FALL 2012

TECHTRACKS

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

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A NEWSLETTER FOR ALUMNI AND FRIENDS OF THE DEPARTMENT OF MATERIALS SCIENCE AND ENGINEERING AT THE A. JAMES CLARK SCHOOL OF ENGINEERING, UNIVERSITY OF MARYLAND.

IN THIS ISSUE:

The Weird World of "Remote Heating"

DISCOVERY: WHEN ELECTRIC CURRENT IS RUN THROUGH CARBON NANOTUBES, OBJECTS NEARBY HEAT UP WHILE THE NANOTUBES THEMSELVES STAY COOL. UNDERSTANDING THIS PHENOMENON COULD LEAD TO NEW WAYS OF BUILDING COMPUTER PROCESSORS THAT CAN RUN AT HIGHER SPEEDS WITHOUT OVERHEATING BY DISSIPATING THEIR HEAT ELSEWHERE.

It seems like an ordinary morning at first, but when you go to the kitchen for breakfast, something is wrong. Your toast is burned but the toaster is cold. The switch on the stove is set to "HI" and the teapot is whistling, but the burner isn't hot. As you check your e-mail on your laptop, the surface of the kitchen table it sits on gets warmer and warmer, but the computer isn't overheating—in fact, it's cool to the touch.

ASSOCIATE PROFESSOR **JOHN CUMINGS** (LEFT) AND **KAMAL BALOCH** (PH.D. '12).

In an electron microscopy facility at the A. James Clark School of Engineering at the University of Maryland, **Kamal Baloch** and **John Cumings** were having exactly that kind of morning. They ran their experiments over and over, and the result was always the same: when they passed an electrical current through a carbon nanotube, the substrate below it grew hot enough to melt metal nanoparticles on its surface, but the nanotube itself seemed to stay cool, and so did the metal contacts attached to it.

This might not seem so strange at first glance—after all, food cooked in a microwave oven gets hot while the oven itself stays close to room temperature. The problem is that Baloch and Cumings weren't intentionally generating a microwave field. They were only passing a direct electrical current through the nanotube, which should have caused it to heat up. The data were telling them a story that didn't seem to make any sense—one about a plugged-in toaster that could burn bread without getting hot.

The phenomenon known as "Joule heating" dictates that an electrical current will cause travelling electrons to bounce off the atoms of a metal wire, making them vibrate in place. These vibrations create heat, and any conducting wire should show the effect,

continues next page

chair's MESSAGE

ROBERT M. BRIBER

WHAT'S NEW AND EXCITING IN MSE@UMD? PLENTY!

We have achieved another year of record undergraduate enrollment, and we are home to some of the best students in the A. James Clark School of Engineering, as evidenced by three NSF graduate research fellowships awarded in 2012. *(See back cover.)*

We've continued to publish new discoveries in the field: **John Cumings**, who recently received a NSF-CAREER Award and was promoted to Associate Professor with tenure, was the first to describe a nanoscale phenomenon known as "remote Joule heating" *(see our cover story)*; while **Oded Rabin**'s paper on the unexpected growth of silver nanoparticles from silicon pores graced the cover of the journal *Nanotechnology* *(see p. 3)*. **Ichiro Takeuchi** has been working with the Department of Energy's Oak Ridge National Laboratory on the continued characterization of bismuth samarium ferrite, which holds potential as a lead-free substitute for lead zirconium titanate *(see p. 4)*. **Richard Livingston** is making new headway on the quest to recycle coal fly ash into quality concrete *(see pp. 4-5)*.

Did you know that Maryland is a hot spot for launching new technologies and businesses? Citing a top-ranked public school system and resources for entrepreneurs, the U.S. Chamber of Commerce has ranked the State of Maryland first in the nation for entrepreneurship and innovation in its "Enterprising States" report, up from 7th place last year. *(See **tinyurl.com/ca8zj95** for more information.)* Our faculty and students have access to excellent programs that help them launch successful startups, patent and license intellectual property, and win funding at competitions and from venture capital firms.

Producing engineering innovations, and innovators, is where the Department of Materials Science and Engineering's potential for greatness lies. You can make a difference with a gift of any amount to help support undergraduate scholarships, graduate fellowships, and named professorships. We encourage you to learn more about giving to the Clark School, and about a wide variety of giving options, by visiting **www.eng.umd.edu/giving**.

And don't forget—if you're an alumnus or alumna, you can keep us informed of the great news in your life and career by joining the "MSE UMD" 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**.

Until next time,

Robert M. Briber
Professor and Chair, MSE

REMOTE HEATING, continued from page 1

including the heating elements of toasters, hair dryers, and electric stovetops. Carbon nanotubes are known to conduct electricity like nanoscale metallic wires, so Baloch and Cumings expected to see the same effect when they passed current through a carbon nanotube.

They used a technique developed in Cumings's lab called electron thermal microscopy, which maps where heat is generated in nanoscale electrical devices, to observe the effect of the current on a nanotube. They expected to see heat traveling along the length of the nanotube to metal contacts attached to it. Instead, the heat seemed to jump directly to the silicon nitride substrate beneath, heating it up while leaving the nanotube relatively cold.

"This is a new phenomenon we're observing, exclusively at the nanoscale, and it is completely contrary to our intuition and knowledge of Joule heating at larger scales—for example, in things like your toaster," says Baloch, who conducted the research while a graduate student at the University of Maryland. "The nanotube's electrons are bouncing off of something, but not its atoms. Somehow, the atoms of the neighboring materials—the silicon nitride substrate—are vibrating and getting hot instead."

"The effect is a little bit weird," admits Cumings, an associate professor in the Department of Materials Science and Engineering who oversaw the research project. He and Baloch have dubbed the phenomenon "remote Joule heating."

But how is it even possible for the nanotube's electrons to vibrate the substrate's atoms if they're separated by distance, even one measuring in nanometers? Baloch and Cumings speculate a "third party" is involved: electrical fields.

"We believe that the nanotube's electrons are creating electrical fields due to the current, and the substrate's atoms are directly responding to those fields," Cumings explains. "The transfer of energy is taking place through these intermediaries, and not because the nanotube's electrons are bouncing off of the substrate's atoms. While there is some analogy to a microwave oven, the physics behind the two phenomena is actually very different."

Baloch adds that the remote Joule heating effect could have far reaching implications for computing technology. "What currently limits the performance of a computer's processor is the speed at which it can run, and what limits the speed is the fact that it gets too hot," he explains. "If you could find some way of getting rid of the waste heat more effectively, then it could run faster. A transistor that doesn't dissipate energy within itself as heat, like the nanotubes in our experiment, could be a game-changer. This new mechanism of thermal transport would allow you to engineer your thermal conductor and electrical conductor separately, choosing the best properties for each without requiring the two to be the same material occupying the same region of space."

For the moment, an air of mystery still surrounds the phenomenon, which has been observed only at the nanoscale, and only in carbon materials. The next steps are to determine if other materials can produce the effect, and if so, what properties they must have. "We now know that silicon nitride can absorb energy from a current-carrying nanotube in this way, but we would like to test other materials, such as semiconductors and other insulators," Cumings explains. "If we can really understand how this phenomenon works, we could start engineering a new generation of nanoelectronics with integrated thermal management."

This discovery was published in the April 8th advance online issue of *Nature Nanotechnology.* The research was supported by a grant from the U.S. Department of Energy Office of Basic Energy Sciences. Baloch and Cumings's collaborators and co-authors on the work are MSE graduate student **Norvik Voskanian** and Department of Physics graduate student **Merijntje Bronsgeest**.

For more information, see: Kamal H. Baloch, Norvik Voskanian, Merijntje Bronsgeest, and John Cumings. "Remote Joule heating by a carbon nanotube." Nature Nanotechnology. Published online 8 April 2012.

LEE, RABIN RESEARCH ON COVER OF *NANOTECHNOLOGY*

One discovery that literally grew out of another has earned a place on the cover of *Nanotechnology.* The paper, authored by Department of Materials Science and Engineering (MSE) graduate student (now alumnus) **Seung Yong Lee** (Ph.D. '12) and his advisor, MSE assistant professor **Oded Rabin**, describes how silver nanoparticles unexpectedly blossomed out of the silicon pores that contained them, transforming into new crystalline structures.

In an earlier study, Lee, Rabin and their colleagues described how nanoscale silver cubes can enhance the effectiveness of surface-enhanced Raman scattering (SERS) by focusing and intensifying the light from a laser probe. Because the cubes are more effective in SERS when clustered, the team drove the nanocubes to self-assemble at predetermined locations, nestled in bowl-shaped pores patterned into a silicon substrate using ion-etching.

When the silver nanocubes were left unattended on the silicon, however, something unexpected and remarkable occurred: their structure changed and they merged, resulting in beautiful crystal growths resembling branches and flowers.

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"Nobody anticipated a reaction that involves solid metal particles changing their shape at room temperature," says Rabin. "The effect is unique in that it only occurs at the nanoscale."

Lee and Rabin theorize that the pores in the silicon, etched by exposing it to energetic sulfur hexafluoride (SF6) ions through a patterned mask, remained reactive because they contained silicon and SF6 "shrapnel" left over from the process. When the shrapnel came into contact with silver nanoparticles, the silver was stimulated to grow into new forms. The pair also discovered that the effect is unique to nanoparticles—when the pores were exposed to a solution of silver ions, nothing happened.

"We think the reason people haven't seen this before is because you need the combination of a nanoscale material and a silicon substrate processed in this particular way," Rabin adds.

Lee and Rabin explored the reaction mechanism by modifying the reaction conditions, eventually discovering how to control and guide the growth of the crystals. Rabin thinks the discovery will lead to more awareness of the complexity of flaws in nanomanufacturing.

For more information, see: Seung Yong Lee and Oded Rabin. "A unique solid–solid transformation of silver nanoparticles on reactive ion-etching-processed silicon." Nanotechnology, 2012, 23(6).

ENERGY TEAM TURNS IN STRONG PERFORMANCE AT $75K BUSINESS PLAN COMPETITION

RedOx, a startup company founded by MSE and ChBE professor and University of Maryland Energy Research Center (UMERC) director **Eric Wachsman** and his colleague **Bryan Blackburn**, took second place in the Graduate Student, Faculty and Researchers Category and received a Warren Citrin Social Impact Award at the Maryland Technology Enterprise Institute's University of Maryland $75K Business Plan Competition.

RedOx received a $7500 prize to further its development of power generation technologies for a variety of applications.

Now entering its thirteenth year, the $75K Business Plan Competition promotes the commercialization of innovative ideas and university-created technologies by offering faculty, students, and alumni prizes for the best new venture plans. The competition emphasizes learning by offering one-on-one coaching for finalists, as well as the experience of presenting ideas to an experienced panel of judges. Companies active in the competition have generated millions in revenues, grants and awards.

ELECTRON MICROSCOPY INSPIRES FLEXOELECTRIC THEORY BEHIND "MATERIAL ON THE BRINK"

Advanced electron microscopy conducted at the Department of Energy's Oak Ridge National Laboratory (ORNL) has led to a new theory to explain intriguing properties in a material originally discovered at the Clark School's Department of Materials Science and Engineering (MSE) that has potential applications in capacitors and actuators.

A research team including ORNL's **Albina Borisevich** examined thin films of bismuth samarium ferrite, known as BSFO, which exhibits unusual physical properties near its transition from one phase to another. BSFO holds potential as a lead-free substitute for lead zirconium titanate (PZT), a similar material currently used in dozens of technologies from sensors to ultrasound machines.

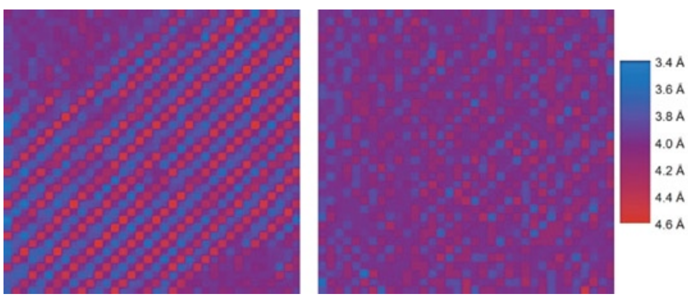
BSFO, discovered using the combinatorial approach by MSE professor **Ichiro Takeuchi** and his colleagues in 2008, is synthesized by pulsed laser deposition at the University of Maryland. Takeuchi and his team, who have dedicated themselves to the ongoing characterization of BSFO and its development for eventual commercial use, received a U.S. patent for the material in May.

Takeuchi's team recently collaborated with Borisevich's to further their investigation. "The fascinating properties of BSFO continue to attract the attention of the community," Takeuchi explains. "We knew that there were interesting nanometer scale structures in the material, but ORNL was able to directly study the inner workings of BSFO at the atomic level, and the results were totally surprising."

Materials such as BSFO and PZT are often called "materials on the brink" in reference to their enigmatic behavior, which is closely tied to the transition between two different phases. These phases are characterized by structural changes in the material that produce different electrical properties.

"The best properties of the material are found at this transition," Borisevich says. "However, there has been a lot of discussion about what exactly happens that leads to an enhancement of the material's properties."

Using aberration-corrected scanning transmission electron microscopy, the team mapped the position of atoms in BSFO films to find what happens to the local structure at the transition between ferroelectric and antiferroelectric phases. The results were published in the April 2012 issue of *Nature Communications.*



ATOMIC SPACING MAP DERIVED FROM HIGH RESOLUTION ELECTRON MICROSCOPY SHOWS MARKED MODULATION IN POSITIONS OF ATOMS IN BSFO..

"We discovered that neither of the two dominant theories could describe the observed behavior at the atomic scale," says Borisevich.

Some theorists have proposed that the material forms a nanocomposite at the transition. In this case, the energy of the boundaries between phases would have to approach zero, but Borisevich's team found something entirely different: the boundary's energy was instead effectively negative.

"When the energy of boundary is negative, it means that the system wants to have as many boundaries as possible, but with atom sizes being finite, you can't increase it to infinity," Borisevich explains. "So you have to stop at some short-period modulated structure, which is what happens here."

Based on its observations, the team concluded that the mechanism behind the observed behavior was linked to a relatively weak interaction called flexoelectricity.

"Flexoelectricity means that you bend a material and it polarizes," says ORNL coauthor **Sergei Kalinin**. "It's a property present in most ferroelectrics. The effect itself is not necessarily very strong on macroscopic scales, but with the right conditions, which are realized in nanoscale systems, it can produce very interesting consequences."

Borisevich adds that the team's approach can be used to investigate a variety of systems with similar phase boundaries, and she emphasizes the importance of mapping out materials at the atomic scale.

"In this particular case, electron microscopy is the only way to look at very local changes because this material is a periodic structure," she says. "The decisive atomic-scale information had been missing from the discussion."

The work was carried out in collaboration with MSE alumnus **Nagarajan Valanoor** (Ph.D. '01), currently an associate professor at the University of New South Wales, Australia.

Story courtesy of and adapted from the original by Morgan McCorkle, Oak Ridge National Laboratory.

RECYCLING COAL BYPRODUCTS INTO QUALITY CONCRETE

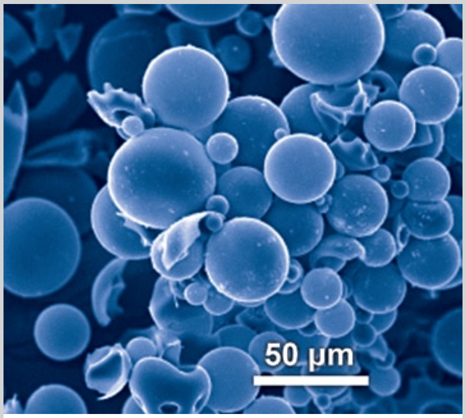
Department of Civil and Environmental Engineering professor **Amde M. Amde** and Department of Materials Science and Engineering adjunct professor **Richard A. Livingston** have been awarded a three-year, $300,000 grant from the National Science Foundation's (NSF) Civil Engineering Division to investigate the use of fly ash, a byproduct of the coal industry, as a replacement for Portland cement in the manufacturing of concrete.

Generated by the combustion of coal, fly ash is currently recycled in a variety of ways—including use in road construction, soil stabilization, paint, and building materials—to help keep some of the millions of tons of it produced each year out of landfills. One of its popular uses is as a substitute for a portion of the Portland cement required to make concrete.

It is less expensive than Portland cement, and its glassy quality improves the flow of the concrete in its liquid state. However, concrete made with fly ash does not always perform as expected because the ash's particle size and chemical composition may vary widely depending on the coal and combustion conditions it came from. This inherent variability also makes it difficult to study and improve materials made with it.

The newly-funded project builds on the results of a 2009 proof-of-concept study in which Amde, Livingston and their colleagues created and characterized a synthetic glass fly ash that could serve as an accurate predictive model of behavior of real fly ash in concrete. Because the synthetic material's particle size and composition can be controlled, it held the promise of enabling systematic studies of fly ash-based concrete for the first time. With the NSF's support, those studies can now take place.

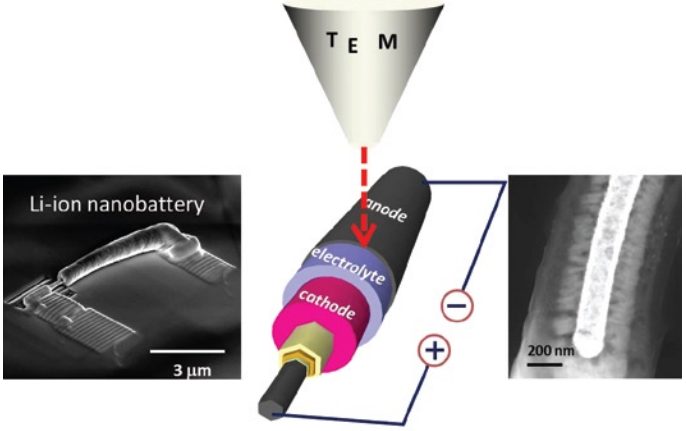
"There is a lot of industry interest in this research because of its potential to transform the way that fly ash is used as a replacement for Portland cement," Livingston explains. "[The new grant] will enable us to investigate a wider range of fly ash compositions and conduct systematic studies of the variation of key factors. It will also use a wider range of analytical techniques, including nuclear magnetic resonance [imaging] and cluster analysis."



A SCANNING ELECTRON MICROSCOPY IMAGE OF SYNTHETIC FLY ASH.

WORLD'S SMALLEST BATTERY: HOW SMALL IS TOO SMALL?

It turns out you can be too thin—especially if you're a nanoscale battery. Researchers from the National Institute of Standards and Technology (NIST), the Clark School's Department of Materials Science and Engineering (MSE), and Sandia National Laboratories built a series of nanowire batteries to demonstrate that the thickness of the electrolyte layer can dramatically affect the performance of the battery, effectively setting a lower limit to the size of the tiny power sources.[1] The results are important because battery size and performance are key to the development of autonomous MEMS—microelectromechanical machines—which have potentially revolutionary applications in a wide range of fields.



HOW SMALL IS TOO SMALL? USING A TRANSMISSION ELECTRON MICROSCOPE, NIST RESEARCHERS WERE ABLE TO WATCH INDIVIDUAL NANOSIZED BATTERIES WITH ELECTROLYTES OF DIFFERENT THICKNESSES CHARGE AND DISCHARGE. THE NIST TEAM DISCOVERED THAT THERE IS LIKELY A LOWER LIMIT TO HOW THIN AN ELECTROLYTE LAYER CAN BE MADE BEFORE IT CAUSES THE BATTERY TO MALFUNCTION. CREDIT: TALIN/NIST

MEMS devices, which can be as small as tens of micrometers (that is, roughly a tenth the width of a human hair), have been proposed for many applications in medicine and industrial monitoring, but they generally need a small, long-lived, fast-charging battery for a power source. Present battery technology makes it impossible to build these machines much smaller than a millimeter—most of which is the battery itself—which makes the devices terribly inefficient.

NIST researcher and MSE adjunct professor **Alec Talin** and his colleagues, including MSE associate professor **John Cumings**, created a veritable forest of tiny solid-state lithium ion batteries—about 7 micrometers tall and 800 nanometers wide—to see just how small they could be made with existing materials and to test their performance.

Starting with silicon nanowires, the researchers deposited layers of metal (for a contact), cathode material, electrolyte, and anode materials with various thicknesses to form the miniature batteries. They used a transmission electron microscope to observe the flow of current throughout the batteries and watch the materials inside them change as they charged and discharged.

The team found that when the thickness of the electrolyte film falls below a threshold of about 200 nanometers,[2] the electrons can jump the electrolyte border instead of flowing through the wire to the device and on to the cathode. Electrons taking the short way through the electrolyte—a short circuit—cause the electrolyte to break down and the battery to quickly discharge.

"What isn't clear is exactly why the electrolyte breaks down," says Talin. "But what is clear is that we need to develop a new electrolyte if we are going to construct smaller batteries. The predominant material, LiPON, just won't work at the thicknesses necessary to make practical high-energy-density rechargeable batteries for autonomous MEMS."

1 D. Ruzmetov, V.P. Oleshko, P.M. Haney, H.J. Lezec, K. Karki, K.H. Baloch, A.K. Agrawal, A.V. Davydov, S. Krylyuk, Y. Liu, J. Huang, M. Tanase, J. Cumings and A.A. Talin. Electrolyte stability determines scaling limits for solid-state 3D Li-ion batteries, Nano Letters 12, 505-511 (2011).

2 Represents the group's latest data collected after publication of the paper cited above.

Story courtesy of and adapted from the original by Mark Esser, National Institute of Standards and Technology. Originally published as "Nanopower: Avoiding Electrolyte Failure in Nanoscale Lithum Batteries" in NIST Tech Beat, March 20, 2012.

CUMINGS PROMOTED

The Department of Materials Science and Engineering (MSE) and the A. James Clark School of Engineering extend their congratulations to **John Cumings**, who was promoted to the rank of associate professor with tenure, effective July 1.

"John's accomplishments in teaching and research are exemplary and the promotion is an acknowledgement of the excellent work he has done over the past seven years," says MSE professor and chair **Robert M. Briber**.

Cumings, who earned his Ph.D. in physics at the University of California at Berkeley in 2002, studies the dynamic properties of nanoscale systems. Since joining MSE in 2005, he and his group have routinely been recognized for their unusual discoveries at the nanoscale and the development of novel research techniques that made many of them possible. Among their notable accomplishments are the creation of a "pseudo ice" used to study the behavior of hydrogen atoms in real ice that seem to defy the Third Law of Thermodynamics; the invention of an technique called electron thermal microscopy, which allows real-time tests of nanoscale devices *in situ;* and the discovery of a phenomenon dubbed "remote Joule heating." *(See cover story.)*

Cumings leads the University of Maryland Energy Frontier Research Center's anode team, which is developing a silicon nanowire-based battery anode capable of enhancing energy storage in lithium-ion batteries. He is also part of a group of faculty and staff that has been instrumental in the development of the university's Nanoscale Imaging Spectroscopy and Properties (NISP) Laboratory, where he conducts most of his research.

In 2011, he received a National Science Foundation (NSF) Faculty Early Career Development (CAREER) Award for his work on frustration in nanomagnetic lattices and the Clark School's Junior Faculty Outstanding Research Award.

Cumings has been active in improving the education of students and young scientists. He is a member of the Clark School's Keystone Faculty, a group dedicated to the success and retention of freshmen engineering students, and also serves as one of MSE's undergraduate advisors. In 2010, he was a co-PI on proposal that received $15 million from National Institute of Standards and Technology to establish a postdoctoral research program at the Maryland NanoCenter.

"I have always been very proud of my colleagues and the research conducted here," says Cumings. "This achievement is an affirmation that Maryland is also proud me. I am excited about what the future holds."

RABIN WRITES *NATURE NANOTECHNOLOGY* NEWS AND VIEWS COLUMN


ODED RABIN

MSE assistant professor **Oded Rabin**, an innovator in the use of nanocubes and plasmonic nanostructures to improve the effectiveness of surface enhanced Raman spectroscopy (SERS), was invited to comment on a new discovery in the field in *Nature Nanotechnology*'s July 2012 op-ed News and Views column.

Rabin's essay, "Self-assembly: Judging a nanocube by its cover," introduces readers to a paper in the same issue, "Self-orienting nanocubes for the assembly of plasmonic nanojunctions." In the paper, **Andrea R. Tao** (University of California, San Diego) and her colleagues demonstrate how a mixture of polymers placed around a collection of silver nanocubes guided their self-assembly into particular patterns. The silver nanocubes were coated with a hydrophilic (water-miscible) polymer and embedded in a thin film of a hydrophobic (water-repelling) polymer. The two polymers repel each other, pushing the nanocubes into linear and branched formations. By varying the length of the polymer strings Tao's team successfully controlled whether neighboring cubes aligned face-to-face or edge-to-edge. Rabin comments that such small modifications in the positions of plasmonic nanoparticles lead to dramatic changes of the optical properties of the whole structure.

Rabin explains that novel technologies for guiding the parallel self-assembly of nanoscale objects into larger structures are key to the development of scalable and inexpensive nanomanufacturing techniques. The incorporation of tunable polymers whose properties can be activated or reversed by external stimuli in Tao's systems, he proposes, could result in easily-processed smart-materials suitable for many types of sensing and diagnostic applications.

"[C]ombinations of bottom-up and top-down approaches could potentially offer greater control and reproducibility of the nanoparticle assembly process," he writes. "…The more we understand about the non-specific interactions in such systems, and how they can be used to balance attractive and repulsive forces on multiple length scales, the more deterministic and technologically relevant the self-assembly process will become."

WACHSMAN: OUTSTANDING ACHIEVEMENT AWARD

University of Maryland Energy Research Center (UMERC) director **Eric Wachsman** (joint, Departments of Materials Science & Engineering and Chemical & Biomolecular Engineering) has received the Electrochemical Society High Temperature Division's 2012 Outstanding Achievement Award.

Wachsman will receive the award at a ceremony at the society's 2012 Pacific Rim Meeting on Electrochemical and Solid-State Science (PRIME) in Honolulu, Hawaii, in October, where he is also scheduled to deliver a talk.

Wachsman's research interests include the development of solid oxide fuel cells (SOFCs), gas separation membranes, solid-state gas sensors, electrocatalytic conversion of CH_4, and the post-combustion reduction of NO_x using advanced ion conducting materials.

DID YOU KNOW THAT WHEN HE'S NOT IMPROVING SOLID OXIDE FUEL CELLS *(SEE STORY BELOW),* COLIN GORE IS ONE OF THE PILOTS OF *GAMERA II,* THE CLARK SCHOOL'S RECORD-SETTING HUMAN-POWERED HELICOPTER? VISIT www.agrc.umd.edu/gamera TO LEARN MORE! BELOW: COLIN (CENTER, SEATED) PEDALS *GAMERA II* INTO ACTION.

PHOTO BY LISA HELFERT.

EPSTEIN NAMED ONE OF UMD'S UNDERGRADUATE RESEARCHERS OF THE YEAR

MSE senior (now alumnus) **Eric Epstein** was named an Undergraduate Researcher of the Year by the Maryland Center for Undergraduate Research for his accomplishments in the field of lithium-ion battery research. He was selected from a highly competitive group of nominees working in diverse fields throughout the university. Epstein received his award and was introduced by his advisor, MSE associate professor **John Cumings**, at the opening ceremony of the 2012 Undergraduate Research Day, held on April 25.

Epstein worked in Cumings's research group, where he collaborated with MSE graduate student **Khim Karki** on an investigation into the electrochemical properties of silicon nanowires as they undergo charge and discharge in lithium ion battery cells.

Silicon anodes have great potential for use in lithium ion batteries because they have ten times the capacity of typical carbon anodes, but they tend to break down during use. Using an *in situ* transmission electron microscopy technique, Epstein and Karki were able to observe, analyze and document the behavior of silicon nanowires in realtime. They also explored the nanowires' potential to self-heal.

"There are some serious issues with silicon that prevent it from being successfully employed in commercial battery cells," Epstein explains. "One problem is it is brittle, so it tends to fracture when lithium is inserted and extracted....To mitigate this issue, people have engineered electrodes using nanostructured silicon [nanowires]; however, even [that] fails in batteries. People don't yet fully understand the failure mechanisms of nano-silicon in battery cells. This is where we come in."

Epstein was also the recipient of a 2012 Graduate Research Fellowship from the National Science Foundation *(see related story, back cover),* a 2010-2011 L-3 Undergraduate Scholarship, and the recipient of MSE's 2012 Engineering Student Research Award.

A self-described "avid member" of Engineers Without Borders (EWB), Epstein was part of a team that designed a water pump, storage, and filtration system for a medical center in Burkina Faso, Africa. During winter break in 2010, he collaborated with several students from the University of Maryland EWB chapter to build a bioretention facility near a large campus parking lot, which currently filters water runoff from over 2.5 acres of impervious land coverage on campus.

FOUNDATION SUPPORTS GORE'S EFFORTS TO IMPROVE FUEL CELLS

MSE graduate student **Colin Gore**, advised by MSE professor and University of Maryland Energy Research Center director **Eric Wachsman**, has been awarded a 2012-2013 Achievement Rewards for College Scientists (ARCS) Hesse Endowment Fellowship for his proposal to improve the fuel flexibility of low-temperature solid oxide fuel cells (SOFCs).

Unlike the more familiar proton exchange membrane (PEM) fuel cells, SOFCs can convert any kind of fuel into electricity—not just hydrogen—and do it far more efficiently than steam or internal combustion engines. Gore is part of a larger team of researchers in Wachsman's group working to make SOFCs more powerful while reducing their operating temperature and production costs.

"Engineered properly, SOFCs can be the most efficient power sources for vehicles, homes, or entire cities, depending on the size of the fuel cell stack," says Gore. Companies such as Bloom Energy have already commercialized SOFC boxes that are being used by Google, Walmart, and other high-profile customers. Gore describes the SOFCs designed by his group as belonging to the next generation of products, which will address certain problems and shortcomings.

Conventional SOFC anodes are prone to accumulating carbon deposits when they are operated using hydrocarbon fuels like gasoline. Eventually, the carbon clogs the cell, which results in a loss of power. To address the problem, Gore has developed a novel anode composed of layers of multiple materials that meet different demands in different regions, have the necessary conductivity, and are immune to carbon deposits.

Gore says his ARCS fellowship is not only a great honor, but will also provide additional support for his research by funding the equipment he will use to model reformed hydrocarbon fuels and to assess his anodes' power and stability under different operating conditions.

Gore, who received his B.S. in materials science and engineering from Lehigh University, describes himself as a "broadly curious" person who was attracted to the field's many practical applications and interdisciplinary approach to research. He chose the University of Maryland and the Clark School so he could study under Wachsman, an expert in SOFCs.

"He has a keen perspective on the societal energy issues that drive his research," says Gore, "so I know my work has focused potential for meaningful impact."

Sponsored by the Metropolitan Washington Chapter of the ARCS Foundation, Inc., ARCS fellowships provide outstanding students in science, medicine and engineering with a renewable award of $15K per year to support their contributions to the advancement of their fields. Each year, the Foundation also provides an endowed ARCS Fellowship to a student in a selected field of study.

Gore's fellow MSE graduate student and ARCS Scholar **Jane Cornett**, advised by MSE Assistant Professor **Oded Rabin**, had her fellowship renewed.

Watch an interview with Colin Gore in which he discusses his work at: youtu.be/ubFaORN12Rs

NSF RESEARCH FELLOWSHIPS, continued from back cover

for use in the early diagnosis of neurodegenerative diseases. Outside of class, Godo has been a mentor for high school students in nanotechnology and robotics programs, as well as a tutor on campus for his fellow college students. His ultimate goal, he says, is to “make significant contributions to the scientific and engineering communities in the emerging field of nanotechnology, especially its applications to medicine.”


ERIC EPSTEIN

“Tunji impressed me with his high motivation, enthusiasm, openness to suggestions, and his determination to enhance his research experience by exploring on his own topics related to the work in my lab,” says Oehrlein.

Eric Epstein (B.S. ’12) worked in MSE associate professor **John Cumings**’ group, where he collaborated with graduate student **Khim Karki** on an investigation into the electrochemical properties of silicon nanowires as they undergo charge and discharge in lithium ion battery cells. *(See related story, p. 7.)* Silicon anodes have great potential for use in lithium ion batteries because they have ten times the capacity of carbon anodes, but they tend to fracture. Epstein and Karki worked to document silicon’s exact failure mechanisms, and also explored its potential to self-heal.

Epstein got his start working for Cumings as a participant in the UMD MRSEC’s Research Experiences for Undergraduates program, and his experience enabled him to obtain a position conducting similar research for the Naval Research Laboratory. He is now a graduate student at the University of Illinois at Urbana-Champaign, where he hopes to specialize in optoelectronics, photovoltaics, and batteries. “I hope my work has a major impact in developing renewable energy technology that is practical,” he says.

Current graduate student **Hanna Nilsson**, also advised by Cumings, focuses on characterizing the thermal contact resistance and thermal conductivity of carbon nanotubes using an *in situ* transmission electron microscopy technique called electron thermal microscopy. Estimated at up to 6,000 W/(mK), carbon nanotubes’ theoretically high thermal conductivity should make them ideal for heat management in small-scale electronics, but experimental measurements have shown much lower values because of the tubes’ thermal contact resistance. Nilsson’s goal is to characterize this property and determine how it might be controlled, paving the way for the material’s broader use in electronics.


HANNA NILSSON

Nilsson plans to pursue a career in academia, where she can pass on her fascination with atomic scale physics to the next generation of students. She chose to attend the University of Maryland for her graduate studies, she says, because of its unique combination of a large campus offering top-notch research facilities and MSE’s small department size, which allows students and faculty to build strong relationships.

“I could not be more proud of Eric and Hanna’s success,” says Cumings. “It is a testament to the quality of the students and the quality of our programs.”

AWARD FUNDS DEVELOPMENT OF SOLID-STATE, HIGH POWER LITHIUM-AIR BATTERY

MSE graduate student **Marshall Schroeder**, advised by Maryland NanoCenter director Professor **Gary Rubloff** (MSE, Institute for Systems Research), was named a John and Maureen Hendricks Energy Research Fellow.

Established by the John and Maureen Hendricks Charitable Foundation in 2008 to support the efforts of the University of Maryland Energy Research Center (UMERC), the John and Maureen Hendricks Energy Research Fellowship program supports students engaged in research that advances the frontiers of energy science and technology, particularly forward-looking approaches to alternative energy generation and storage.

Schroeder received the award for his proposal to design and construct a novel three-dimensional, high-aspect ratio, all-solid-state, lithium-O_2 battery. The battery is a proposed successor to today’s popular lithium-ion batteries, which Schroeder believes are approaching the material limits of further improvements.

Lithium-O_2 batteries, also known as lithium-air batteries, consist of a lithium anode, a lithium ion-conducting electrolyte, and a porous cathode that uses oxygen from the surrounding environment as its oxidant rather than storing ions within the battery’s electrodes. Lithium-O_2 batteries have a potential energy density of up to ten times that their lithium-ion cousins. Schroeder will explore the use of a new material and nanostructure for the cathode, the most complex component of a lithium-O_2 battery, that exhibits good oxygen capture, decomposition, and diffusion, high conductivity, and stability through cycles of charging and discharging. He will also design and characterize the battery’s other components, integrate them with the new cathode using atomic layer deposition, optimize their interfaces, and finally fabricate and test a prototype.

Schroeder will conduct the research under the auspices of the Nanostructures for Electrical Energy Storage (NEES) group, the university’s Department of Energy-sponsored Energy Frontier Research Center (EFRC) directed by Rubloff.

Schroeder began working for Rubloff as an undergraduate majoring in materials science and engineering. As he neared the completion of his degree, he came to the conclusion there was more he wanted to accomplish.

"I realized that I had access to a tremendous number of facilities and instruments here at UMD, and was very interested in pursuing the work I had started," he says. After being accepted into MSE's graduate program and earning his B.S. with university honors in 2010, he remained with the Rubloff Group. He performs his current research on the system he helped to assemble as an undergraduate.

Outside of the lab, Schroeder enjoys soccer and flag football, and is one of the captains of the university's Ultimate Frisbee team. He describes himself as an avid fisherman and guitarist.

Schroeder is the second member of the Rubloff Group in recent years to be named a John and Maureen Hendricks Energy Research Fellow; he was preceded by **Parag Banerjee** (Ph.D. '11) in 2008.

Watch an interview with Marshall Schroeder in which he discusses his work at: http://youtu.be/L5fNw8_WrLU

ASHLEY PARTICIPATES IN NIST SUMMER RESEARCH PROGRAM

ASHLEY

MSE senior **Elizabeth Ashley** was accepted into the 2012 National Institute of Standards and Technology's (NIST) Summer Undergraduate Research Fellowship program (SURF).

Ashley spent the summer at NIST's Material Measurement Laboratory, where she conducted research on the use of polymer thin films in semiconductors under the guidance of Dr. **R. Joseph Kline**. Kline, a project leader in NIST's Polymers Division, is using small angle X-ray scattering (SAXS), reflectivity, and resonant soft X-rays to characterize line structure and pattern shapes in block copolymer lithography. The results could be used to improve the quality of semiconductor chips.

"I chose this project because I love nanotechnology and studying nanoscale materials," says Ashley. "Optical and electronic material properties are incredibly fascinating and have enormous untapped commercial potential. I'd like to be a part of the cutting edge research that goes toward improving electronic devices by manipulating materials on an atomic level."

Ashley had previously worked in MSE professor **Manfred Wuttig**'s research group, where she studied smart materials, shape memory alloys, and multiferroic materials. She assisted Wuttig's group in its study of novel block copolymers with ferroelectric and ferromagnetic properties by preparing thin film samples and characterizing the materials using atomic force microscopy.

To learn more about NIST SURFs in the Washington, D.C. area, visit www.nist.gov/surfgaithersburg.

MSE STUDENTS VISIT W.L. GORE

MSE UNDERGRADUATES AT W.L. GORE

Nine students from MSE recently toured the W.L. Gore and Associates facilities in Newark, Delaware. The trip was sponsored by the department's undergraduate Materials Engineering Society (MatES) and organized by its treasurer, **Douglas Trigg**. W.L. Gore's **Tiffany Herman** hosted the visit.

Gore is a leading manufacturer of specialty materials, including its famous GORE-TEX® fabric, which is used in high-performance outerwear. The company also produces cables, electronic and energy components, clean room and safety fabrics, filtration products, biomedical and pharmaceutical products, vents, and sealants.

"We choose [to visit Gore] because of their strong background in applications of materials science—specifically with ePTFE," says Trigg, referring to the company's proprietary version of polytetrafluoroethylene, a polymer with a variety of useful properties, including high strength and thermal and chemical resistance. "It was also chosen because of its great work atmosphere."

Students were given a tour of the Gore Capabilities Center, which demonstrates how the company handles problems and finds different applications for the same base material, such as ePTFE, by changing one or two of its properties to fit a particular need.

"What I think students came away with was a thought process on how to address problems," says Trigg. "First problems are assessed based on their impact [on] people. Then the solutions are looked at based on a certain material: How can we improve this existing situation with the application of our material? Then design, testing, and characterization come into play....One strong takeaway was the concept of designing to meet a goal, which is the essence of engineering."

DAUNHEIMER WINS MSE GRADUATE RESEARCH AWARD

DAUNHEIMER

Congratulations to MSE graduate student **Stephen Daunheimer,** winner of the 2012 MSE Graduate Research Award for his doctoral thesis and related presentation, titled "Artificial Kagome Ice: Frustration for Engineering."

Daunheimer, advised MSE associate professor **John Cumings**, is currently studying patterned magnetic thin films known as "artificial kagome ice." His dissertation focuses on the magnetic reversal of this system to investigate the function of geometric frustration on arrays of nanoscale magnetic elements. Patterned magnetic thin films have applications in many fields including data storage, spintronics, and other nanoscale electric and magnetic devices.

STUDENTS WIN BEST PAPER AWARD AT MICRO/NANO SYMPOSIUM

Three students from Institute for Systems Research director and Department of Electrical and Computer Engineering (ECE) professor **Reza Ghodssi**'s MEMS Sensors and Actuators Laboratory (MSAL) won the Best Student Poster Award at the 2012 Mid Atlantic Micro/Nano Alliance Symposium, held in March in Annapolis, Md. Department of Materials Science and Engineering graduate student **Brendan Hanrahan** and undergraduate researchers **Jeremy Feldman** (ECE) and **Saswat Misra** (ECE) won for their research, "Off-the-Shelf MEMS for Rotary MEMS."

The same team presented their work at the prestigious IEEE MEMS 2012 Conference in Paris, France, at the end of January 2012, where it was well received by colleagues in the international MEMS community.

TEAM MSE TAKES 3RD IN ALUMNI CUP COMPETITION

The Department of Materials Science and Engineering (MSE) took third place in a first-of-its-kind competition at the Clark School during National Engineers Week in February 2012.

The inaugural Alumni Cup competition gave eight teams of students–one from each engineering department–less than one week to create a Rube Goldberg-inspired device designed to inflate and pop a balloon at least ten inches in diameter. During the competition, each team had three chances to run their devices. They were judged on overall success, effective incorporation of themes and concepts from their respective disciplines in their devices' functionality, and school spirit.

The members of Team MSE, who showed their spirit by donning decorated cleanroom suits, included undergraduates **Natan Aronhime**, **Nick Faenza**, **Coit Hendley**, **Sepideh Parvinian**, **Kathleen Rohrbach**, **Ben Shefter**, **Komal Syed**, and **Nick Weadock**.

Team MSE's device began with a ball resting on a piece of toilet paper. After water was applied to the toilet paper, it corroded, releasing the ball down a tube. The ball landed on a switch, which turned on both a vacuum pump, whose exhaust began to inflate the balloon, and a hair dryer aimed at a piece of stretched shape memory metal. As the shape memory metal heated, it contracted to its original form, pulling open a gate and releasing a magnetic metal ball, which rolled through a slightly angled copper tube. The ball's magnetic field created an opposing field in the tube, slowing down its progress so it would take approximately 20 seconds to reach the other end, allowing the balloon time to inflate to the required size. When the magnetic ball finally emerged from the tube, it dropped into a cup, triggering the release of a toy car down a ramp. At the end of the ramp, the car knocked a ball onto a plinko board. The ball traveled down the plinko board (which in this case represented phonon scattering), knocked into another toy car, which in turn sent yet another ball through a funnel and into a miniature Ferris wheel. As the Ferris wheel turned, it pulled a pin, releasing a platform. A piece of Silly Putty attached to the platform began to stretch from the load placed on it (representing creep) until it broke. The Silly Putty fell into a cup, which pressed down on a pair of scissors, cutting a string holding a hammer (representing a Charpy impact test), which in turn fell on the balloon, popping it.

The competition was conceived and funded by a team from the Clark School Alumni Chapter led by **Kevin Schoonover** (B.S. '06, aerospace engineering) and **Liz Goldwasser**, (B.S. '03, mechanical engineering). It was judged by Associate Dean **Bill Fourney**, Alumni Director **Josey Simpson**, **Doyin Adewodu** (M.S. '10, electrical engineering), and engineering alumni chapter president **Gregg Wollard** (B.S. '89, civil engineering).

studentAWARDS

Congratulations to the following students, who have all demonstrated outstanding performance and have made contributions to the Department and field. Complete award citations are available on our web site at: **www.mse.umd.edu/news/news_story.php?id=6426**

DEPARTMENT AWARDS

Chairman's Outstanding Senior Award: **Natan Aronhime**

Outstanding Materials Student Service Award: **Steven Ramiro** and **Douglas Trigg**

The Department of Materials Science and Engineering Student Research Award: **Eric Epstein**

CLARK SCHOOL AWARDS

The Dinah Berman Memorial Award: **Nicholas Weadock**

INDUSTRY AWARDS

L-3 Undergraduate Scholarship: **Alex Sposito**

KARKI, KOZEN SELECTED FOR FUTURE FACULTY PROGRAM

The Department extends its congratulations to graduate students **Khim Karki** (advised by Associate Professor **John Cumings**) and **Alexander Kozen** (advised by Professor **Gary Rubloff**), who were two of only 20 students from throughout the Clark School chosen to join the 2012 Future Faculty Program cohort.

The program prepares students for academic careers in top-50 engineering schools by helping them hone their skills in areas such as technical and grant writing, curriculum development, teaching, research, oral presentations, and interviewing. It includes seminars, a teaching practicum, and a research mentoring practicum.

KHIM KARKI

Both Karki and Kozen look forward to inspiring the scientists who will one day be members of their research groups, and feel the Future Faculty program will provide them with skills and expectations they need to both find positions and succeed in academia.


DWIGHT HUNTER
Alfred P. Sloan Foundation Minority Ph.D. Program

HUNTER PROFILED IN NACME ANNUAL REPORT

MSE alumnus **Dwight Hunter** (Ph.D. '11, formerly advised by Professor **Ichiro Takeuchi**), was prominently featured in the National Action Council for Minorities in Engineering's (NACME) 2011 Annual report, "Resilience: Ensuring U.S. Competitiveness in a Flat World."

NACME, whose vision is to shape "an engineering workforce that looks like America," supports U.S. competitiveness by helping to increase the number of Latino, African American, and Native American men and women in science, technology, engineering and mathematics education and careers.

Hunter, who currently works at Intel, is one of four "resilient members of the NACME Continuum" profiled in the report. The piece tells the story of Hunter's journey from an aspiring young scientist in Jamaica to a doctor of materials science and engineering and corporate research engineer in the U.S., overcoming a number of financial challenges in the process. His studies at the Clark School were supported in part by NACME's Alfred P. Sloan Foundation Minority Ph.D. Program.

GODO ESTABLISHES BIOMEDICAL RESEARCH SCHOLARSHIP

With a donation of $5,000, MSE alumnus **Olatunji Godo** (B.S. '11) has established a scholarship for undergraduate students conducting biomedical research in the Fischell Department of Bioengineering and the Departments of Chemical and Biomolecular Engineering and Materials Science and Engineering. Godo established the scholarship so that other students might have similar opportunities to those awarded him as a Clark School student.

He was a recipient of an A. James Clark Scholarship, a University of Maryland Scholarship, an L-3 Communications Research Scholarship and a National Science Foundation (NSF)-funded Louis Stokes Alliances for Minority Participation Scholarship while a student at the Clark School. He also received funding to attend an international conference to present the results of his research investigating a method of early diagnosis of neurodegenerative diseases such as Alzheimer's using nanotechnology. Godo went on to receive an NSF Graduate Research Fellowship Program fellowship *(see related story, back cover).*

ALUMNA NAMED INTERNATIONAL NUCLEAR SAFETY ATTACHÉ

The United States Nuclear Regulatory Commission (NRC) has appointed alumna **Cynthia C. Jones** (M.S. '96 and Ph.D. '01, nuclear engineering) as its new Nuclear Safety Attaché at the U.S. Mission to International Organizations in Vienna, Austria. Jones will serve as the Mission's expert on nuclear safety issues and programs, and provide programmatic and policy oversight of the International Atomic Energy Agency's (IAEA) safety program on behalf of the United States. She will formally assume the post in September 2012.

Jones, who previously served as the Senior Level Advisor for Nuclear Security in NRC's Office of Nuclear Security and Incident Response, has extensive international experience in radiation safety and nuclear security. She also serves as the U.S. National Officer and Advisory Committee member for the IAEA's International Nuclear and Radiological Event Scale (INES). In 2011, she was elected as one of 100 scientific experts worldwide to serve as a Council Member to the U.S. National Council on Radiation Protection and Measurements. Prior to joining the NRC, she held positions at government institutions and universities in the areas of nuclear engineering, radiation protection and environmental sciences.

"I'm very proud of Cynthia's achievement," says Department of Materials Science and Engineering professor and nuclear reactor director **Mohamad Al-Sheikhly**. He was Jones' advisor during her time at Maryland, and she was his first Ph.D. student. Her dissertation research, he says, has had long-reaching, positive effects on both human health and the environment.

"Using electron beam radiation, she was the first person able to remediate PCB from the oil used in transformers and capacitors in electric power stations," he explains, referring to polychlorinated biphenyl, an industrial dielectric fluid that was discovered to be highly toxic and difficult to safely dispose of. "She not only converted the PCB into a less toxic material, but also made the oil reusable. Her approach was magnificent."

Story adapted from the NRC press release.

recent GRADUATES

MAY 2012 B.S. GRADUATES

Natan Aronhime
Eric Epstein
Schuyler Fearins
Eric Feldman
Kevin Mecadon
Coit Hendley
Maureen Perry
Steven Ramiro
Ben Shefter
Alex Sposito
Jason Thomen
Doug Trigg
Chris Wolfram

MAY 2012 M.S. GRADUATES

Paul Lambert
Jennifer Shih

MAY 2012 PH.D. GRADUATES & DISSERTATIONS

Amanda Forster: "Long Term Stability and Implications for Performance of High Strength Fibers Used in Personal Body Armor." Advisor: Mohamad Al-Sheikhly

Konstantinos Gerasopoulos: "Integration and Characterization of Tobacco Mosaic Virus Based Nanostructured Materials in Three-dimensional Microbattery Architectures." Advisor: Reza Ghodssi (Electrical and Computer Engineering/ISR)

Seung Yong Lee: "Assembly of Silver Nanocube Clusters and Tuning of Surface Plasmon Resonances for Surface-Enhanced Raman Scattering." Advisor: Oded Rabin

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ABOUT THE COVER IMAGE

THE SCANNING ELECTRON MICROSCOPY IMAGE (COLORED RED) USED ON THE COVERS SHOWS A GOLD NANOPARTICLE ARRAY THAT HAS BEEN TEMPLATED BY AN UNDERLYING PATTERN FROM A BLOCK COPOLYMER FILM. SUCH UNIFORMLY DISTRIBUTED GOLD NANOPARTICLE ARRAYS CAN BE FABRICATED BY THE METHOD DEVELOPED BY ROBERT M. BRIBER'S AND ODED RABIN'S RESEARCH GROUPS. THE PROCESS HAS RECENTLY BEEN SCALED UP TO 4-INCH WAFERS. THIS GOLD NANOPARTICLE ARRAY CAN BE USED IN SURFACE ENHANCED RAMAN SCATTERING (SERS) APPLICATIONS. SERS IS AN OPTICAL SPECTROSCOPY TECHNIQUE USEFUL IN DETECTING TRACE AMOUNT OF CHEMICALS, INCLUDING EXPLOSIVES, CONTAMINANTS, PATHOGENS, ALLERGENS AND TOXINS.

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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Editor: Faye Levine

THREE MSE STUDENTS WIN NSF GRADUATE RESEARCH FELLOWSHIPS

Three students from Department of Materials Science and Engineering (MSE) were awarded 2012 Graduate Research Fellowships from the National Science Foundation (NSF).

Each highly competitive Graduate Research Fellowship consists of 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. Fellows are also granted access to TeraGrid, the NSF's open scientific discovery supercomputing infrastructure, and have the opportunity to take part in professional development activities.

OLATUNJI GODO (B.S. '11) WORKING AT A TRANSMISSION ELECTRON MICROSCOPE

Post-baccalaureate student **Olatunji Godo** (B.S. '11) has been active in research throughout and following his undergraduate studies, starting with a project for MSE professor **Gottlieb Oehrlein** in which he analyzed X-ray photoelectron spectroscopy data to broaden the understanding of material modifications during plasma processing. More recently he worked on a project led by professors **Sheryl Ehrman** (Department of Chemical and Biomolecular Engineering) and **Sameer Shah** (formerly of the Fischell Department of Bioengineering) in which he fabricated and characterized biocompatible iron nanoparticles

continues page 8