SPRING 2014

TECHTRACKS

MATERIALS SCIENCE AND ENGINEERING

A. JAMES CLARK SCHOOL *of* ENGINEERING

www.mse.umd.edu

"Perfect Fault"

Self-correcting crystals may end dropped calls.

INSIDE: THE FUTURE OF POWER GENERATION | WIND ENERGY | SAVING ARTIFACTS

chair's MESSAGE

ROBERT M. BRIBER TAKES A LOOK THROUGH THE SAMPLE CHAMBER OF OUR NEW SAXS SYSTEM

OUR MSE RESEARCH ACTIVITIES ARE THRIVING AT THE UNIVERSITY OF MARYLAND.

We are actively upgrading the department's research instrumentation with a recently installed Xenocs small angle X-ray scattering instrument (SAXS) and the imminent purchase of a focused ion beam microscope (dual beam FIB). These instruments will provide complimentary tools to the already excellent electron microscopy and X-ray characterization tools for nanotechnology research at Maryland.

MSE Professors **Eric Wachsman** and **Bing Hu**, along with their colleague Professor **V. Thangadurai** (University of Calgary), won the university's Office of Technology and Commercialization's 2014 Invention of the Year Award in the physical sciences for their work on safe, low cost, high energy density solid state lithium ion batteries. Their work was supported by the Advanced Research Projects Agency for Energy (ARPA-E) and will form the basis of a new start-up company. A second invention, a highly-accurate, self-limiting technique of performing atomic layer etching by MSE Professor **Gottlieb Oehrlein** and graduate student **Dominik Metzler**, was a finalist in the competition. Gottlieb's discovery has made such an impact that the American Vacuum Society has called it a "milestone" *(see page 5).* It also inspired SEMATECH to host the Atomic Layer Etch and Atomic Layer Clean Technology Workshop in San Francisco in April, where Gottlieb was a featured speaker.

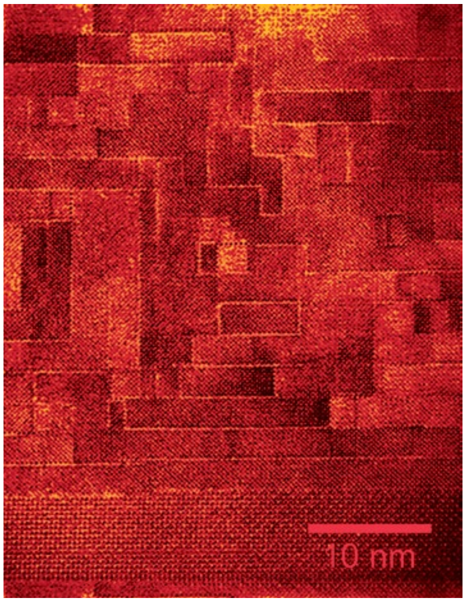
We also received some great news as we were heading to press, which we'll likely tell you more about in our next issue: **Jane Cornett** (Ph.D. '13), advised by Associate Professor **Oded Rabin**, won the university's Distinguished Dissertation Prize in Mathematics, Physical Sciences, and Engineering; graduate student **Willa Freedman**, advised by Professor **Ray Phaneuf**, won a National Science Foundation Graduate Research Fellowship; and so did **Nicholas Weadock** (B.S. '13), who is currently a graduate student at Caltech.

Don't forget—if you're an alumnus or alumna, you can share great news about your life and career by joining the "MSEUMD" Facebook group or e-mailing us at **mse@umd.edu**. You can get the latest MSE news at any time by visiting **mse.umd.edu/news**. Please contact us if you are in the D.C. area and want to visit or reconnect with your professors or the campus.

Until next time,

Robert M. Briber, Professor and Chair, MSE

IN THIS ISSUE:



ON THE COVER:

Not a brick wall. Transmission electron microscopy image of a cross section of a newly characterized tunable microwave dielectric clearly shows the thick layers of strontium titanate "bricks" separated by thin "mortar lines" of strontium oxide that help promote the largely defect-free growth of the bricks. Image courtesy of **David Mueller**. Color added for clarity by **Nathan Orloff**. For the full story, see page 3.

Self-Correcting, "Perfect Fault" Crystals May End Dropped Calls

Professor **Ichiro Takeuchi** is part of an international team that has engineered and measured a new class of nanostructured materials—a family of multilayered "crystalline sandwiches"—that could enable a new generation of compact, high-performance, high-efficiency components for communications devices such as cell phones. The team's results, the culmination of a multi-year collaboration, were published in *Nature,* the world's top weekly scientific journal.

The new multilayer crystals are "tunable dielectrics," materials that enable cell phones and other communications devices to tune to a precise frequency, picking a unique signal out of the large jumble of possible ones.

"This work represents a demonstration of tour de force capabilities by the team which can be unleashed to design and discover new functional materials," Takeuchi says. "The abilities to predict complex materials properties, synthesize them, and test their functional response across a broad frequency range, temperature and electric field, as we did here, is exactly the type of collective effort we would like to pursue more in the future. This is a good example of 'materials-by-design.'"

Takeuchi, a member of the A. James Clark School of Engineering's Department of Materials Science and Engineering (MSE), has been working with National Institute of Standards and Technology (NIST) physicist **James Booth** to develop new techniques to measure these designer dielectrics. Takeuchi is a world leader in the field of combinatorial materials synthesis ("combi"), the rapid, efficient creation of large numbers of compositionally varying samples, which are then screened en masse for desired properties.

Tunable dielectrics work well in the microwave range and beyond, but have been difficult to make and have required too much power, says former Takeuchi Group member and co-lead author **Nathan Orloff** (Ph.D. '10, physics). Orloff, now a materials scientist at NIST, has been working under Booth's guidance on the project since he was a graduate student.

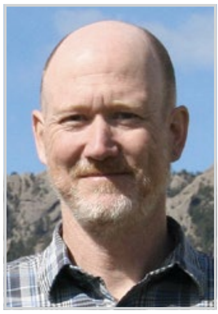
Modern cell phone dielectrics use materials that suffer from misplaced or missing atoms within their crystal structure. These defects interfere with the dielectric properties and lead to power loss. One major feature of the new materials, Orloff explains, is that they self-correct, reducing the effect of defects in the part of the crystal where it counts.

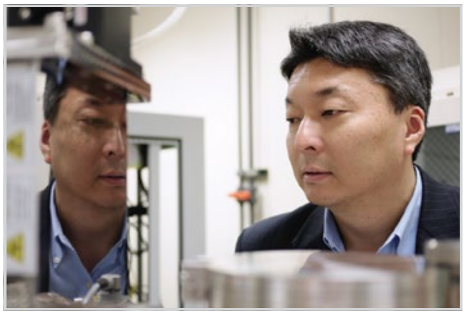
"We refer to this material as having 'perfect faults,'" he says. "When it's being grown, one portion accommodates defects without affecting the good parts of the crystal. It's able to correct itself and create perfect dielectric bricks that result in the rare combination of high tuning and low loss."

The new material has layers of strontium oxide, believed to be responsible for the self-correcting feature, separating a variable number of layers of strontium titanate. Strontium titanate on its own is normally a stable dielectric—not really tunable at all—but another bit of nanostructure wizardry solves that. The sandwich layers are grown as a thin crystalline film on top of a substrate material with a mismatched crystal spacing that produces strain within the strontium titanate structure. This makes it a less stable dielectric—but one that can be tuned.

The new material performs so well as a tunable dielectric, over such a broad range of frequencies, that Booth's team had to develop a new measurement technique just to describe its electronic characteristics.

"We were able to characterize the performance of these materials as a function of frequency running from 10 hertz all the way up to 125 gigahertz," says Orloff. "That's the equivalent of measuring wavelengths from kilometers down to microns all with the same experimental set-up."



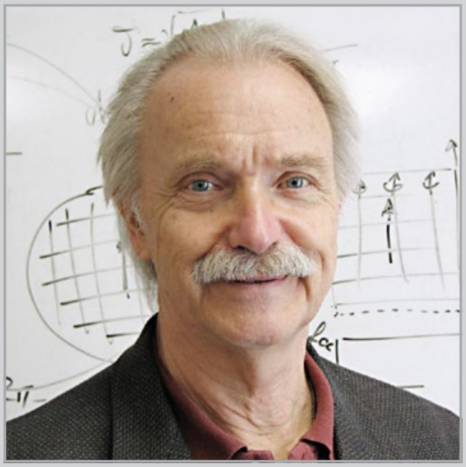


TOP LEFT: JAMES BOOTH. TOP RIGHT: NATHAN ORLOFF. BELOW: ICHIRO TAKEUCHI.

SEE: C-H LEE *et. al.* EXPLOITING DIMENSIONALITY AND DEFECT MITIGATION TO CREATE TUNABLE MICROWAVE DIELECTRICS. NATURE, 502, 532–536, OCT. 24, 2013. DOI:10.1038/NATURE12582.

BOOTH, ORLOFF AND TAKEUCHI'S PRIMARY COLLABORATORS ON THE PROJECT WERE CORNELL UNIVERSITY PROFESSORS CRAIG FENNIE (DEPARTMENT OF APPLIED ENGINEERING AND PHYSICS), WHO PREDICTED THE STRONTIUM TITANATE FILMS' TUNABLE PROPERTIES USING COMPUTATIONAL TECHNIQUES; AND DARRELL SCHLOM (MSE), WHO GREW THE CRYSTAL FILMS USING MOLECULAR BEAM EPITAXY.

STORY ADAPTED FROM "PERFECT FAULTS: A SELF-CORRECTING CRYSTAL MAY UNLEASH THE NEXT GENERATION OF ADVANCED COMMUNICATIONS," BY MICHAEL BAUM, COURTESY OF NIST.



WUTTIG WINS 2013 SENIOR FACULTY RESEARCH AWARD

MSE professor and graduate program director **Manfred Wuttig** received the A. James Clark School of Engineering's 2013 Senior Faculty Outstanding Research Award.

Wuttig was recognized for his transformational contributions to the traditional fields of metallurgy and ceramics into the modern field of functional materials. Most recently, Wuttig's groundbreaking research in the area of multiferroic materials has paved the way for the design of materials with novel and unique properties, which will have far-reaching implications for several engineering fields.

"Professor Wuttig is known not only for his profound impact and discoveries in materials science and engineering, but also for his extensive and extremely successful mentorship of graduate students and young scientists," says Dean and Farvardin Professor **Darryll Pines**.

Among these successful students are Professor **S. Pamir Alpay** (Ph.D. '99), head of UConn's MSE department; and **Shenqiang Ren** (Ph.D. '09), now a professor at the University of Kansas.

Wuttig's recent and current research topics include the synthesis and characterization of magnetoelectric composites, organic multiferroics for spintronics, alloys with magnetostrictive properties, and elastocaloric cooling technologies.

Learn more about Professor Wuttig at **mse.umd.edu/faculty/wuttig**

MARTÍNEZ-MIRANDA RECEIVES APS BOUCHET AWARD

MSE associate professor **Luz J. Martínez-Miranda** received the American Physical Society's (APS) Edward R. Bouchet Award. The award, established to promote the participation of underrepresented minorities in physics, recognizes minority physicists who have distinguished themselves in and made significant contributions to the field.

Martínez-Miranda, an elected Fellow of the APS and past president of the National Society of Hispanic Physicists, was selected "for her pioneering research on liquid crystals, in particular on the interactions of ordered liquid crystals and nanoparticles, and their applications; and [for her] extensive effort in mentoring and increasing diversity in physics and materials science."

She was honored at the society's annual March Meeting, at which she delivered a talk about her most recent discoveries, including a new technique for assessing the suitability of organic liquid crystal nanocomposites for use in photovoltaics. This has enabled her to describe the effects of nanoparticles on the bulk and local structure of liquid crystals.

In addition to a cash prize and an all-expenses paid trip to the March Meeting, the Bouchet Award funds at least three presentations by the awardee at high schools or universities where the promotion of research, studies or careers in physics would have the most impact on minority students.

Watch Professor Martínez-Miranda's Bouchet Award lecture online at: **ter.ps/bouchetvideo**

BRIBER: FELLOW OF THE NEUTRON SCATTERING SOCIETY OF AMERICA

Professor and Chair **Robert M. Briber** was elected to fellowship in the Neutron Scattering Society of America (NSSA). The organization recognized him for "elucidating the structure and dynamics of polymeric and biopolymeric materials and dedicated service to the neutron scattering community."

Briber served as the NSSA's vice president from 1999-2002, and as its president from 2002-2005. He also served as the conference chair of the first American Conference on Neutron Scattering, an event that drew over 400 participants.

His research program has focused on probing the structure, thermodynamics and dynamics of polymer and biopolymer systems using neutron scattering. His current projects include the synthesis and characterization of structured hydrogels, data analysis and modeling of off-specular neutron reflectivity, the synthesis and characterization of nanocomposites, nanoporous Low K dielectric films, and RNA folding.

Briber has played a key role in strengthening the university's neutron scattering programs and facilities. Over the past decade, he has helped secure millions of dollars in grants from the National Institute of Standards and Technology (NIST) and the National Science Foundation (NSF) to support instrumentation purchases, cooperative research and postdoctoral fellowships.

Learn more about Professor Briber at **mse.umd.edu/faculty/briber**

"MILESTONE FOR ATOMIC LAYER ETCHING" HIGHLIGHTED BY AVS

It's not uncommon to hear MSE professors and students discussing their work using atomic layer deposition (ALD), a technique in which a product is built or a coating is applied in layers that may be only atoms thick. ALD's conceptual counterpart is atomic layer etching (ALE), which is used to remove particles from a surface at a similar scale. ALE, however, is considerably less precise and not as efficient.

"ALE is an ideal dry etching technique since it enables atomic-level precision in etching different materials," says Professor **Gottlieb Oehrlein** (joint, MSE and Institute for Research in Electronics and Applied Physics) "This ability is increasingly required as smaller and smaller devices need to be fabricated." Unfortunately, he explains, it has not worked very well in industrial practice.

That could soon change. Oehrlein's group and a team of IBM researchers have devised a process in which precisely applied fluorocarbon reactants and bursts of argon ions are used to etch silicon oxide film, with results accurate down to as little as one angstrom (one ten-billionth of a meter). Unlike current techniques, the reaction is self-limiting, meaning once the reactant is used up, the process stops without the need for external intervention. This also helps improve the quality of the final product.

The research, described as a "milestone" by the American Vacuum Society (AVS), was highlighted in an article in *Beneath the AVS Surface,* the society's newsletter.

Oehrlein's co-authors and collaborators on the ALE project include MSE graduate student **Dominik Metzler** and IBM T.J. Watson Research Center scientists **Robert L. "Bobby" Bruce** (Ph.D. '10), **Sebastian Engelmann** (Ph.D. '08), and **Eric A. Joseph**. Alumni Bruce and Engelmann were members of Oehrlein's Laboratory for Plasma Processing of Materials during their graduate studies at the University of Maryland.

To learn how Oehrlein and his team achieved their results, see:

Fluorocarbon assisted atomic layer etching of SiO_2 using cyclic Ar/C_4F_8 plasma. *J. Vac. Sci. Technol. A* 32, 020603 (2014).

Close Shave: A Milestone for Atomic Layer Etching (ALE). *Beneath the AVS Surface,* January 2014. Download a PDF of the issue at **ter.ps/alemilestone**

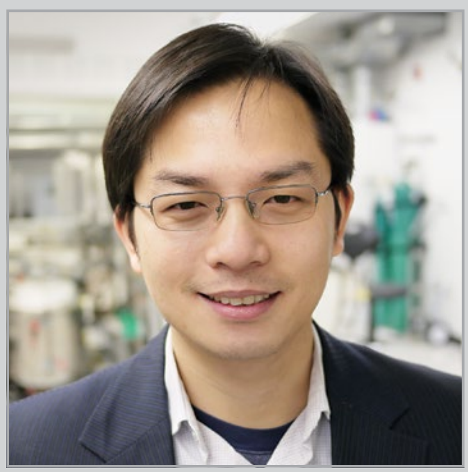
HU HONORED BY ASEE

MSE assistant professor **Liangbing Hu** has been named a "Campus Star" by the American Society for Engineering Education (ASEE). The distinction is granted to society members who have demonstrated excellence in engineering education and research. Campus Stars will be profiled on the ASEE web site, its social media outlets, and in its flagship publication, *Prism*. The program is part of the ASAEE's efforts to raise awareness of the importance and impact of engineering education.

"I try to be innovative and push…for 'surprise' ideas, and linking my fundamental research to practical applications," Hu says in his profile on the ASEE web site. "I encourage [my students] to constantly think about how to come up with great ideas, design experiments, and publish…I encourage them to constantly investigate the fundamentals and think about how to apply them."

Hu, who is also a member of the Maryland NanoCenter and University of Maryland Energy Research Center, studies and develops nanomaterials for use in energy storage systems and flexible electronics. His research group has received attention for its "battery made of wood," which was featured on National Public Radio; and for its transparent nanopaper, which could be used in printed and flexible electronics, sensors and organic solar cells *(see related story, p. 10).* His work has appeared in top publications including *Chemical & Engineering News, ACS Nano, Chemistry World, Energy and Environmental Science,* the *Journal of Materials Chemistry C., Nano Letters, MRS Meeting Scene, Nanowerk,* and *Nature Photonics.*

In addition to his growing roster of graduate students, postdoctoral researchers, and visiting professors, Hu has welcomed many undergraduate and high school students into his group, giving them early hands-on opportunities in energy research. When not in the lab, Hu teaches Materials for Energy I and II at the undergraduate and graduate levels.



To learn more about Hu's work and publications, visit **bingnano.com**, or see:

Morning Edition, National Public Radio: All Charged Up: Engineers Create A Battery Made Of Wood. (Audio and story) **ter.ps/hunpr**

Is This the Future of Electricity Generation?

Based on the original press release by Eric Schurr, Maryland Technology Enterprise Institute (Mtech)

REDOX POWER SYSTEMS, LLC has partnered with University of Maryland researchers to deliver breakthrough fuel cell technologies designed to provide always-on electricity to businesses, homes and eventually automobiles, at about one-tenth the cost and one-tenth the size of current commercial fuel cell systems.

Those fuel cells, based upon patented technology developed by MSE professor **Eric Wachsman**, director of the University of Maryland Energy Research Center, are the foundation of a system being commercialized by Redox that provides safe, efficient, reliable, uninterrupted power, on-site and optionally off the grid, at a price competitive with current energy sources.

The promise is this: generate your own electricity with a system nearly impervious to hurricanes, thunderstorms, cyber attacks, derechos, and similar dangers, while simultaneously helping the environment.

Enter Redox's PowerSERG 2-80, also called "The Cube," which connects to your natural gas line and electrochemically converts methane to electricity. About the size of a large washing machine, the system sits comfortably in a basement, outside of a building, or on a roof, and—with no engine and virtually no moving parts—quietly goes about its business of providing power.

The first-generation Cube runs off natural gas, but it can generate power from a variety of fuel sources, including propane, gasoline, biofuel and hydrogen. The system is a highly efficient, clean technology, emitting negligible pollutants and much less carbon dioxide than conventional energy sources. It uses fuel far more efficiently than an internal combustion engine, and can run at 80 percent efficiency when used to provide both heat and power.

Proprietary technical advances enable Redox to offer the Cube at a tenth of the cost of current systems. Combined with the increasing abundance and falling prices of natural gas, it's a winning solution.

Redox plans to release The Cube in 2015. The first version will be configured to 25 kilowatts, which can comfortably power a gas station, moderately sized grocery store or small shopping plaza.

Additional power offerings will follow. Using fuel cell stacks in a variety of sizes, the company can offer The Cube at 5 kW, to provide always-on electricity for an average American home, or up to 250 kW in one system. Cubes can also be combined to provide even more power in a modular fashion.

A BETTER, CHEAPER FUEL CELL: A 25-YEAR BREAKTHROUGH

Inside The Cube are stacks of small, ten-centimeter-square, millimeter-thick, solid oxide fuel cells (SOFC). Like a battery, each SOFC has a cathode, an anode and an electrolyte, but the comparison ends there. Fuel cells don't store electricity; rather, they create it, and they do so chemically, pulling oxygen ions from the air and conducting them through the cell, where they meet and oxidize the fuel on the other side, creating electricity. The materials the cells are made of are critical to their performance, and that's where Wachsman's expertise lies.

With more than 220 publications and nine patents, Wachsman's greatest contribution may come after a hurricane rips through the East Coast and our lights are still on. That's because he's solved the two main problems that have plagued solid oxide fuel cells: high operating temperature and high cost.

Conventional SOFCs must operate at temperatures as high as 950 degrees Celsius

A REDOX SOLID OXIDE FUEL CELL

to run effectively. This degrades performance, prevents the system from being easily turned on and off, and requires much of it to be constructed with expensive, heat-resistant alloys that drive up prices.

Wachsman decreased the operating temperature of SOFCs to 650 degrees Celsius, with future reductions likely to 300 degrees. At these lower temperatures, the system can turn on much more rapidly, operate with greater reliability, and allow Redox to build The Cube out of conventional stainless steel parts.

But Wachsman didn't stop there. Drawing upon scores of graduate and undergraduate students over two and a half decades, millions of dollars in research funding and a state-of-the-art laboratory at the University of Maryland, he created fuel cells that generate ten times the power at these lower temperatures than anything else on the market.

> "The response to the technology has been overwhelming. We've received thousands of e-mails and phone calls from people asking where they can buy a Cube or how they can invest in the company."
>
> **–Eric Wachsman**

He did this by tackling nearly every aspect of the cell. He developed dual-layer electrolytes using new materials and dramatically improved the anode so it can withstand cycling the system on and off. No part escaped his expert touch, and the entire family of materials he created allows Redox to build systems for a wider range of applications.

"Over a 25-year time period, we have achieved major advances in both the composition of fuel cell materials and the micro- and nanostructure of those materials," says Wachsman. "Putting these together has resulted in a cell that has an extremely high power density, on the order of two watts per square centimeter."

More power means you need fewer cells to do the same work, which also means the systems that contain them can be smaller.

WINNING OVER FEDERAL AGENCIES

After 25 years of advocating the benefits of low-temperature SOFCs, Wachsman finally appears to have the attention of federal agencies that have traditionally focused their interests and funding on hydrogen fuel cells.

The congressionally mandated Hydrogen and Fuel Cell Technical Advisory Committee, which oversees the Department of Energy's fuel cell program, invited Wachsman to give a presentation about Redox at their April 2014 meeting. The Department of Defense recently issued a solicitation for "Ultra-High Power Density Solid Oxide Fuel Cell Stack for High Efficiency Propulsion and Power Systems," whose benchmark and reference was Wachsman's work. (Redox won the grant.) Most recently the Advanced Research Projects Agency–Energy issued a solicitation for "Reliable Electricity Based on Electrochemical Systems," and once again Wachsman's results were used as a benchmark for what the agency wants to achieve.

BIG RESEARCH MEETS BIG BUSINESS

Wachsman started working on solid oxide fuel cells as a graduate student in the 1980s. He always intended for them to make it to market. As far back as 2005, he and then-Ph.D. student **Bryan Blackburn** began exploring the idea of forming a company. In early 2012 they entered the VentureAccelerator Program, an elite initiative of the Maryland Technology Enterprise Institute, or Mtech, that helps select University of Maryland inventors get their research out of laboratories and into industry by creating successful companies.

REDOX MEDIA COVERAGE

The Atlantic: The Navy Has Fuel-Cell Generators; Will You Have Them Soon, Too?
ter.ps/redoxatlanti

Forbes: Redox Power Plans To Roll Out Fuel Cells That Cost 90% Less Than Currently Available Fuel Cells
ter.ps/redoxforbes

Green Tech Media: Could This Be the Fuel Cell to Beat All Fuel Cells?
ter.ps/redoxgreen

MIT Technology Review: An Inexpensive Fuel-Cell Generator
ter.ps/redoxmit

MIT Technology Review: Avoiding the Power Grid
ter.ps/redoxoffgrid

The Washington Post: At Redox Power Systems, the Future of Electricity Lies in Fuel Cells
ter.ps/redoxwpost

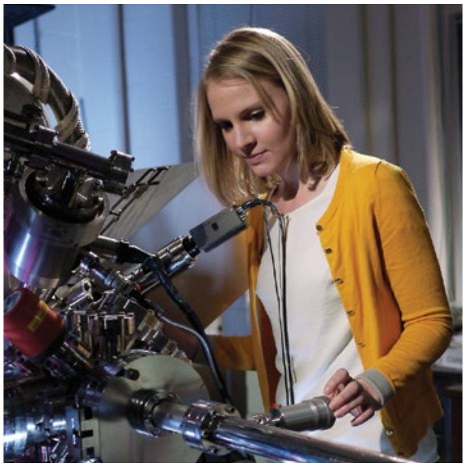
After just three months, a record for the shortest time in the program, Wachsman and Blackburn teamed with **Warren Citrin** and fellow entrepreneurs **David Buscher** and **Robert Thurber** to form Redox Power Systems. The team of five garnered exclusive rights to Wachsman's patents. Redox contracted research to UMD to further refine and improve the fuel cells.

In the future, Redox plans to produce fuel cell systems for automobiles, which the company claims could triple the gas mileage you get from your car.

But for now, they will be happy if, after the next Snowmageddon, Hurricane Sandy or vicious cyber attack, we all still have power.

Learn more about Professor Wachsman's research at **wachsman.umd.edu**.

Using Materials Science & Engineering to Save Priceless Artifacts



AMY MARQUARDT USING X-RAY PHOTOELECTRON SPECTROSCOPY TO ANALYZE THE SURFACE CHEMISTRY OF SILVER AND BRONZE BEFORE AND AFTER A PROTECTIVE COATING IS APPLIED.

ABOUT THE CIC-SMITHSONIAN FELLOWSHIP: IN ADDITION TO RESEARCH-IN-RESIDENCE, THE AWARD INCLUDES A $30,000 STIPEND, TUITION REMISSION AND BENEFITS FOR THE 2014-2015 ACADEMIC YEAR. THE SMITHSONIAN'S OFFICE OF FELLOWSHIPS AND INTERNSHIPS OFFERS THE APPOINTMENTS IN PARTNERSHIP WITH THE CIC, THE ACADEMIC COUNTERPART OF THE BIG TEN CONFERENCE.

MSE graduate student **Amy Marquardt** has received a research-in-residence appointment to the Smithsonian's Museum Conservation Institute (MCI), where she will collaborate on a project that could create a more effective way to preserve bronze art and artifacts. The position is part of a Committee on Institutional Cooperation (CIC)–Smithsonian Institute Fellowship, a highly selective and prestigious award that offers Ph.D. candidates the opportunity to work with Smithsonian staff members and access its resources and facilities. Marquardt's fellowship was one of only six awarded in the entire Big Ten University Conference.

Marquardt, advised by MSE professor **Ray Phaneuf**, is using her expertise in materials science to help museum conservators analyze, clean and preserve their art and artifacts. For the past several years, she has been part of a team working with conservators from the Walters Art Museum to develop nanometers-thick coatings that protect silver from tarnish. The material, applied using atomic layer deposition (ALD), is currently being tested on an artifact from the museum's collection. The project has been reported by *Science,* highlighted by the American Physical Society and the American Vacuum Society, and was the subject of a National Science Foundation video segment called "Silver Saver," narrated by former CNN chief technology and environment correspondent **Miles O'Brien**.

Marquardt recently returned from an international research exchange program at the University of Trento, Italy, where she worked with **Massimo Bersani** at the Fondazione Bruno Kessler. Her project focused on the development of a kinetics model for the corrosion and tarnishing of cultural heritage metal objects, and she continued her work on the optimization of atomic layer deposited metal oxide films that could be used to protect them.

In a previous internship at the MCI, she used microscopy, microanalysis, and spectroscopy to determine the color, mineralogy, and stability of artificial bronze patinas used by conservators to restore the appearance of and protect an object after it's cleaned. Now, on her return, she'll draw on that experience, her time in Italy, and her collaboration with the Walters as she works with Research Scientist **Edward Vicenzi**, Senior Objects Conservator **Carol Grissom**, and Phaneuf to evaluate the ability of ALD coatings to protect bronze patinas. The team will also determine what techniques are required to remove them from an artifact without altering or damaging it.

"So far my ALD coating research has focused on silver, which represents an ideal substrate because it has a uniform surface chemistry," Marquardt explains. "The Smithsonian houses a large number of bronze art and cultural heritage objects from around the world and throughout time. These objects often have a natural or applied patina–an oxide surface layer–whose preservation is challenging because their surface chemistry is extremely complex, non-uniform and sensitive to atmospheric corrosion. With silver, the tarnish layer is typically removed to leave a clean surface; however, patina compositions can vary depending on the object's age, environmental exposure or chemicals used during patination. The big question is whether ALD barrier coatings can be used on, and to stabilize, these non-ideal surfaces while meeting the rigorous standards of art conservation. I am very excited about this unique opportunity to find out!"

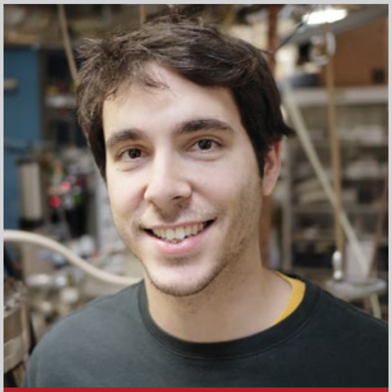
"Amy's work, which aims to develop a safe, visually acceptable and long-lasting conservation treatment for patinated art and artifacts, reflects the Smithsonian's mission of 'Valuing World Cultures.'"

–MSE Professor Ray Phaneuf

BARTIS AND WAN JOIN FUTURE FACULTY PROGRAM

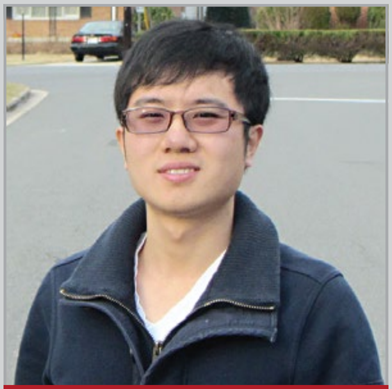
MSE graduate students **Elliot Bartis** (co-advised by Professor **Gottlieb Oehrlein** and Assistant Professor **Joonil Seog**) and **Jiayu Wan** (advised by Assistant Professor **Liangbing Hu**) were among only 24 students chosen to join this year's Future Faculty Program cohort.

The Clark School's Future Faculty Program prepares doctoral students for career-long success in the academic world as mentors and researchers. Participants build skills in areas such as technical and grant writing, curriculum development, teaching, research, oral presentations, applying for academic positions, and interviewing. The program, which includes seminars, a teaching practicum, and a research mentoring practicum, takes three to five semesters to complete.



ELLIOT BARTIS

Bartis works in the emerging field of "plasma medicine"–in this case referring to ionized gas, not the blood component. While plasma/material interactions have long been used to manufacture electronics, the study of its medical applications is relatively new. At room temperature and atmospheric pressure, plasma can be used to sterilize surgical equipment and promote wound healing due to its antibacterial and antimicrobial properties. However, little is known about why and how this works. Bartis is conducting a study designed to explain the complex reactions that occur between plasma and biological materials.



JIAYU WAN

Bartis has wanted to become a professor since his time as an undergraduate, but when he joined MSE's graduate program, he discovered it wasn't as simple as earning a Ph.D. "I realized very quickly that there was far more to being a professor than teaching, and that I did not have any experience in writing proposals or running a research group," he says. "The Future Faculty Program is the best way [for me] to reach my goal as it covers all the bases."

Wan would like to be part of the effort to create a clean and secure energy future. His research focuses on renewable energy conversion and energy storage solutions. Currently, he is developing a new electrochemical intercalating technique (a layering of materials in which the molecules of one insert themselves between the molecules of the other). Wan combines two-dimensional nanomaterials into new, novel materials that have what he describes as "extraordinary" optoelectronic properties. They can be used to make transparent conductors, and the study of them increases our understanding of the kinetic and solid electrolyte interphase problems encountered in the design of rechargeable batteries.

"Academia is a place filled with creativity," says Wan when asked why he would like to become a professor. "It is also a great pleasure to share my passion with students who are interested in materials science."

recent GRADUATES

DECEMBER '13 B.S. GRADUATES

Rajinder Bajwa
Nesredin Kedir
David Newton

DECEMBER '13 M.S. GRADUATES

Yueying Liu
Richard Suchoski
Chanel Tissot

DECEMBER '13 PH.D. GRADUATES AND DISSERTATIONS

Richard Bergstrom: "Morphotropic Phase Boundaries in Ferromagnets." Advisor: Manfred Wuttig

Jane Cornett: "Thermoelectric Transport Phenomena in Semiconducting Nanostructures." Advisor: Oded Rabin

Stephen Daunheimer: "Magnetic Reversal of Artificial Kagome Ice." Advisor: John Cumings

Khim Karki: "Real-Time Investigations of Silicon Nanostructured Electrodes for Lithium-Ion Batteries." Advisor: John Cumings

ROHRBACH NAMED PHILIP MERRILL PRESIDENTIAL SCHOLAR

MSE senior **Kathleen Rohrbach** was named one of 2013-2014's Merrill Presidential Scholars. The honor recognizes the University of Maryland's most successful rising seniors and their mentors from both the University faculty and their K-12 education. Each year, scholars and their mentors are recognized in a special ceremony, and teachers and faculty participate in a workshop designed to strengthen relationships between the university and K-12 schools. To continue the legacy of academic excellence and mentoring, UMD scholarships are awarded in the K-12 mentors' names to first year students from their respective high schools or school districts.

Rohrbach, who minors in nanoscale science and technology, is a member of MSE assistant professor **Liangbing Hu**'s lab, where her current research includes the study of nanobatteries. She is the co-author of one

MERRILL, continued from page 9

of the group's papers, "Highly Transparent and Flexible Nanopaper Transistors," which was published in the high impact journal *ACS Nano.* She is also part of the University Honors Program.

Rohrbach's University of Maryland faculty mentor is Professor **C. Robert Warner** (Department of Mathematics), and her teacher mentor is **Patricia Davis** (Howard High School, Ellicott City, Md.).

Rohrbach says that Davis has made the greatest impact on her life because she was a great teacher both in and out of the classroom. Davis took an interest in Rohrbach's potential and became "a huge source of support" when she was diagnosed with Lyme disease.

Warner was Rohbach's Calculus II professor. "In the first lecture he inspired me to learn as diligently as I could," she writes. "His class was difficult, but it showed me that I was capable of learning things that a week earlier I could not even fathom."

Learn more at: **www.ugst.umd.edu/merrill**

STUDENT'S PRESENTATION HIGHLIGHTED BY MRS

A presentation on transparent, conductive nanopaper by MSE graduate student **Colin Preston** was highlighted in *MRS Meeting Scene,* the Materials Research Society's e-bulletin covering "the very best" its major conferences have to offer.

Preston, advised by MSE assistant professor **Liangbing Hu**, presented his work at the MRS' annual Fall Meeting in Boston, Mass. "Highly Transparent and Conductive Nanopaper Electrode with Enhanced Light Scattering" described the latest developments in the Hu Group's efforts to cut down on electronics waste by creating a conductive material that is also sustainable and biodegradable: nanopaper.

Like ordinary paper, nanopaper is made of wood pulp fibers, but they have been broken down into nanoscale lengths. The fibers, now a network of nanofibrillated (tangled) cellulose (NFC), reduce the paper's ability to scatter light, making it 90-95% transparent. Previously the Hu Group discovered that the addition of a carbon nanotube coating made the paper very strong and highly conductive, which could allow it to be used for printed electronics (such as circuit boards) and in products that require a lightweight construction.

In his presentation, Preston explained that while the original nanopaper has a lot to offer, the extraction of NFC from ordinary paper fibers consumes both time and energy. The next generation of the Hu Group's nanopaper doesn't require NFC. Instead, the cellulose fibers are "detangled" or "unraveled" using a process called tempo-oxidation, and they become "nanoribbons" of cellulose instead of the much shorter nanofibrils. The nanopaper made from these ribbons is 91 percent transparent, strengthened using surface oxidation, and includes a layer of silver nanowires that give it conductivity.

The new nanopaper is being considered for use in solar panels because it scatters more light than indium tin oxide, the material currently used. Increased scattering leads to better light absorption, which should ultimately lead to a more efficient solar panel.

Learn more about nanopaper at: **ter.ps/hucanden2013**

Colin Gore contributed to this story.

THE ECS TOUR GROUP POSES UNDER A MASSIVE ELECTROMAGNET FROM THE RETIRED CYCLOTRON AT LAWRENCE BERKELEY NATIONAL LAB. PHOTO COURTESY OF COLIN GORE.

STUDENTS TOUR LBL-ALS AND POLYPLUS BATTERY COMPANY

The University of Maryland (UMD) student chapter of the Electrochemical Society (ECS) organized tours for student members during the 224th meeting of the ECS. The group visited Lawrence Berkeley National Lab's Advanced Light Source (ALS) and the PolyPlus Battery Company. UMD ECS chapter president and MSE graduate student **Colin Gore** arranged the event.

ECS chapter members **William Gibbons** (Department of Chemical and Biomolecular Engineering), **Ying Liu** (MSE), and **Thomas Winkler** (Institute for Systems Research) joined Gore on the tours. Students from the University of Virginia and Colorado School of Mines chapters also participated.

ALS lab manager **Doug Taube** led the group through the facility. He began by chronicling the history of the lab and its founder, Nobel Laureate Earnest Lawrence, who invented the cyclotron in the 1930s. He also described the eventual repurposing of the facility as a synchrotron source–currently the brightest soft x-ray source in the U.S.–in the 1980s after its cyclotrons were decommissioned. The group was then guided around the synchrotron and its 43 beamlines. Taube highlighted some of the breakthrough research being conducted at several of the end stations, including surface science of advanced fuel cells at ambient pressure and 3D tomography of the xylem in drought-tolerant grape vines.

Following the ALS tour, the group visited the offices of the PolyPlus Battery Company, where CEO/CTO and former ECS Division Chair Dr. **Steven J. Visco** arranged for a demonstration of his company's award-winning technology. PolyPlus specializes in new primary and rechargeable lithium-air, lithium-water, and lithium-sulfur batteries and battery components. New Business Development officer **Thomas Conry** described PolyPlus' unique "protected Li electrode" technology and its implementation in each of their devices. Visco subsequently traveled to UMD, where he delivered a talk titled "Roadmap to Next-Generation Batteries."

Offshore Wind Energy and Reliability

PROFESSOR ARIS CHRISTOU

Among renewable energy sources, wind energy is the most immediately available, and it is a reality in some countries like Germany, Denmark and the U.K.

Development of large wind turbines on a vast scale first took place in the United States and Denmark following the 1973–1974 Arab Oil Crisis, supported mainly by the U.S. Federal Wind Energy Program. In more recent years, wind energy has experienced impressive growth in some northern European countries by going off shore.

The State of Maryland is committed to the development of offshore wind energy, as demonstrated by the passage of the Maryland Offshore Wind Energy Act of 2013. However, cost and reliability remain major issues to overcome. It has been estimated that the cost of an offshore turbine operation is ten times that of its land-based counterpart. This makes the role of reliability crucial.

At UMD, we're leveraging our extensive expertise in energy, reliability, physics of failure, corrosion, environmentally induced degradation, and wide band gap semiconductor power electronics to assist the state in achieving its objectives. My research, funded by the State of Maryland, will provide a power predictive tool and definite reliability figures for turbine designs being considered for implementation in the Atlantic Ocean.

Prior and current work carried out in Denmark and Germany will assist us in obtaining a deeper understanding of the reliability of offshore wind turbines. For this very reason, I became part of a delegation from the State of Maryland which visited the two countries in November 2013.

The trip illustrated the manufacturing and installation issues faced by each developer and industrial supplier. Our conclusion was that the reliability of wind turbines must be improved because of the difficult accessibility of marine locations, which raises the cost of delivered energy to unacceptable levels.

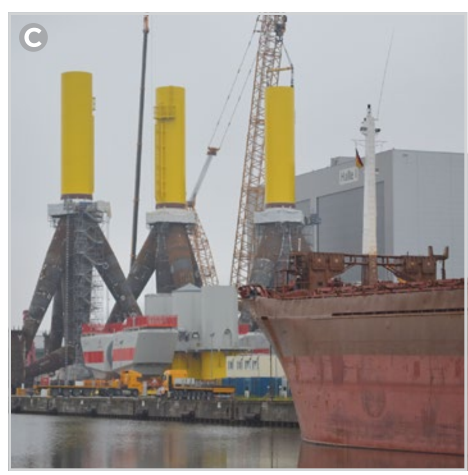
Photos from our visit illustrate the magnitude of both the technology and the challenges of maintaining an offshore wind turbine grid. The tripod-like base alone of the type shown (A, C) is about 91m (300') tall, and each of its blades (D) is up to 30m (100') long. The largest turbines have a diameter of 126m (413'). In contrast, the wingspan of an Airbus A380 is 80m (about 262.5').

Manufacturing (B) is actually the least problematic part of the process. Assembly in the open ocean is dangerous and requires specialized equipment and personnel, as well as the erection of temporary construction platforms. The turbines face life in a harsh environment. Their massive size translates into more surface area that can be attacked by corrosion, fatigue, or mechanical crack propagation. Each contains over 2000 sensors, generating a constant stream of data that must be analyzed on shore to monitor its performance. If one turbine fails, the entire grid may be affected, resulting in power fluctuations–a problem that can't be resolved by simply shutting down the bad unit.

Our research is now producing some key results, by incorporating our knowledge of physics of failure and statistical techniques. We can now predict root cause of turbine failure, as well as assess the criticality of each failure. The degradation models we have previously developed for corrosion and corrosion-fatigue will assist us in assessing the dynamic states of the turbines. We are currently implementing a Monte Carlo approach in order to understand device and component faults and their effect on grid performance.

PROFESSOR CHRISTOU AT THE BASE OF AN OFFSHORE WIND TURBINE IN GERMANY.

TURBINE ENGINES AND HOUSINGS DWARF WORKERS AT A MANUFACTURING FACILITY IN GERMANY.



TURBINE BASES NEAR A BARGE IN GERMANY MAKE NEARBY 16-WHEEL TRUCKS LOOK LIKE TOYS.

A. JAMES CLARK
SCHOOL OF ENGINEERING

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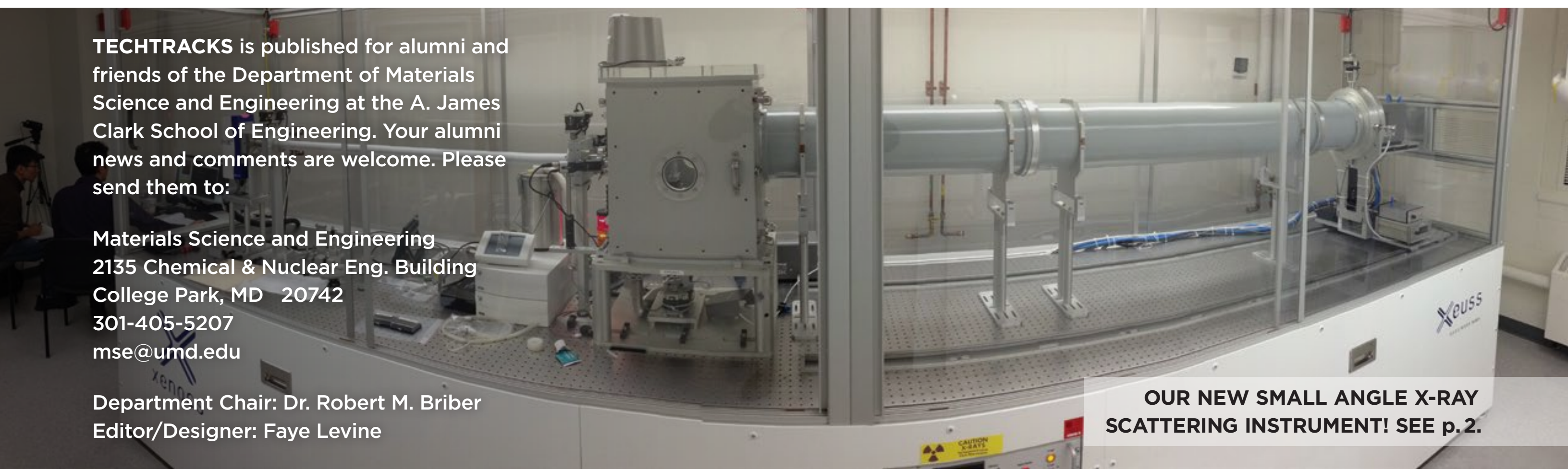

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OUR NEW SMALL ANGLE X-RAY SCATTERING INSTRUMENT! SEE p. 2.

Exploring Offshore Wind Energy for Maryland

Is the technology behind offshore wind turbines reliable? Is offshore wind energy conversion cost effective? What sort of degradation or potential failures should be expected of the equipment as it ages in the ocean? Will Maryland's investment in offshore wind farms to help meet its energy needs?

These are the questions University of Maryland professors **Aris Christou** (Materials Science and Engineering) and **F. Patrick McCluskey** (Department of Mechanical Engineering) will answer after completing a new study funded by Maryland's Higher Education Commission, the Maryland Energy Administration, and the Exelon Corporation.

The project, "Reliability and Failure Mechanisms of Offshore Wind Energy Systems (ROES)," recently received a two-year Maryland Offshore Wind Energy Challenge Grant (MOWER). MOWER grants are designed to recruit Maryland's research community to develop the technology and deployment strategy necessary for the state to establish a wind power industry and supply chain that is expected to create local jobs.

Christou and McCluskey are conducting research that will determine the reliability of grid interconnected wind energy conversion systems (WECS) and the impact of the marine environment on their mechanical and electronic equipment. Their reliability studies on corrosion and environmental stress degradation will be conducted at the device, component and systems level through the development of innovative models and physics-of-failure based protocols.

The work addresses key concerns the Department of Energy has expressed about WECS by modeling the fundamental device and packaging mechanisms that cause failures, and providing design recommendations for improved reliability.

TO LEARN MORE, SEE DR. CHRISTOU'S ESSAY ON PAGE 11.