly appointed to MSE and the Institute for Research in Electronics and Applied Physics (IREAP), received her Ph.D. from the Universidade Estadual de Campinas, Brazil, in 2007. Her research group focuses on the development of energy harvesting and energy storage devices, particularly high-efficiency solar cells, solid-state batteries, and plasmonics (metallic and highly conductive nanostructures). Using unique nanoscale imaging techniques to probe light/material interactions, the team is advancing our understanding of the optical and electrical responses of photovoltaic devices. *(See related story, p. 6.)* Leite was nominated for the OYS award by IREAP director and Department of Electrical and Computer Engineering professor **Thomas Murphy**.

"In the few years since completing her Ph.D. degree, Professor Leite has quickly earned a reputation as a young scientist of remarkable versatility and uncompromising standards," says Murphy. "She possesses the rare combination of creativity, ambition, perseverance, and interpersonal skills that are critical for success in academia. She is already distinguishing herself in her field of expertise, and I expect that she will emerge as a leader in this field in the coming years."

Watch Maryland Science Center videos about professors Hu and Leite at **go.umd.edu/huoye** and **go.umd.edu/leiteoys**.

MARINA LEITE

Undergrads Win NSF Graduate Research Fellowships

BAILEY AMONG FIRST TO MAP SOLAR CELL PARAMETERS AT SUB-MICRON RESOLUTION; CHANG DEVELOPED PLASMONIC ALLOYED NANOPARTICLES FOR SOLAR CELLS

ABOVE: ALLEN CHANG (B.S. '15)
BELOW: ERIC BAILEY (B.S. '15)

MORE NSF-GRF HONORS FOR MSE STUDENTS!

In addition to Graduate Research Fellowships, the NSF grants Honorable Mentions to meritorious applicants who do not receive fellowships as an acknowledgement of significant national academic achievement. In 2015, three MSE graduate students, **Steven Lacey**, **Samuel Schwarm** and **Elizabeth Tennyson** received Honorable Mentions. To learn more, visit **go.umd.edu/msensfgrf15**

MSE alumni **Eric Bailey** and **Allen Chang**, both B.S. '15 and members of MSE and Institute for Research in Electronics and Applied Physics assistant professor **Marina Leite**'s research group, were awarded Graduate Research Fellowships from the National Science Foundation (NSF).

NSF Graduate Research Fellowships, which are among the most prestigious academic awards in the nation, provide three years of support that may be used over a five-year period. For each year of support, the NSF provides a stipend of $30,000 to the fellow and a cost-of-education allowance of $10,500 to the degree-granting institution.

Bailey, a University of Maryland Merrill Presidential Scholar, was active in research throughout his undergraduate career, and has previously been recognized by the NSF for his work. In 2015, he received a Successful Engineering Education and Development Support Research Fellowship from the NSF in support of one of his final projects, which is expected to expand what we know about the fundamental mechanisms and characteristics of solar cell performance.

Working under the mentorship of MSE graduate student and fellow group member **Elizabeth Tennyson**, Bailey used a new imaging technique developed by the Leite Lab to spatially map solar cell parameters such as current density, fill factor, and power conversion efficiency at the sub-micron (one millionth of a meter) level. The project marked the first time these characteristics have been studied at this resolution. According to Bailey, the results will increase our understanding of solar cell functionality and the short- and long-term effects of material defects on performance. The technique can be applied to many different devices and be used to study a variety of problems.

Bailey's fellowship will support his graduate studies in the University of Pennsylvania's Department of Materials Science and Engineering. He expects to work on polymers or nanocomposites, pursuing his interests in structure-property relationships and computational materials science. After receiving his Ph.D., he would like to explore careers in product development, but hopes to maintain ties with academia in a lecturing or mentoring role.

Chang has been active in research at UMD since his junior year of high school. Most recently, he won the A. James Clark School of Engineering's 2015 Outstanding ASPIRE Student Research Award for his work on developing a new type of plasmonic (metallic and highly conductive) alloyed nanoparticle for use in solar cells He carried out his project under Leite's direction, and was also mentored by MSE graduate student and fellow group member **Chen Gong**.

Chang's goal was to improve the nanoparticles that are deposited on the top surfaces of solar cells, whose function is to increase the amount of light scattered into them. These particles are typically made of silver. In his ASPIRE project, Chang explored whether he could replace the pure silver nanoparticles with ones made of a silver-aluminum alloy, and determine whether those new particles could perform as well or better than the originals. Since aluminum scatters short wavelengths of light more effectively and costs less than silver (about 5¢/oz. versus over $16.50/oz. in March 2015), the adoption of a successful alloy nanoparticle in industry would reduce the overall cost of solar cells.

In September, Chang joined the University of Massachusetts Amherst, where he will pursue his Ph.D. in the Department of Polymer Science and Engineering. Ultimately, he hopes to bring organic LEDs and organic photovoltaics to higher levels of efficiency and market competition.

To learn more about Bailey and Chang's undergraduate research careers, visit

go.umd.edu/msensfgrf15
go.umd.edu/changaspire

Cooking with Materials Science

The triumphant conclusion to **Helen Lan**'s internship at the U.S. Army Research Laboratory (ARL) was cooking a burger at a symposium–and the audience at the Aberdeen Proving Ground loved it.

This was no ordinary lunch order. Lan, now a junior in the University of Maryland's Department of Materials Science and Engineering, was there to demonstrate a new kind of kitchen burner she developed under the guidance of research chemical engineer Dr. **Ivan C. Lee**, a member of the ARL's Sensors and Electron Devices Directorate.

While this may seem like a project for interns at Whirlpool or GE, the Army takes feeding hundreds or thousands of soldiers at a time very seriously, and it doesn't use ranges like the ones we have in our homes.

Power grids and natural gas supplies—let alone a Sears or a Home Depot—may be unavailable when the Army is on the move. In order to increase efficiency and reduce costs, the Army powers as many appliances, pieces of equipment and vehicles as possible with a fuel known as JP-8. This includes their kitchen burners, which are specifically designed to use it.

These burners, however, have a few problems that may make you lose your appetite. According to Lan, they are noisy, release carbon monoxide due to incomplete fuel combustion, and are only 10–25 percent efficient. In order to propose something better, Lee decided that since they couldn't change the fuel, they would rethink the appliance.

"Our objective was to create a JP-8-fueled catalytic burner that is quieter, results in complete combustion [so it] does not release carbon monoxide, and is 95 percent heat transfer efficient," Lan explains. "Our approach was to deposit a catalyst layer onto the backside of an aluminum cooking surface. Preliminary results have shown that applying a catalyst layer allows for over a 50 percent reduction in fuel consumption compared to [cooking surfaces] without one." Lan presented their results—and cooked a burger using their prototype—at an ARL Student Symposium and competition, where she won a Silver Medal for her efforts. She hopes that one day a consumer version of the burner will be available.

Lan got her start in research even before she was a student at UMD. The summer before her senior year of high school, she worked with Professor **Rachel Pinker** (Department of Atmospheric and Oceanic Sciences), investigating the accuracy of temperature-recording satellites. During her senior year, she joined Assistant Professor **Dongxia Liu** (Department of Chemical and Biomolecular Engineering) and graduate student **Laleh Emdadi** on the development of fast, high-yield catalysts for use in the bio-fuel production process. It was Liu who introduced her to Lee, who was seeking an intern with prior experience.

"I really enjoyed getting hands-on and professional experience," says Lan of her time at the ARL. In addition everything she learned on the project, she says Lee also prepared and encouraged her to speak at the symposium, something she had previously never imagined she would enjoy. "I also got to meet so many other smart, kind, helpful interns and full-time employees," she adds, "and I'd love to work with them all again."

After earning her degree in materials science and engineering, Lan plans to attend graduate school.

THE FACE OF THE CLARK SCHOOL!

This spring, **Helen Lan** was featured on the cover of the Clark School's *E@M* magazine! In "The Power of Place," Lan explains how the Clark School's location enabled her to get laboratory experience starting in her freshman year. Just 10 minutes from the UMD campus, the U.S. Army Research Laboratory (ARL) is providing exciting new opportunities for research collaborations through its Open Campus initiative. Clark School faculty and students and ARL engineers are working collaboratively and side-by-side on important research topics at ARL's facilities. To download this issue of *E@M,* visit **go.umd.edu/laneatm**.

MSE UNDERGRADUATE **HELEN LAN** (CENTER) RECEIVING THE SILVER MEDAL AND A CASH PRIZE FOR HER PRESENTATION OF A MORE EFFICIENT KITCHEN BURNER. LEFT: ARL DIRECTOR **THOMAS RUSSELL**. RIGHT: ARL FELLOW **ROSE PESCE-RODRIGUEZ**.

LEFT: RAY PHANEUF. RIGHT: AMY MARQUARDT. PHOTO BY THAI NGUYEN.

PHANEUF: KEYNOTE ON CONSERVATION RESEARCH

MSE professor **Ray Phaneuf** delivered a keynote address at the 10th Nanoforum conference and expo, held at Sapienza University of Rome.

Phaneuf spoke on the use of nanotechnology for cultural heritage conservation. For the past several years, his group has been working with conservators from the Walters Art Museum to develop nanometers-thick metal-oxide coatings that protect silver from tarnish. The coatings, applied using atomic layer deposition, are designed to be invisible, safely removable, more consistent and longer-lasting than the meticulously hand-applied layer of nitrocellulose lacquer typically used by conservators.

The work has been expanded to explore its potential for preserving bronze and patinas through MSE graduate student **Amy Marquardt**'s collaborations with the Smithsonian's Museum Conservation Institute and the University of Trento, Italy. Another Phaneuf Group member, NSF Graduate Research Fellow **Willa Freedman**, is studying how the coatings could be applied to limestone used in historic buildings such as the Castel del Monte, a UNESCO World Heritage Site in Apulia, Italy.

Coating Research Wins Top Prizes in Int'l 3-Min. Thesis Competition

Think fast: Could you describe the five years of Ph.D.–level research behind your passion to anyone you meet in three minutes? MSE graduate student **Amy Marquardt** can. Her video explaining how she uses nanotechnology to protect silver art and artifacts won both the Judges' Choice and People's Choice Awards in the international Three Minute Thesis Competition (3MT).

Marquardt was one of over 800 entrants in the competition, which challenges students to explain the importance of their work to a non-technical or non-specialist audience in only three minutes. It's a skill she can call on as she collaborates with conservators and art historians to preserve irreplaceable works in museum collections.

While polishing tarnished silver objects may seem harmless, it actually removes metal, and eventually fine details disappear. Currently, museum conservators meticulously hand-paint or spray silver artifacts with a plastic coating called nitrocellulose to protect them from tarnish. The treatment lasts for about ten years.

"At that ten-year mark, the coating has to be removed, the silver polished, and a new coating applied," Marquardt, advised by MSE professor **Ray Phaneuf**, explains in her video. "For museums with thousands of silver objects, this creates a nearly constant cycle of damage and recoating."

Marquardt wants to break that cycle by trading nitrocellulose for transparent ceramic coatings. Using a technique called atomic layer deposition (ALD), she can apply them one atomic layer at a time. This level of control allows her to create nearly invisible films that can be consistently applied to even the finest and deepest details on an object's surface.

A SILVER HALF-DOLLAR COIN THAT HAS BEEN COATED WITH PLASTIC (BOTTOM 1/3) AND ALD COATING (TOP 1/3). THE CENTER OF THE COIN IS WITHOUT COATING.

Marquardt describes her 3MT presentation as "one of the most challenging" she has ever given.

"Conveying my research in 3 minutes was much harder than I expected, but also a lot of fun," she told Universitas 21 (U21), the network of research universities that runs the competition. "[It] allowed me to explain why I'm excited about my research to a broad audience, hopefully sparking their interest in a topic they never considered."

The 3MT prizes include a cash award, a funded trip to a U21 member university of Marquardt's choice, and the opportunity to have her presentation transformed into an animated video by 99Scholars.

Winning the 3MT Competition is the latest in a series of honors, awards and recognition Marquardt has received for her work. The project has been reported by *Science* and highlighted by the National Science Foundation. She is currently serving a research-in-residence fellowship at the Smithsonian's Museum Conservation Institute, where she is exploring the use of her coating technique to preserve bronze art and artifacts. She also took part in an international research exchange partnership between the University of Maryland and the Autonomous Province of Trento, Italy, where she studied the corrosion and tarnishing of metal cultural heritage objects at the Fondazione Bruno Kessler.

Watch Amy Marquardt's winning 3MT video at: **ter.ps/marquardt3mt**

Watch a video about Marquardt and Phaneuf's collaboration with the Walters Art Museum: **ter.ps/nsfsilvervid**

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WHAT'S THIS? It's a beautiful day at the beach, but you'll need to be only microns tall to enjoy it! This island getaway is actually a colorized scanning electron microscopy image of a highly porous polystyrene/graphene oxide film created by MSE graduate student **Jiayu Wan** (advised by Assistant Professor **Liangbing Hu**). The piece, titled *Graphene Tide,* won 1st place in the Materials Research Society's Spring 2015 Science-As-Art competition. The film could be used to create high energy density sodium-ion batteries for use in grid-scale energy storage facilities.

TECHTRACKS is published for alumni and friends of the Department of Materials Science and Engineering at the A. James Clark School of Engineering. Your alumni news and comments are welcome. Please send them to:

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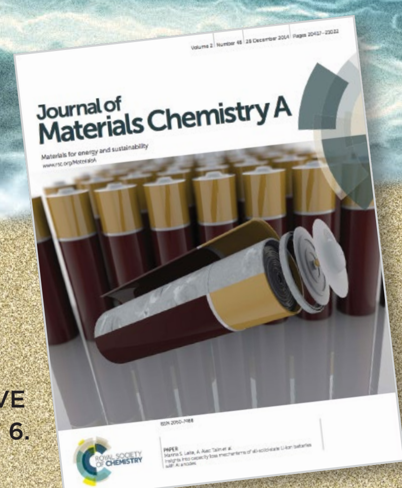

INSIDE: A NEW WAY TO OBSERVE BATTERY FAILURE. SEE PAGE 6.

moreONLINE!

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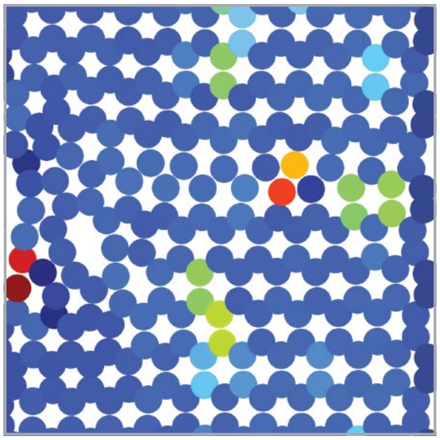
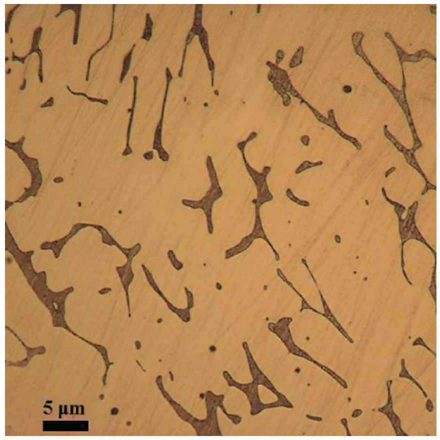


NEW SOFTWARE WILL ENHANCE MSE'S UNDERGRADUATE PROGRAM

UMD is one of six schools nationwide that will receive advanced materials modeling software for use in its undergraduate curriculum. ASM International's Computational Materials Data Network awarded tools from Thermo-Calc Software through its 2015 Materials Genome Toolkit program. **go.umd.edu/asmtoolkit**

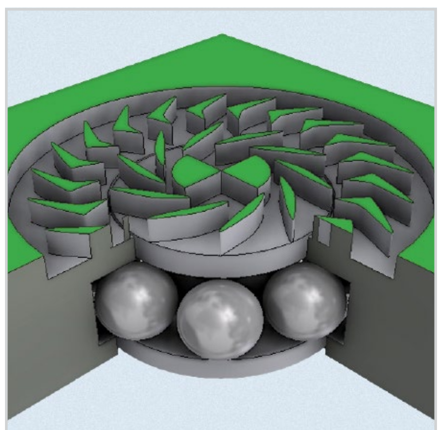
SHAHIN WINS ASEE NAVAL RESEARCH INTERNSHIP

The American Society for Engineering Education awarded MSE graduate student **David Shahin** a Naval Research Enterprise Internship Program fellowship. Shahin worked at the Naval Research Laboratory in Washington, D.C. Shahin, advised by Professor **Aris Christou**, is focused on developing improved processing for the production of vertical gallium nitride (GaN) metal-oxide-semiconductor field effect transistors. **go.umd.edu/shahinnreip**



WILL OUR NUCLEAR REACTOR COMPONENTS BE SAFE FOR ANOTHER 20–30 YEARS?

MSE graduate student **Samuel Schwarm** received a three-year, $155,000 Nuclear Energy University Programs Fellowship from the DOE. The award supports his long-term study of the performance of stainless steel used in the cooling systems of commercial nuclear reactors. **go.umd.edu/schwarmneup**



HANRAHAN, *ET AL.* PAPER SELECTED AS JMM HIGHLIGHT

An paper co-authored by MSE alumnus **Brendan Hanrahan** (Ph.D. '13) and his former advisor, Professor **Reza Ghodssi** (ECE) was honored by the *Journal of Micromechanics and Microengineering.* "Isotropic etching technique for three-dimensional microball-bearing raceways" describes a multi-step plasma etching technique used to fabricate deep-grooved microscale ball bearing raceways for microturbines. Hanrahan currently works at the Army Research Laboratory, where he leads studies of pyroelectric materials for energy conversion applications. **go.umd.edu/hanrahanjmm14**

LACEY: NAT'L DEFENSE SCIENCE & ENGINEERING GRAD. FELLOWSHIP

This highly-competitive award will support MSE graduate student **Steven Lacey**'s exploration of the synthesis, modification, and characterization of low-dimensional (1D and 2D) nanomaterials, such as nanowires and graphene, for use in printed electronics, flexible electronics, and energy storage devices. **go.umd.edu/laceyndseg**

ELECTROCHEMICAL SOCIETY WINS 2ND STUDENT CHAPTER AWARD

The UMD chapter of the ECS received one of two of the society's 2014 Chapters of Excellence Awards. The group was recognized at the plenary session of the 226th Meeting of the ECS, held in conjunction with the Sociedad de Eletroquímica meeting in Cancun, Mexico. **go.umd.edu/ecs2ndaward**

Alumni: Please send us your news!

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...or join our Facebook group!

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Alumnus Is New Chair of Mechanical Eng. at Temple U.

HARSH DEEP CHOPRA

MSE alumnus and MSE Board of Visitors member **Harsh Deep Chopra** (Ph.D. '93) was appointed Chair of Temple University's Mechanical Engineering Department. Chopra came to Temple from SUNY–Buffalo, where he had been a professor in the Department of Mechanical & Aerospace Engineering since 2005.

During his time at the Clark School, Chopra was advised by MSE professor **Manfred Wuttig**. Together, the pair studied functional and smart materials for sensors and actuators for automotive, aerospace and robotics applications. Chopra has remained in the field, pioneering his own approach to materials genomics in order to understand how a variety of material properties—such as electric and magnetic—evolve from the single atom to the bulk scale. He continues to collaborate and publish with Wuttig. *(See related story, p. 4).*

Chopra chose a career in academia for the freedom it provides to pursue his own ideas at his own pace. He decided to take on the demanding role of department chair because he saw opportunity and potential. Temple's Mechanical Engineering Department, he says, is poised to double its size within the next few years.

"That's very attractive to me," he explains. "It has just the right elements, just the right faculty now, to grow and mature. That isn't something that comes along often. This is more than management—this is about guiding the department to the next level."

That includes implementing what he describes as a comprehensive curriculum that teaches students how to innovate, prepares them to work in either academia or industry, stresses design for sustainability, and demonstrates that research, teaching and service should all be part of a scientist's education and career.

Chopra is also thinking about the future of the field, which he believes will shift toward materials-by-design over the next ten years. "In this age of scarcity of resources, it will become critically important that researchers be able to design materials suited to specific needs and for maximum impact," he says.

Asked what advice he has for current or prospective students of MSE, Chopra urges them to broaden their views. "Learn to solve complex problems, because all of them are becoming interdisciplinary. Don't narrow your focus. Look beyond, and take ideas from other areas to innovate in your own."

Alumnus Receives Clark School Early Career Award

MSE alumnus **Nagarajan (Nagy) Valanoor** (Ph.D. '01) was one of three inaugural recipients of the A. James Clark School of Engineering's Early Career Award. The winners were nominated by their peers and selected for meritorious contributions in their respective fields, significant rapid advancement in the early stages of their careers, and dedication to the University of Maryland. Valanoor was honored at a gala celebration on the university's College Park campus.

Valanoor, who was advised by MSE professors **Ramamoorthy Ramesh** (now at UC Berkeley) and **Alexander Roytburd**, is currently a professor and the research director of the School [Department] of Materials Science at the University of New South Wales, Australia (UNSW). He has maintained his ties with MSE, including working with MSE professor **Ichiro Takeuchi** on the development of environmentally friendly piezoelectrics.

"Nagy has a set of accomplishments that would be recognized as outstanding at Maryland or any other top research institution in the world," says MSE professor and former chair **Robert M. Briber.** "He has made seminal contributions to the field of materials science and is credited with the discovery and characterization of complex oxides that may form the basis for new sensor materials and microelectronics based on electron spin rather than traditional silicon transistors."

Valanoor has published over 130 peer-reviewed papers on the synthesis and characterization of ferroelectric thin films in high-impact journals such as *Science, Nature Materials, Nature Communications,* and *Physical Review Letters.* He is the author of seven book chapters and is in the process of editing a book. His research has attracted more than 5,200 citations.

In 2014, he received the Institute of Electrical and Electronics Engineers' (IEEE) Ferroelectrics Young Investigator Award for "his outstanding contributions in experiments and theory of nanoscale electromechanical phenomena in ferroelectric thin films and interfaces." His other honors include UNSW's Vice-Chancellor's Award for Excellence in Postgraduate Research Supervision and its Faculty of Science Research and Teaching Excellence Award, the Edgeworth David Medal from the Royal Society of New South Wales, the International Symposium for Integrated Functionalities Young Investigator Award, and back-to-back Australian Research Fellowships.

Prior to joining UNSW in 2005, Valanoor conducted research in Germany as an Alexander von Humboldt Fellow at Forschungszentrum Juelich, and was an MSE research associate.

recent DISSERTATIONS

December 2014

John Bavier: "Silicon on Insulator Bipolar Junction Transistors for Flexible Microwave Applications." Advisor: John Cumings.

Miriam Cezza: "Study of the Feasibility of Controlling the Length Scale of the Phase Separation of Organic Molecular Mixtures on Si(111) Substrates." Advisor: Raymond Phaneuf.

Colin Gore: "Ceramic and Composite Anodes for Hydrocarbon-fueled Intermediate Temperature Solid Oxide Fuel Cells." Advisor: Eric Wachsman.

Paris Noelle Alexander Nero: "*In situ* Manipulation of Magnetization via Direct Mechanical Interaction in Magnetostrictive Thin Films." Advisor: John Cumings.

Colin Daniel Preston: "Random Networks Of One-Dimensional Conductive Nanomaterials: Fabrication, Properties, And Applications." Advisor: Liangbing Hu.

Da Song: "High Frequency Generation Based On Carbon Nanotube Field-Effect Transistors." Advisor: John Cumings.

Chanel Nicole Tissot: "Radiation-Grafted Fabrics for the Extraction of Uranium from Seawater." Advisor: Robert M. Briber. (Nuclear)

Norvik Voskanian: "Heat Dissipation in Current Carrying Multiwalled Carbon Nanotubes." Advisor: John Cumings.

May 2015

Elliot Bartis: "Low and Atmospheric Pressure Plasma Interactions with Biomolecules and Polymers." Advisor: Gottlieb Oehrlein.

Sean Fackler: "Combinatorial Investigation of Rare-Earth Free Permanent Magnets." Advisor: Ichiro Takeuchi.

Yi-Lin Huang: "Fundamental Understanding of SOFC Cathode Durability; A Kinetics and Catalysis Study." Advisor: Eric Wachsman.

Will Joost: "Modeling the Influence of Phase Boundaries and Oxygen Interstitials on the Nucleation and Growth of Deformation Twins in the Alpha-Phase of Titanium Alloys." Co-advisors: S. Ankem and Maija Kuklja.

Alex Kozen: "Atomic Layer Deposition of Solid Electrolytes for Beyond Lithium-Ion Batteries." Advisor: Gary Rubloff.

Ashley Lidie Ruth: "Solid Oxide Ionic Materials for Electrochemical Energy Conversion and Storage." Advisor: Eric Wachsman.

Marshall Schroeder: "ALD-Enabled Cathode-Catalyst Architectures for Li-O_2 Batteries." Advisor: Gary Rubloff.

student AWARDS

DEPARTMENT AWARDS

The Department of Materials Science and Engineering Chairman's Outstanding Senior Award: **Eric Bailey**

The Department of Materials Science and Engineering Outstanding Materials Student Service Award: **Griffin Godbey**

The Department of Materials Science and Engineering Student Research Award: **Katherine Atwater and Allen Chang**

CLARK SCHOOL AWARDS

The A. James Clark School of Engineering Kim Borsavage and Pamela J. Stone Student Award for Outstanding Service: **Eric Bailey**

Outstanding ASPIRE Research Award: **Allen Chang**

The Center for Minorities in Science and Engineering Service Award: **Luke Bittner**

Dean's Master's Student Research Award: **Feng Gu**

Dean's Doctoral Student Research Award: **Alex Kozen**

To learn more about our undergraduate honorees, visit: **go.umd.edu/mseawards15**

UNIVERSITY AWARDS

Outstanding Graduate Assistant Award: **David Shahin**

Ann G. Wylie Dissertation Fellowship: **Hanna Nilsson** (see **go.umd.edu/nilssonwylie**)

NATIONAL AWARDS

NSF Graduate research Fellowship: **Eric Bailey and Allen Chang** (see **go.umd.edu/msensfgrf15** or p.10)

DOE Nuclear Energy University Programs Fellowship: **Sam Schwarm** (see **go.umd.edu/schwarmneup**)

National Defense Science and Engineering Graduate Fellowship: **Steven Lacey** (see **go.umd.edu/laceyndseg**)

Naval Research Enterprise Internship Program Fellowship: **David Shahin** (see **go.umd.edu/shahinnreip**)

Silver Medal, ARL Student Symposium: **Helen Lan** (see **go.umd.edu/lanarljp8** or p. 11)

SOCIETY AWARDS

CIRMS Student Grant: **Travis Dietz** (see **go.umd.edu/dietzcirms**)