NC STATE

DEPARTMENT OF MATERIALS SCIENCE AND ENGINEERING | **NEWS** | **2017**

THE **NSF TRAINEESHIP PROGRAM**

UNITING DATA WITH MATERIALS SCIENCE

- PAGE 16

RESEARCH **HIGHLIGHTS**

THE LATEST RESEARCH FROM THE DEPARTMENT

- PAGES 4-8

SCI**BRIDGE**

THERMOELECTRIC PHONE CHARGERS AND STUDENT SCHOLARSHIPS

A NEW DIMENSION OF MATERIALS SCIENCE AND ENGINEERING RESEARCH

- PAGE 10

AWARDS & PROMOTIONS

FACULTY AND STUDENT AWARDS

- PAGE 29

UNDERGRADUATE RESEARCH

ALEX HSAIN WINS **2017 TRUMAN SCHOLARSHIP**

- PAGE 9

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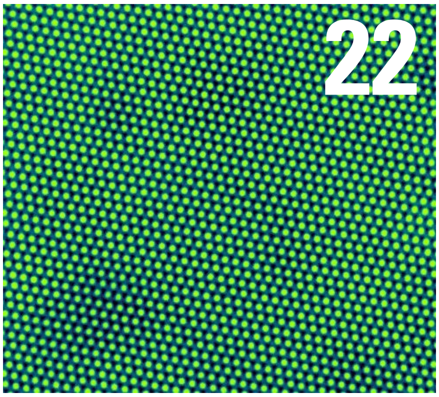
2017 NEWS
DEPARTMENT OF MATERIALS SCIENCE AND ENGINEERING

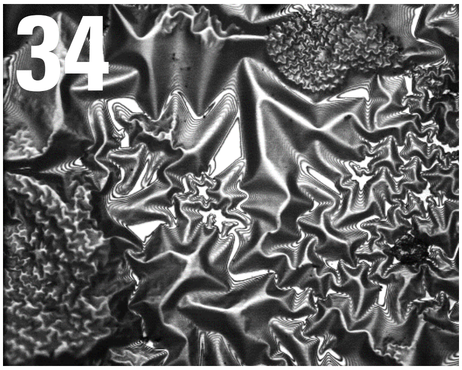
CONTENTS

RESEARCH **HIGHLIGHTS**

FRONT COVER IMAGE: *Michael Theis via Flickr Creative Commons.* Veronica Augustyn discusses the latest SciBridge experiment kit that can charge a mobile phone, and the impact the international project is having on her students and her collaborators in Africa.

UNDERGRADUATE STORIES





FROM THE DEPARTMENT

Dear MSE Friends and Stakeholders.

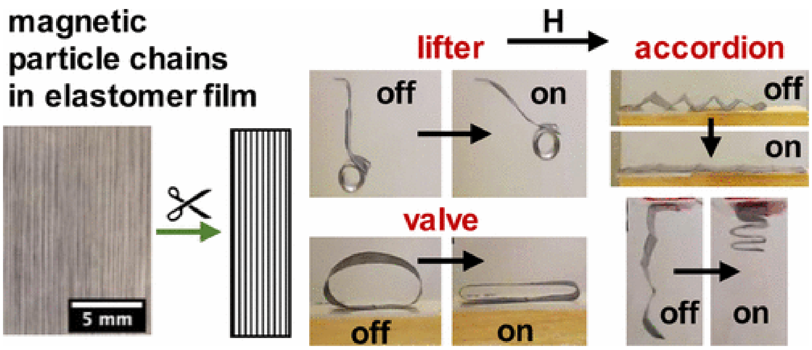
Welcome to the fall 2017 newsletter. We are very proud to be able to share with you the many accomplishments of our faculty, the quality and impact of our research, the innovations in our education and outreach activities, and the most important product of our department – our graduates. All of these have come together to create an exciting and vibrant community of researchers who are pushing the frontiers of science and engineering, while turning out the leaders of tomorrow who will shape our community for the decades to come.

This past year our department head, Professor Justin Schwartz, moved on to become the Harold and Inge Marcus Dean of Engineering at Penn. State University. Through Professor Schwartz's leadership, our department saw tremendous growth in both the size and in the accomplishments of our faculty and students. As we search for a new permanent department head, we will continue to carry this momentum forward. As this newsletter goes to press, we are adding exciting new research areas to our department, and continuing to expand the world-class research facilities on which our department, the university and the broader research communities have come to rely. We are already excited to bring you more details of this expansion in the next newsletter!

Achievements like those in the pages of this newsletter are only possible through the hard work and commitment of our faculty, students, alumni and friends like you who remain dedicated to supporting our mission. We appreciate your interest in our department and thank you for giving us a chance to share our enthusiasm. We look forward to continuing our relationship with you.

DONALD W. **BRENNER**
KOBE STEEL DISTINGUISHED PROFESSOR
INTERIM DEPARTMENT HEAD

NEW ADVANCES IN SOFT ROBOTICS: MANIPULATION OF MICROPARTICLE CHAINS USING MAGNETIC FIELDS



Schmauch's participation was funded by the Research Triangle MRSEC, NSF grant number DMR-1121107. The work was also supported by NSF grant number DMR-1056653.

Joe Tracy, associate professor studying applications for colloidal magnetic, metallic and semiconductor nanoparticles, and his research group have used magnetic fields to remotely manipulate microparticle chains embedded in soft robotic devices. Their findings represent a fundamental advance in the control of soft robots.

"By putting these self-assembling chains into soft robots, we are able to have them perform more complex functions while still retaining relatively simple designs," says Tracy, corresponding author of the paper "Chained Iron Microparticles for Directionally Controlled Actuation of Soft Robots", published earlier this year in *ACS Applied Materials & Interfaces*. "Possible applications for these devices range from remotely triggered pumps for drug delivery to the development of remotely deployable structures."

The new technique builds on previous work in the field of self-assembling, magnetically actuated composites by Tracy and Orlin Velev, the INVISTA Professor of Chemical and Biomolecular Engineering at NC State.

Lead author of the paper is Marissa Schmauch, a former undergraduate student at the University of Tulsa, who worked on the project while at NC State as part of the NSF's Research Experiences for Undergraduates program. For this study, Tracy and Schmauch introduced iron microparticles into a liquid polymer mixture and then applied a magnetic field to induce the microparticles to form parallel chains. The mixture was then dried, leaving behind an elastic polymer thin film embedded with the aligned chains of magnetic particles.

"The chains allow us to manipulate the polymer remotely as a soft robot by controlling a magnetic field that affects the chains of magnetic particles," Tracy explains. Specifically, the direction of the magnetic field and its strength can be varied. The chains of iron microparticles respond by aligning themselves and the surrounding polymer in the same direction as the applied magnetic field.

Using this technique, Tracy, Schmauch and Velev, together with coauthors Benjamin Evans, associate professor of physics at Elon University, and former NC State Ph.D. student Sumeet Mishra, have created three kinds of soft robots. One device is a cantilever that can lift up to 50 times its own weight. The second device is an accordion-like structure that expands and contracts, mimicking the behavior of muscle. The third device is a tube that is designed to function as a peristaltic pump – a compressed section travels down the length of the tube, much like someone squeezing out the last bit of toothpaste by running their finger along the tube.

"We're now working to improve both the control and the power of these devices, to advance the potential of soft robotics," Tracy says.

The group has also developed a metric, called the specific torque for assessing the performance of magnetic lifters, such as the cantilever device. "We do this by measuring the amount of weight being lifted and taking into account both the mass of particles in the lifter and the strength of the magnetic field being applied," says Evans. "We think this is a useful tool for researchers in this area who want to find an empirical way to compare the performance of different devices."

The results of this study promise to facilitate further development of soft robots based on chained magnetic particles, and also advance the engineering of materials with higher specific torque. ■

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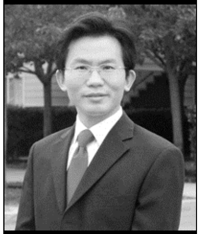
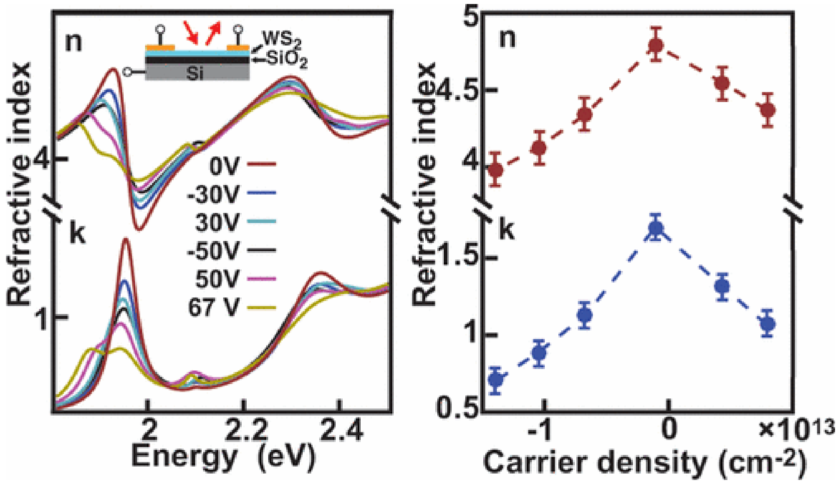
CONTROLLING LIGHT WITH ELECTRIC FIELDS



This work was supported by the National Science Foundation under grant ECCS-1508856, and the Center for the Computational Design of Functional Layered Materials at Temple University, which is funded by the Department of Energy under grant DESC0012575.

LINYOU CAO DISCOVERS HOW TO TUNE REFRACTIVE INDEX USING CMOS-COMPATIBLE ELECTRICAL GATING



In May this year, Linyou Cao, associate professor specializing in photons and charge carriers in nanostructured materials, and his Ph.D. student Yiling Yu, lead author, revealed that they can manipulate light with electric fields in the paper: "Giant Gating Turnability of Optical Refractive Index in Transition Metal Dichalcogenide Monolayers", published in *Nano Letters*.

"Our method is similar to the technique used to provide the computing capabilities of computers," explains Cao. "With this new discovery, light may be controlled to be strong or weak, spread or focused, pointing one direction or others by an electric field. We think that, just as computers have changed our way of thinking, this new technique will likely change our way of watching. For instance, it may shape light into arbitrary patterns, which may find applications in goggle-free virtual reality lenses and projectors, the animation movie industry or camouflage."

Controlling light with electric fields is difficult. Photons, the basic units of light, are neutral – they have no charge, so they usually do not respond to electric fields. Instead, light may be controlled by tuning the refractive index of materials. Refractive index refers to the way materials reflect, transmit, scatter and absorb light. The more one can control a material's refractive index, the more control you have over the light that interacts with that material.

"Unfortunately, it is very difficult to tune refractive index with electric fields," Cao says. "Previous techniques could only change the index for visible light by between 0.1 and 1 percent at the maximum."

Cao and Yu worked with Yifei Yu and Lujun Huang, two other graduate students in Cao's lab, as well as Haowei Peng of Temple University and Liwei Xiong of Wuhan Institute of Technology, to develop the technique, which allows them to change the refractive index for visible light in some semiconductor materials by 60 percent – two orders of magnitude better than previous results. The researchers worked with transition metal dichalcogenide monolayers, a class of atomically thin semiconductor materials. Specifically, they worked with thin films of molybdenum sulfide, tungsten sulfide and tungsten selenide.

"We changed the refractive index by applying charge to two-dimensional semiconductor materials in the same way one would apply charge to transistors in a computer chip," Cao says. "Using this technique, we achieved significant, tunable changes in the index within the red range of the visible spectrum."

This new technique now allows researchers to tune the refractive index by any amount up to 60 percent – the greater the voltage applied to the material, the greater the degree of change in the index. And, because the researchers are using the same techniques found in existing computational transistor technologies, these changes are dynamic and can be made billions of times per second.

"This technique may provide capabilities to control the amplitude and phase of light pixel by pixel in a way as fast as modern computers," says Yu.

"This is only a first step," Cao adds. "We think we can optimize the technique to achieve even larger changes in the refractive index. And we also plan to explore whether this could work at other wavelengths in the visual spectrum." Cao hopes this work will lead to the development of field-effect photonics, with optical functionality being controlled by complementary metal-oxide-semiconductor (CMOS) circuits.■

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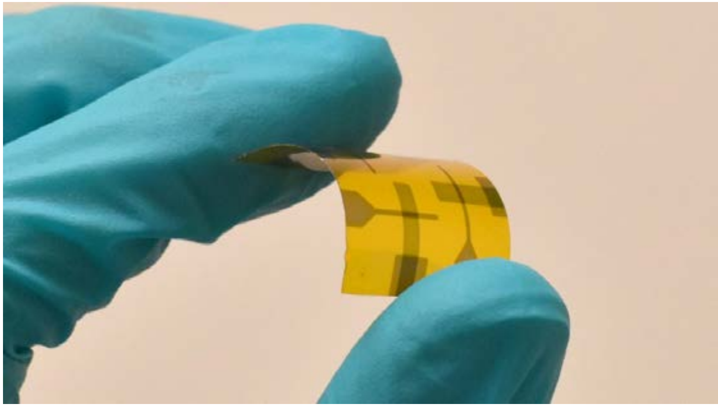
FIRST FLEXIBLE MEMORY DEVICE

MADE USING OXIDE FERROELECTRIC MATERIAL



This work was supported by Nanoholdings LLC; the National Science Foundation, under grant number ECCS-1542015; the U.S. Army Research Office, under grant number W911NF-15-1-0593; and a Research Opportunity Grant from the University of North Carolina General Administration.

For the first time, researchers have been able to deposit an ultra-thin oxide ferroelectric film onto a flexible polymer substrate. The research team used the flexible ferroelectric thin films to make non-volatile memory devices that are wearable and resilient.

"Ferroelectric materials are capable of storing charge, which makes them ideal for non-volatile memory devices," says Jacob Jones, professor of materials science and engineering at NC State and co-author of a paper on the work. "But ferroelectric materials tend to be brittle, and normally have to be made at high temperatures - which would destroy most polymers. We've now found a way to make an extremely thin film of ferroelectric material that can be made at low temperatures."

"What is most exciting about this work is the ability to make ferroelectric thin films at low temperatures and integrate them with carbon-based organic semiconductors to make highly flexible memory devices," says Franky So, the corresponding author of the paper and Walter and Ida Freeman Distinguished Professor of Materials Science and Engineering at NC State.

"The key to success of this work is the special technique we developed to make these ferroelectric thin films at low temperature and maintain the flexibility," says Hyeonggeun Yu, a postdoctoral researcher at NC State and lead author of the paper. "We have created a new device platform which can integrate these memory devices with other flexible electronic circuits."

"This advance allowed us to create a pliable ferroelectric that can be used to create stable memory storage units for use in energy-efficient electronic applications for use in everything from space exploration to defense applications," says Ching-Chang Chung, a postdoctoral researcher at NC State and co-author of the paper.

The researchers worked with hafnium oxide, or hafnia, a material that has ferroelectric properties when applied as a thin film. And, for the first time, the researchers were able to show that the flexible hafnia thin films exhibited ferroelectric properties with thicknesses ranging from 20 nanometers (nm) to 50 nm. "This is a milestone in nanotechnology," So says.

"We made a low-voltage, non-volatile, vertical organic transistor using a hafnia thin film," Jones says. "That level of detail may only be exciting for those in the electrical engineering field. For everyone else, that means this is a practical discovery with very real applications."

"We've found that the prototype is fully functional and retains its functionality even when bent up to 1,000 times," Chung says. "And we're already working on what can be done to improve reliability when the material is bent more than 1,000 times."

The paper, "Flexible Inorganic Ferroelectric Thin Films for Non-Volatile Memory Devices," is published in the journal *Advanced Functional Materials*. ■

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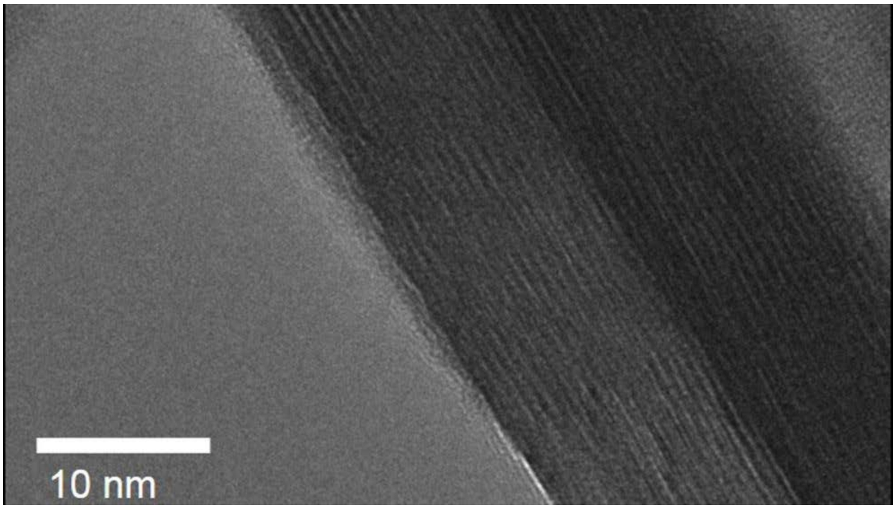
DOI: 10.1002/adfm.201700461

HYDRATED LAYERED OXIDES EXHIBIT PSEUDOCAPACITANCE

VERONICA AUGUSTYN OFFERS NEW STRATEGY FOR ENERGY STORAGE



Low-temperature high-resolution transmission electron microscopy image of a platelet of tungsten oxide dihydrate, containing individual layers of atoms separated by water layers.

Veronica Augustyn, assistant professor investigating new materials for electrochemical energy storage and conversion, has found that a material which incorporates atomically thin layers of water is able to store and deliver energy much more quickly than the same material that doesn't include the water layers. The finding raises some interesting questions about the behavior of liquids when confined at this scale and holds promise for shaping future energy-storage technologies.

"This is a proof of concept, but the idea of using water or other solvents to 'tune' the transport of ions in a layered material is very exciting," says Augustyn, corresponding author of the paper, published in *Chemistry of Materials* in April this year. "The fundamental idea is that this could allow an increased amount of energy to be stored per unit of volume, faster diffusion of ions through the material, and faster charge transfer.

"Again, this is only a first step, but this line of investigation could ultimately lead to things like thinner batteries, faster storage for renewable-based power grids, or faster acceleration in electric vehicles," Augustyn says.

"The goal for many energy-storage researchers is to create technologies that have the high energy density of batteries and the high power of capacitors," says James Mitchell, a Ph.D. student in Augustyn's group and lead author of the paper. "Pseudocapacitors like the one we discuss in the paper may allow us to develop technologies that bridge that gap."

For this work, Augustyn and Mitchell compared two materials: a crystalline tungsten oxide and a layered, crystalline tungsten oxide hydrate – which consists of crystalline tungsten oxide layers separated by atomically thin layers of water.

When charging the two materials for 10 minutes, the researchers found that the regular tungsten oxide stored more energy than the hydrate. But when the charging period was only 12 seconds, the hydrate stored more energy than the regular material. One thing that's intriguing, the researchers say, is that the hydrate stored energy more efficiently – wasting less energy as heat.

"Incorporating these solvent layers could be a new strategy for high-powered energy-storage devices that make use of layered materials," Augustyn says. "We think the water layer acts as a pathway that facilitates the transfer of ions through the material. "We are now moving forward with National Science Foundation-funded work on how to fine-tune this so-called 'interlayer,' which will hopefully advance our understanding of these materials and get us closer to next-generation energy-storage devices."

The paper, "Transition from Battery to Pseudocapacitor Behavior via Structural Water in Tungsten Oxide," was co-authored by William Lo, a Ph.D. student at NC State; Arda Genc of Thermo Fisher Scientific; and James LeBeau, an associate professor of materials science and engineering at NC State. ■

DOI: 10.1021/acs.chemmater.6b05485

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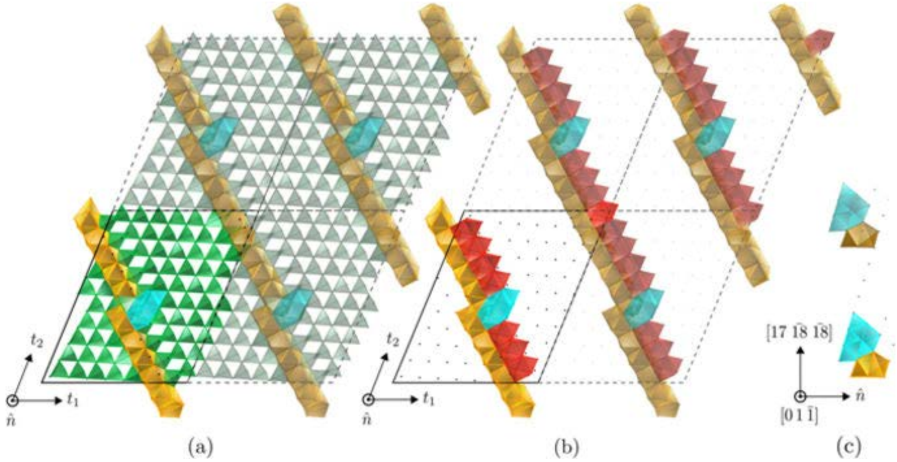
FINDING ORDER AND STRUCTURE IN THE ATOMIC CHAOS

WHERE MATERIALS MEET



This work was supported by the National Science Foundation under CAREER award grant DMR-1554270.

Srikanth Patala, an assistant professor of materials science and engineering at NC State, and his team have developed a model that can account for irregularities in how atoms arrange themselves at the so-called "grain boundaries" - the interface where two materials meet. By describing the packing of atoms at these interfaces, the tool can be used to help researchers determine how grain boundaries affect the properties of metal alloys and other materials.

"We've known that these grain boundaries influence material characteristics for many decades," says Patala, corresponding author of a paper on the work. "But it's been extremely difficult to understand what those defects look like at the atomic level and, therefore, to understand how these structural irregularities affect a material's strength, stiffness, ductility and so on. "Now we have a tool that lets us see and actually understand what these disordered atomic structures really look like - and that's a big step toward figuring out exactly what's going on," Patala says.

Most materials have a particular atomic structure that is fairly regular. For example, aluminum has a cubic structure, with atoms that line up into long chains of cubes, whereas titanium forms into what are basically stacks of hexagons. But when two materials meet, such as in a metal alloy, these tidy, organized structures clash with each other, creating the disordered grain boundary.

The model developed in Patala's research group finds irregular three-dimensional shapes within the grain boundary, classifies them and then identifies patterns of those irregular shapes.

"Advances in microscopy can help us capture images of how atoms are arranged in a grain boundary, but then we don't really know what we're looking at - you can connect the dots any way you want," Patala says. "Our tool helps to discern patterns of geometric features in an atomic landscape that can appear chaotic. Now that these patterns can be identified, the next step is for computational researchers - like me - to work with experimental researchers to determine how those patterns affect a material's properties," Patala says.

Once the effect of the patterns is well understood, that information can be used to better identify the strengths and weaknesses of specific grain boundary types, expediting the development of new alloys or other materials. The tool, called the Polyhedral Unit Model, can be used to model grain boundaries for any material in which the attraction between atoms is governed solely by the distance between atoms, such as metals and ionic solids - including some ceramics. However, the approach doesn't work for materials, such as carbon, that form so-called directional bonds.

"We are currently working on making the Polyhedral Unit Model publicly available through open source software," Patala says. "We plan to have it out by the end of the year, and hopefully sooner."

The paper, "A Three-Dimensional Polyhedral Unit Model for Grain Boundary Structure in fcc Metals" is published in the Nature journal npj *Computational Materials*. Lead author of the paper is Arash Banadaki, a postdoctoral researcher at NC State. ■

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THE HARRY S. TRUMAN SCHOLARSHIP FOUNDATION

ALEX HSAIN

WINNER OF 2017 TRUMAN SCHOLARSHIP

This year, Hanan "Alex" Hsain, an NC State junior majoring in materials science and engineering was been awarded a 2017 Truman Scholarship.

Hsain, 21, of Colonial Heights, Virginia, will use the scholarship — a highly competitive, merit-based award of up to $30,000 offered to U.S. citizens and U.S. nationals from Pacific Islands who want to go to graduate school in preparation for a career in public service — to pursue her Ph.D. in materials science engineering or electrical engineering to help further her goal of becoming a leader in sustainable energy development. Hsain is NC State's ninth Truman Scholar; its eighth recipient, Tómas Carbonell, was named in 2002.

Hsain has worked as an assistant under the supervision of Michael Dickey, professor of chemical and biomolecular engineering on NC State's Advanced Self-Powered Systems of Integrated Sensors and Technologies Center for two years. Her work focuses on reclaiming ambient energy from the environment and converting it to electricity for wearable devices. She has also participated in research experiences at Texas A&M University and NASA Langley Research Center.

"The first thing I thought was 'thank you' to all who have supported and loved me and for the privilege and honor of U.S. citizenship," said Hsain, a first-generation American, in an interview with NC State's Fellowship Advising Office. "This experience has reaffirmed my commitment to ensure opportunities of freedom and the pursuit of happiness for future generations through scientific innovation. As an aspiring scientist and advocate for evidence-based decision making, I am honored to enact the 'Think and Do' mentality and represent NC State in the Truman community."

In addition to her research, Hsain helps organize and schedule educational, volunteer and social activities for students in the University Scholars Program. She is also a founding member and currently vice president of the Undergraduate Research Council, a campus organization that provides support and outreach for students involved or interested in undergraduate research. She is also a founding member of SciBridge, and works with Veronica Augustyn, assistant professor of materials science and engineering, to connect U.S. scientists and students with African universities through hands-on "materials for energy" experiment kits that promote sustainability and scientific collaboration.

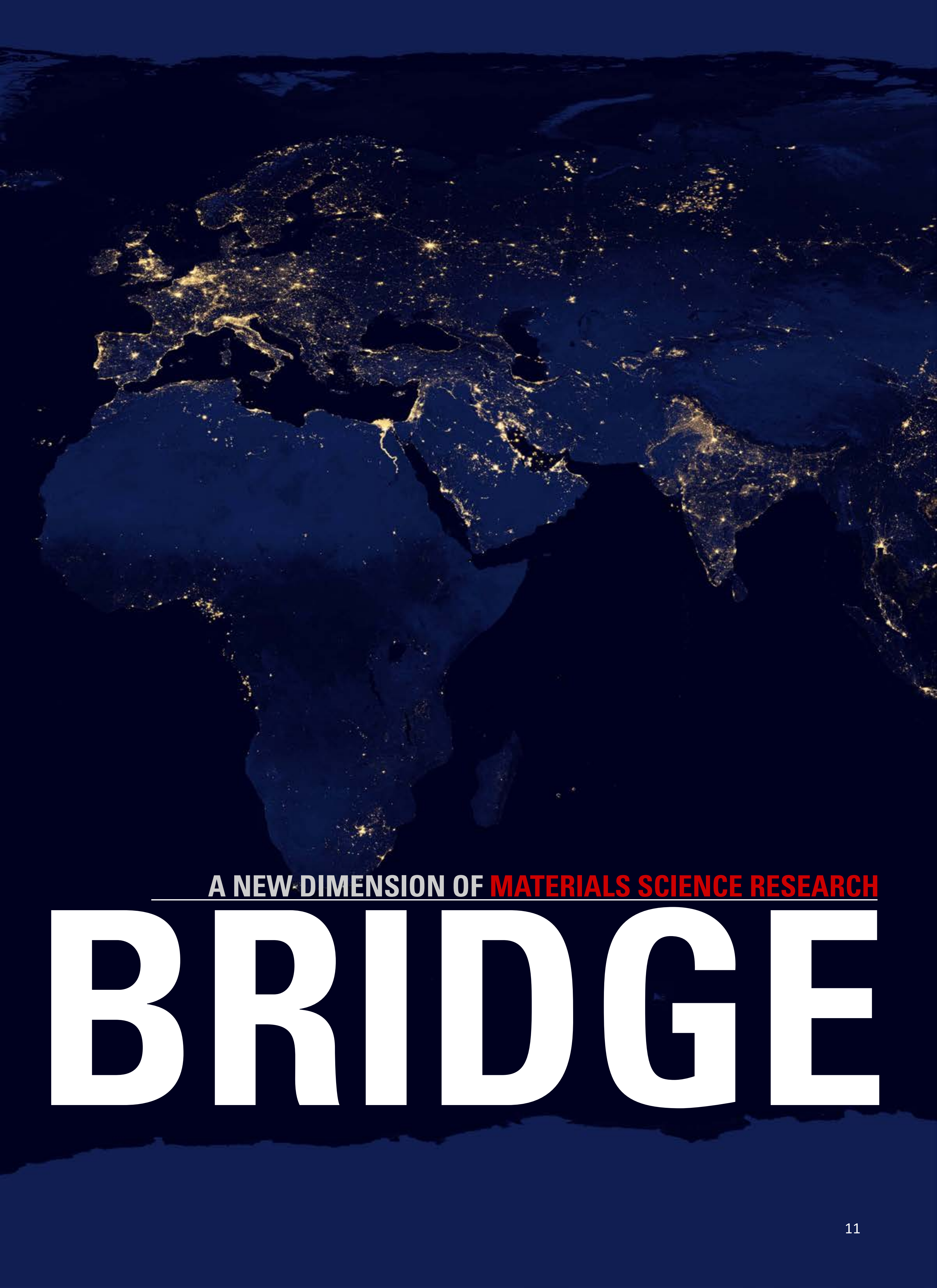
"Alex is an exceptional student," says Augustyn. "During her time in SciBridge and through personal conversations with her she told me that being in SciBridge allowed her to see how science policy actually works. It's another dimension to her portfolio which already includes undergraduate research." ■

IMAGE CREDIT: NASA GODDARD SPACE FLIGHT CENTER

IN 2012, TWO GRADUATE STUDENTS ON EITHER SIDE OF THE ATLANTIC OCEAN DECIDED TO TACKLE **SUSTAINABLE ENERGY** IN AFRICA.

FIVE YEARS LATER, WE CATCH UP WITH THE PROJECT THEY CREATED:

SCI



A NEW DIMENSION OF MATERIALS SCIENCE RESEARCH

BRIDGE

SCI**BRIDGE** IS NOT A **ONE-SIDED** EFFORT. EVERYONE BENEFITS, AND THIS IS **WHY IT WORKS.**

In a quiet corner of Engineering Building I, away from the clutter of the labs, six students armed with bubble-wrap, FedEx boxes and Uganda Customs forms began assembling custom-made experiment kits. As they carefully wrapped and packed voltage steppers, thermoelectric power generators, screw jacks and thermometers, an industrious hush fell over the group – save for a few light cheers when one student returned with more bubble-wrap, scavenged from a nearby office. Once filled, each box received an experiment manual written by the students, and a letter from Veronica Augustyn, assistant professor and Chair of the SciBridge project, thanking the recipient university for taking part in the international collaboration.

"Within the MSE department, SciBridge is a project that's valued," Augustyn says. "It brings new opportunities for our students, new ways for our students to exercise their creativity or their passion for helping others."

The origins of SciBridge trace back to Addis Ababa, Ethiopia, in 2012, when Augustyn met John Paul Eneku, from the Iteso tribe of Uganda, at a two-week Joint U.S.-Africa Materials Initiative (JUAMI) research school. By the end of the second week, Augustyn and Eneku, both graduate students at the time, had come up with the idea to form SciBridge, an intercontinental collaboration to facilitate sustainable energy development in Africa. Their plan was simple: Researchers in the U.S. would build and ship experiment kits to African researchers, who would use the kits and then discuss the topic and data with the U.S. scientists via web seminars. After presenting their concept at the Africa Materials Research Society (MRS) conference, in 2014 the pair received a Grassroots Grant from the MRS Foundation to fund the project.

Three years later, SciBridge is not only narrowing the knowledge gap between African and U.S. researchers, but also enriching student development at NC State. Augustyn's students design and build the kits before sending them to Eneku – now an assistant lecturer in the Department of Physics at Makerere University in Kampala, Uganda – who then circulates the kits among other partnering universities. The most recent kits contain everything needed to build a thermoelectric module with a USB port that can charge a cell phone. Like all SciBridge kits, the module represents a valuable opportunity for MSE students in Africa, since more than 600 million people living in sub-Saharan Africa still lack access to electricity. But, crucially, Augustyn's students reap significant benefits too.

"Our focus is to send supplies and things that are needed to demonstrate or to do experiments on different sustainable energy technologies," Augustyn says. "[But] the beauty of these projects is that most of the U.S. students involved in building this thermoelectrics kit have never worked with thermoelectrics before either."

Additionally, writing comprehensive instructions for students on a different continent is a challenge that is helping NC State students develop innovative approaches to both communication and teaching. A new addition to the most recent kit is an instructional video, directed and filmed by the students, which will

VERONICA **AUGUSTYN**, SCIBRIDGE CHAIR

"MOST OF **THE [U.S.] STUDENTS** INVOLVED… HAVE NEVER WORKED WITH **THERMOELECTRICS** BEFORE, EITHER."

accompany the experiment manual they have written.

In Africa, although societies such as MRS are providing free access to subscription-based journals, the high cost of materials characterization tools remains a major barrier to materials science research, and prevents thousands of students from keeping pace with the rest of the global field. At NC State, home to an Analytical Instrumentation Facility housing million-dollar pieces of equipment, SciBridge has been popular with students who are keen to share knowledge and influence science policy, with the goal of advancing human development and sustainable energy in countries that need it most.

"RIGHT NOW, IT'S VERY RUDIMENTARY, BUT THE **POTENTIAL IMPACT** COULD BE HUGE."

JAMES **MITCHELL**, NC STATE GRADUATE STUDENT

"[In Uganda] they have the space and the minds but not the financial aspects to do research," says James Mitchell, one of Augustyn's graduate students and first author of the group's paper on layered transition metal oxides, published in *Chemistry of Materials* earlier this year. Like his fellow students, he acknowledges the advantages he enjoys in the U.S. and wants to help researchers in developing countries gain access to better resources. "Right now, it's very rudimentary, but the potential impact could be huge."

With the fierce competition for scholarships and grants that young researchers face today, Augustyn has quickly recognized the impact that SciBridge is having on the future careers of her students. Alex Hsain, an undergraduate student and SciBridge participant, received a Truman Scholarship this year. Shelby Boyd, another of Augustyn's graduate students, and Alexandria Cruz, supervised by outgoing Department Head Justin Schwartz, have both received NSF Graduate Research Fellowships, in which SciBridge was a central aspect of their broader impact statements.

"A big part of having a broader impact is teaching science," says Cruz. As well as contributing to kit design, she has used email and Skype to provide feedback on experiments for her African counterparts. For Cruz and the rest of the group, SciBridge has opened a door to the world beyond their own research projects. In today's world, Augustyn knows that early exposure to an international collaboration will help create a versatile, perceptive generation of future scientists.

"The situation in Africa is rapidly changing. Those countries are developing very quickly," Augustyn says, and emphasizes that SciBridge has clear benefits for researchers on both continents. For Eneku and other African scientists, their work on sustainable energy technologies using SciBridge kits can help their countries leapfrog over fossil fuel technologies and develop in a sustainable manner. At NC State, SciBridge is adding a new dimension to materials science research, and earning students an important place in a globally engaged engineering workforce. ■

TO **FIND OUT MORE** ABOUT SCIBRIDGE, THE TEAM, AND TO READ THEIR **LATEST NEWS**,

VISIT **WWW.SCIBRIDGE.ORG**

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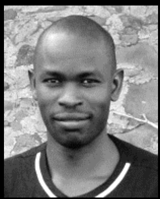

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JAGDISH NARAYAN

NEW MEMBER OF THE NATIONAL ACADEMY OF ENGINEERING

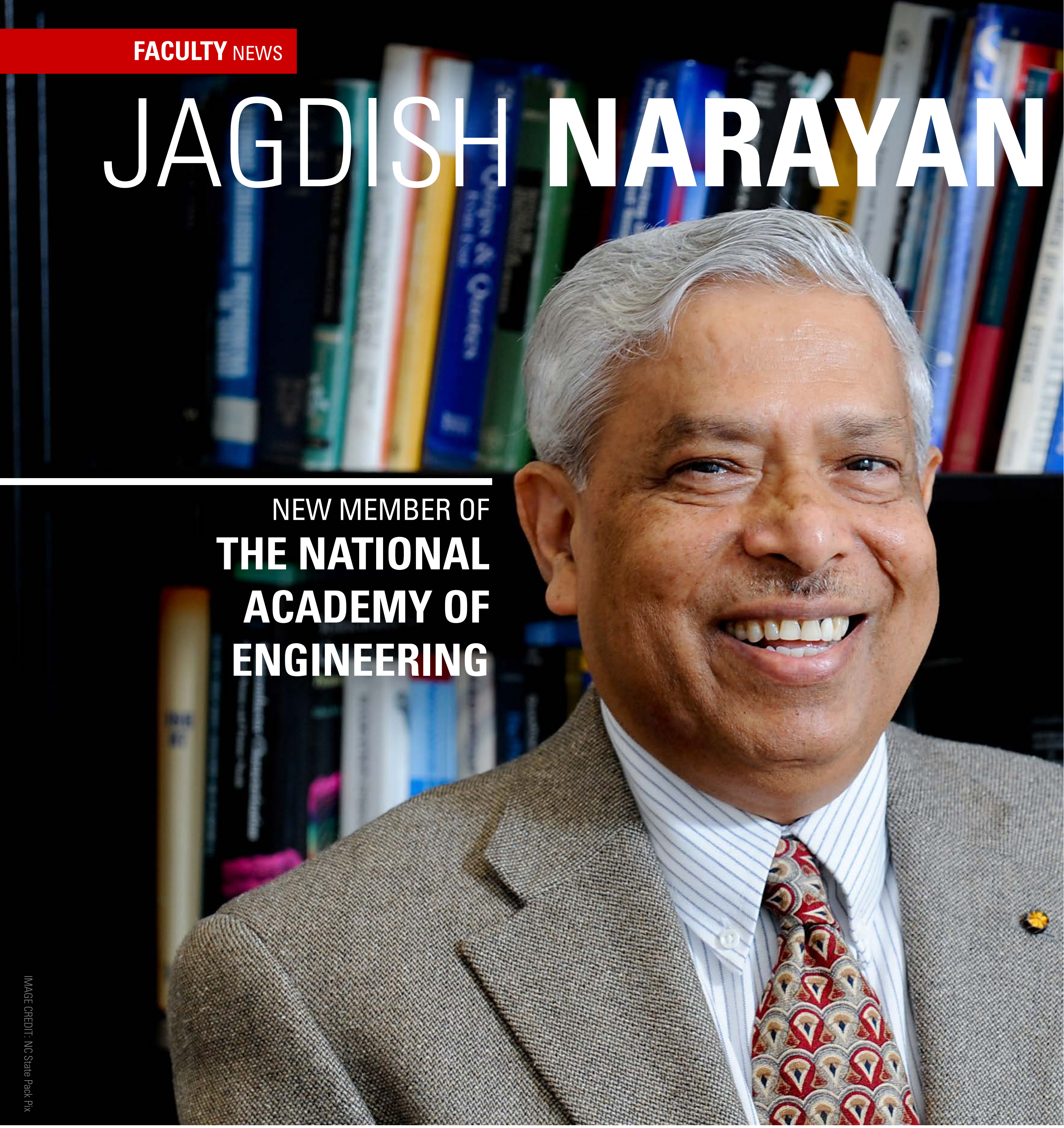

IMAGE CREDIT: NC State Pack Pix

On October 8, 2017, Jay Narayan, the John C. Fan Distinguished Chair Professor of MSE at NC State will be formally inducted into the National Academy of Engineering (NAE). Together with Paul Turinsky, a professor from the Department of Nuclear Engineering who has also been elected this year, Narayan's induction will increase the number of NAE members in NC State's College of Engineering to 17, and MSE's to 3 (joining Professor's Koch and Cuomo).

Narayan's election signifies his extensive influence in thin film science, and in particular, his contributions in heteroepitaxial film growth by laser ablation in large misfit systems and new materials. Since the publication of his influential papers on laser annealing in *Science* 1979 and 1991, and on nickel colloid nanodots in *Physical Review Letters* in 1981 – a paper that led a revolution in nanoscience – Narayan has published more than 500 archival journal papers and made pioneering advancements in crystal growth and Q-phase discovery.

In 2015, with his co-author and graduate student Anagh Bhaumik, he unveiled Q-carbon, the third

phase of solid carbon and perhaps his most exciting creation yet. With an extraordinary combination of electrical conductivity, ferromagnetism, luminosity and extreme hardness, Q-carbon will likely be game-changing for multitudinous applications, from biocompatible drug delivery systems and surgical prosthetics, to industrial drilling and power electronics.

"We are at the cusp of history right now," Narayan says as he discusses his achievement of unpaired spin and magnetization of carbon, which could transform superconductor technology. In Q-carbon, the electrons take 80 angstrom-long strides – far longer than that made by electrons in other superconducting materials. Consequently, the electrons are less susceptible to defects, a quality that is permitting remarkable superconductivity in the new material. "This is the first time we have bulk ferromagnetism in carbon. This has people excited all over the world. We have really done it."

The versatility and significance of applications that Q-carbon promises to offer emulates the profound impact that his previous inventions have already had on society. Today's high-efficiency LED technology is a direct outcome of Narayan's earlier work in new material design, novel laser-assisted processing methods and thin film science; and next-generation high-power devices, novel oxide electronics, multifunctional sensors and nanomagnetic computers are following suit.

Domain matching epitaxy (DME), a paradigm he and Bennett Larson from Oak Ridge National Laboratory invented more than ten years ago and for which Narayan still holds two U.S. patents, has served as his platform for tackling lattice mismatch, defects and interfaces, and laser processing of new materials. Among its many functions, DME has revolutionized the growth and integration of fully relaxed films of III-nitrides and II-oxides involving large misfits on polar and non-polar substrates, and facilitated the creation of 3D self-assembled nanostructures by manipulating the magnetic orientation of nanodots.

"Usually, thermodynamics sets the boundaries of what you can and cannot do," Narayan says, discussing his focus on laser ablation. "The whole process of converting carbon into diamond is completed in one fifth of a millionth of a second. By controlling kinetics, you can bypass thermodynamics. That's the exciting part of creating new materials."

He attributes much of his accomplishments to his interdisciplinary expertise in advanced materials processing, characterization and modeling, diamond thin films, advanced semiconductor thin film heterostructures and devices, and high-temperature superconductors. "Materials science is ubiquitous," Narayan states, and emphasizes the broad scope of research that he nurtures within his graduate student cohort.

In addition to his role at NC State, Narayan is fellow of the American Physical Society, American Association for the Advancement of Science, ASM-International, The Metals, Minerals and Materials Society (TMS), Materials Research Society, National Academy of Sciences (India), Bohmische Physical Society, and the National Academy of Inventors.

He has previously been awarded three R&D (IR-100) Awards, the ASM Gold Medal, the Acta Materialia Gold Medal, the TMS RF Mehl Gold Medal, the Edward DeMille Campbell Memorial Lecture and Campbell Prize, the Lee Hsun Lecture Award from the Chinese Academy of Sciences, and the North Carolina Award in Science. He holds 48 U.S. patents, many of which are licensed by Kopin Corporation and his own company, Q-Carbon, LLC. Following his inventions of nano-oil and nano-fuel additives, which significantly improve fuel efficiency, reduce friction, and decrease nitrogen oxide and sulphur oxide emission from combustion engines, he also founded Star Nanotech Inc.

Narayan's creation of Q-carbon marks a prominent milestone in a career bestrewn with noteworthy scientific discoveries. The significant impact his discoveries continuously have on both society and materials science research and industries makes his election to the NAE well-earned. ■

KEEPING UP WITH THE DATA

THE NSF TRAINEESHIP PROGRAM AT NC STATE

Today, advances in data analysis are redefining how materials scientists are utilizing data from cutting-edge analytical and computational experiments. At NC State University and NC Central University, the National Science Foundation Research Traineeship (NRT) has facilitated the establishment of Data-Enabled Science and Engineering of Atomic Structure (SEAS), a five-year educational program for PhD students. With their top ranked Departments of Statistics and Materials Science and Engineering, NC State is in a unique position to promote diversity within the research community and tackle the growing need for interdisciplinary training in big data and materials science.

"The nationwide increase in attention toward the opportunities offered by large-scale computation and data-intensive experiments has really hit home in our own department," says Elizabeth Dickey, a professor of materials science and engineering and director of the SEAS-NRT program at NC State. "The investments we're making in interdisciplinary training as well as faculty and research infrastructure are enabling a lot of new research into disorder in new materials and how it relates to functional properties."

Unprecedented access to vast quantities of modeling and simulation data, afforded by advancements in technology and computational techniques, is exposing exciting new prospects for materials science research. But to profit from and employ the information meaningfully, new expertise must be developed that can both unlock and translate big data.

In answer to this, the SEAS-NRT program for graduate training at NC State is immersing students within the critical intersection of statistics, data science and materials characterization. By placing emphasis on this rapidly growing nexus of research, NC State is equipping students with multifaceted expertise that they can use to undertake data-intensive, interdisciplinary challenges. Ultimately, the program will yield future leaders capable of advancing high-fidelity nanoscale and sub-nanoscale materials structure research.

IMAGE CREDIT: CommScope

The SEAS graduate training program at NC State unites measurement scientists, applied mathematicians, statisticians and computational materials scientists to advance atomic structure determination.

"The SEAS-NRT provides a formal infrastructure that encompasses interdisciplinary research and holistic training, which is often lost in graduate STEM education," says Ashleigh Wright, program coordinator of the SEAS-NRT program at NC State. "Through this program, trainees become experts in one discipline, and gain the technical and professional skills to effectively communicate within, collaborate with, and lead interdisciplinary teams."

The 22 students who are currently participating in the SEAS traineeship program receive mentoring from a team of faculty with diverse specialties, as well as external scientists from national laboratories and industry. With these regular interactions, the program allows the students to build a network of professional colleagues and long-term mentors, thereby ensuring sustainability of their interdisciplinary training.

"Thus far, we have recruited students who are representative of experimental and computational materials science, statistics, mathematics, and physics, and textiles engineering chemistry and science (TECS) disciplines, and hosted a number of research meetings as an introduction to the topics that will be further explored as the program progresses," says Wright. Students are introduced to different research cultures and disciplinary approaches by embedding in research groups outside of their own discipline for several weeks. In addition, they interact with external scientists from organizations, such as Oak Ridge National Lab and Citrine Informatics, that are on the forefront of data-intensive materials science research.

The program also helps students develop a strong professional identity by tasking them with the production of a professional portfolio. The curriculum includes external internships, laboratory rotations, leadership and communication training, research training.

"The NRT program is an amazing opportunity for me to dive into imaging sciences in the materials science field," says Jocelyn Chi, a SEAS-NRT fellow in the Department of Statistics, who is working with materials science SEAS-NRT fellow Matthew Cabral to decipher the origins of high electromechanical responses of relaxor ferroelectrics. "I hope to use the training and experiences I get through the program to motivate methodological development in statistical analysis of big data."

The broad skillset and education that the trainees receive as part of the program, combined with the networking and extramural research experiences that the program offers, will make the students more marketable for competitive career opportunities. If successful, the SEAS Traineeship will likely act as a graduate training model that could be replicated across NC State.

Importantly, the NRT partnership formed between NC State and NC Central University also directly tackles the underrepresentation of minorities in STEM disciplines. Located in Durham, North Carolina, NC Central is a historically African-American university, and by fostering strong relationships with NC State faculty, is cultivating a prosperous, interdisciplinary training environment for both their students and professional community. The leading faculty from NC Central are Dr. Caesar Jackson and Dr. Kimberly Weems from the Department of Mathematics and Physics. Within this partnership, NC State and NC Central are preparing their students for success in the PhD programs that they may choose to embark on.

As part of the NSF's nationwide Research Training Program, the SEAS NRT program at NC State is an enterprising, transformative approach to interdisciplinary graduate training. With the participation of faculty and external scientists from diverse backgrounds, the program is successfully integrating advanced statistical tools with physical science, and nurturing a new generation of innovative, multidisciplinary leaders in materials science research.

"The students have provided very positive and constructive feedback," says Wright. "They enjoy becoming knowledgeable of other disciplines and learning how to apply the research strategies to their own dissertation work. They are also excited about the internship professional development opportunities through the SEAS program, and building relationships with their fellow doctoral peers in other fields." ■

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IMAGE CREDIT: Tom Hall

EOWYN **LUCAS**

FINDING MY PURPOSE IN SCIENCE

I've always been an explorer. I love hiking and climbing, and discovering amazing feats of nature. Growing up, my exploration of the natural world meant I developed a passion for science, and also ignited my life goal: To have a positive impact on Earth by helping to save the environment. When I applied to NC State, I knew I wanted to become an engineer because I believed – and still believe – that this how I will have the greatest impact, because developing sustainable energy is one of the most important ways in which we can save our planet.

When I was choosing my undergraduate program, the Department of Materials Science and Engineering at NC State caught my attention because of the cutting-edge research and its diverse range of applications. Now, having graduated, I can say that the program stood up to the great expectations I had for it at the very start.

As an undergraduate at NC State, I participated in several extracurricular activities, the best of which was undergraduate research. The MSE department strongly supports and encourages undergraduate research and it was easy for me to get involved with a group. For two years, I worked in Professor Augustyn's research lab, researching catalyst materials for the electrochemical splitting of water. This lab group focused on energy storage and energy conversion and I was able to learn a great deal about these fields.

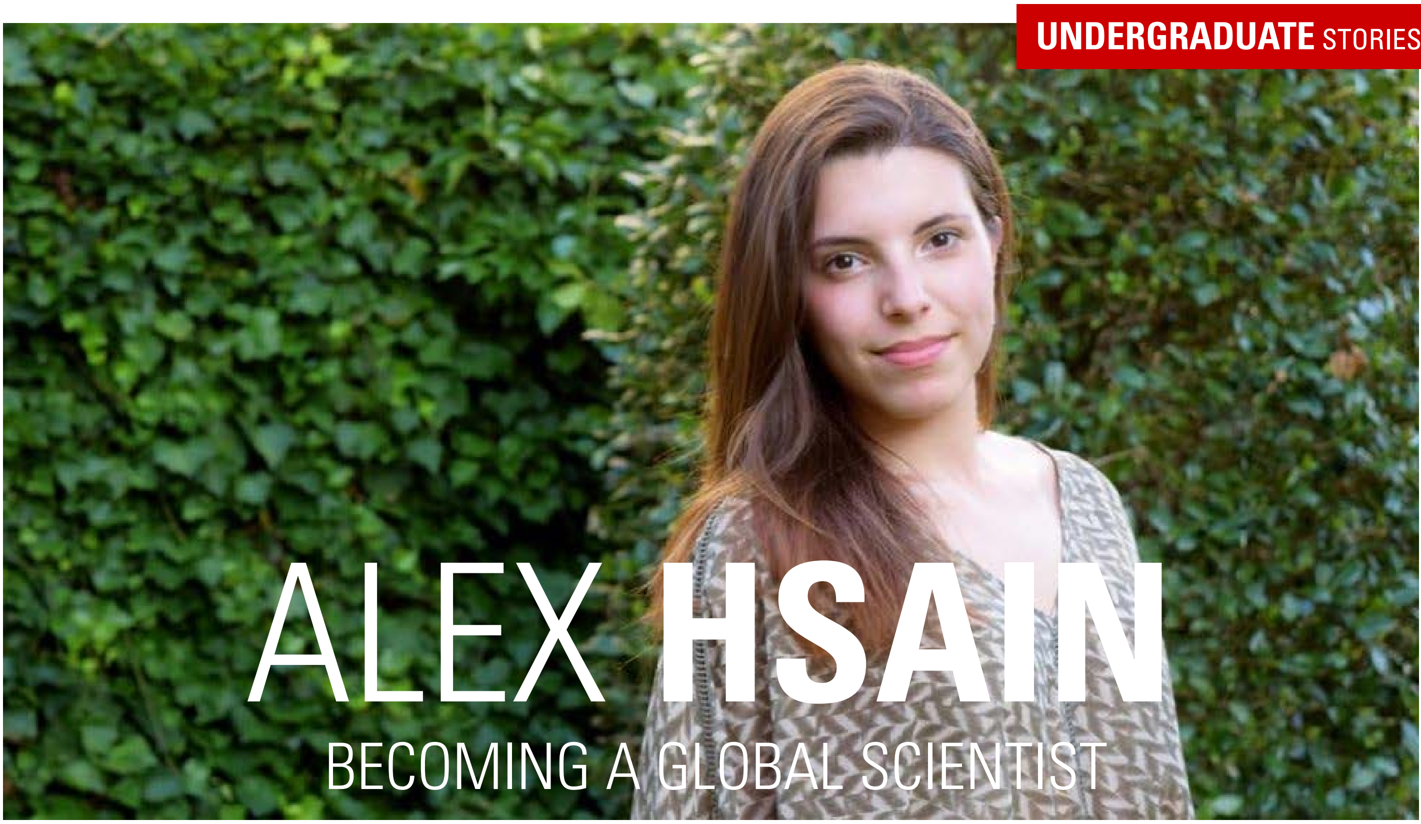
During this time, I also had the chance to present and share my research on multiple occasions, as well as develop important networking connections. Because of the technical skills I gained in the lab and the passion I developed for research, I decided I wanted to attend graduate school to further my research career.

This past year, I have applied for and chosen a graduate school - a process that was challenging and time consuming, but in the end, incredibly rewarding. Starting in September, I will be attending Caltech to pursue a Ph.D. in Materials Science. At Caltech, I will be working in the Atwater group, researching materials for artificial photosynthesis. I am beyond excited about this upcoming part of my journey and I am sure it will open many doors for me down the road.

While applying to graduate school, I also successfully applied for the National Science Foundation Graduate Research Fellowship. This is a prestigious award that supports a graduate student for three years at any school they choose to attend. I am ecstatic that I have received this award, because it will provide me with the ability closely follow my own research and passions. Having this huge support will also make it easier for me to focus on school and my research.

Overall, this past year has been one of the most rewarding years of my life and I now feel like I have great direction and purpose. I know I am heading in the right direction in terms of making an impact in this world, by improving our environment and the way we live. While at NC State, I also became interested in entrepreneurship, because it is crucial to translate research into a useful product with real-world application. Based on this, I would say that beyond graduate school, my greatest dream is to use my research to start a company that develops cutting-edge renewable energy technologies. ■

- Eowyn Lucas



ALEX HSAIN

BECOMING A GLOBAL SCIENTIST

Richard Feynman was right in more ways than one about there being "plenty of room at the bottom." Since beginning my undergraduate research at NC State, I have envisioned a world that uses small-scale energy harvesting to achieve energy efficiency – a world where cell phones, headsets, and portable electronics capture waste energy from the environment and transform it into electricity. My idea is simple: Solar, wind, and large-scale alternative energy represent the future of sustainability, but they should not be exclusive sources of sustainable energy.

My undergraduate research has taught me that we have the capacity to build portable electronics with their own, self-sustaining power source. Exploring nontraditional and small-scale energy harvesting gives us the chance to not only quench our endless thirst for wattage, but also gain independence from fixed energy outlets. When I presented this concept at the 2016 Appalachian Energy Summit in Boone, NC, I was met with much enthusiasm and excitement for the field of micro-energy harvesting. Receiving such a response to my proposal of a paradigm shift in the energy sector, from an audience of more than 200 leaders in the energy industry, was a feeling like no other. In that moment, I realized I wanted to unify my love of scientific research with advocacy, and it was this desire that drove me to apply for the Truman Scholarship this year.

When I applied for the scholarship I quickly appreciated the benefits that NC State has offered me. The access to undergraduate research has not only provided me with a strong foundation in the methods of the research process, but has also encouraged me to become a devout citizen scientist. To me, this is incredibly important, because the only thing I care more about than my research is the potential effect it could have on society. As a scientist and advocate, I want my ideas to spread like wildfire and help people understand just how important scientific research is to their daily lives. Even more so, I want to bring science to the common day person. For this reason in particular, I have presented my research to a broad range of audiences – from specialist to interdisciplinary – to improve my skills in science communication. This past April, I took the opportunity to present my research to policymakers such as Congressman David Price, the representative for North Carolina's 4th congressional district, at the Council on Undergraduate Research Posters on the Hill event in Washington D.C. At this event, my discussions of energy research with politicians, anthropologists and urban housing developers were some of my fondest moments of my undergraduate research career.

This summer I have continued my scientific journey in the pursuit of becoming a global scientist. Through the U.S.-Australia International Research Experience for Students (IRES) program, I travelled to University of New South Wales in Sydney, Australia, to conduct piezoresponse force microscopy on flexible ferroelectrics, which could become the next generation of wearable devices and sensors. During my time in Sydney, I worked with scientists from numerous countries including China, Iran, and Germany, all the while expanding my breath and understanding of science across vast cultures.

Opportunities through the Department of Materials Science and Engineering at NC State, such as IRES and the SciBridge Project, have been integral in allowing me to connect my passion for research with the global enterprise of science and sustainability. Undoubtedly, it has been these experiences that have allowed me to explore the impacts of science on a global scale, and apply for the Truman Scholarship to further my role as a scientist in the public sector.

The Truman Scholarship will enable me to embrace the altruistic nature of science in pursuit of a public service career. Having returned from Australia, I now plan to use my Truman Scholarship to pursue a Ph.D. in materials engineering, focusing on small-scale energy harvesting and electrical materials. My long-term goal is to remain in academia while acting as a policy advisor for the government. Looking back, I know that a major reason I chose to pursue my degree in the Department of Materials Science and Engineering was because of the high percentage of undergraduate students that were actively conducting research. However, what I had not expected was to be welcomed into such a diverse and supportive community of scholars who would help me become a global scientist. ■

- Alex Hsain

JEREMY JORDAN

FROM MATERIALS SCIENTIST TO DATA SCIENTIST

My research experience within the Department of Materials Science and Engineering began the summer before my freshman year when I met Dr. Jerome Cuomo, a Distinguished Research Professor in the department. At the time, I had been debating between an undergraduate degree in computer science and materials science, but I was leaning towards materials science given my fascination with the news about graphene technologies at the time and my general curiosity towards the field.

After explaining my interests to Dr. Cuomo, he encouraged me to join his research group for a few days each week over the summer. It was a great opportunity to learn more about the field. I was introduced to a huge range of topics and concepts I'd never encountered before, from alloy phase diagrams to crystallographic structures, and by the time we reached these topics in my undergraduate classes I had already been exposed to them and was eager to learn more.

During my sophomore year, however, I began to realize that I really missed coding – something I had enjoyed in high school freshman year, when I'd taken an introductory Java course. Around this same time I was enrolled in the mathematical methods course, taught by Dr. Don Brenner, and found myself really enjoying the subject. At the time, these observations didn't seem to too significant but would later prove pivotal in determining my future path.

The summer after my sophomore year, I gained industry exposure to materials science while interning at LORD Corporation in Cary, North Carolina, as a materials research engineer working on their structural adhesive formulations. It was a great experience, providing me with a perspective of materials research in industry.

I also attended several 'Lunch and Learn' sessions throughout the summer hosted by different leaders in the company. Many of these talks advised us (the interns) to determine whether we'd like to focus our career on breadth versus depth with respect to our knowledge and skillsets. Thinking over this, I had trouble picking one over the other.

At the beginning of junior year, I joined Dr. Brenner's computational research group to model and study tribological properties for solvated nanoparticle systems. Given my strong interest in mathematical methods and computer programming, this research position seemed a natural fit.

I really began to think about what my future was going to look like. I had originally planned to pursue a PhD in materials science and one day lead a research group, but I had decided that this was no longer the route I wanted to take. I became stuck on the question of choosing breadth or depth in my career - desiring the freedom to study a variety of topics, but also fearful of becoming a "jack of all trades, master of none." I didn't want to sacrifice deep technical knowledge in an attempt to feed my wide curiosity.

As I mulled over this dilemma, the observations I had made at NC State began to resurface. I remembered how much I had missed coding, and how much I enjoyed the mathematical methods course. (In fact, the thing that sold me on materials science was that it was a combination of chemistry and mathematics - two of my favorite courses in how much I enjoyed the mathematical methods course. (In fact, the thing that sold me on materials science was that it was a combination of chemistry and mathematics - two of my favorite courses in high school.) Further, I knew I wanted to have the flexibility in my career to study a wide range of topics, but not at the cost of never being able to master a given field.

Pondering over this topic of breadth versus depth, I starting looking more seriously into the field of data science – a combination of computer science, mathematics, and statistics. Due to the fact that data science could easily be applied to a wide variety of fields, I wouldn't have to choose between a broad career or a deep one; I could use data science to explore a wide variety of fields, while still deepening my technical expertise of the field.

IMAGE COURTESY OF JEREMY JORDAN

One day on campus during the fall semester of junior year, I walked past a Red Hat booth recruiting computer science students for summer internships. The previous summer I had read a book written by Red Hat's CEO on how open source software had influenced their company culture, arguing that the open culture provides the company with a competitive edge. The book resonated well with me, so after initially walking right past the booth, I turned back to chat with the company representatives about their experience at Red Hat.

I introduced myself as a materials science student, and acknowledged that I knew they weren't looking to hire a materials scientist. But as we talked, I eventually mentioned that I was interested in learning more about data science, perhaps in graduate school, and they in turn told me about a potential summer position as a data science intern. I sent them my resume, and with a bit of luck I got the position. I absolutely loved working at Red Hat as a data science intern, confirming that this was the path I wanted to pursue.

When I returned to NC State in the fall, I had a degree to wrap up and a future to figure out. I knew I needed to decide what my next steps in data science would be. After evaluating and applying to several graduate programs, and comparing data science to data analytics, I eventually decided to pursue an independent study of the field, made possible by the wealth of educational content about machine learning available on the internet.

I've really enjoyed the flexibility that an independent study provides, and have been blogging about the topics I've learned on my website (jeremyjordan.me/data-science). This fall, I plan to move to Seattle to work at a tech firm as a machine learning engineer and data scientist.

For me, undergraduate research was never really a 'resume-builder'. Instead, I saw it as an extension of my education, and simply followed where my interests took me and tried to experience as many opportunities as I could (In addition to the research I mentioned, I also worked on a research project with a professor in the Chemistry department and led an independent research effort senior year).

With so many research opportunities available for undergraduates, the MSE department at NC State was a great place for this type of exploration. After I'd tested a variety of possible directions during the first three years of my undergraduate degree, I used my senior year to reflect on my experiences, distill my observations, and find my path moving forward. I learned that a number of my initial assumptions about what I liked turned out to be wrong, and by staying open-minded, I figured out which subjects I most enjoyed studying. This exploration has been an informative process, preparing me for a lifetime of learning. ■

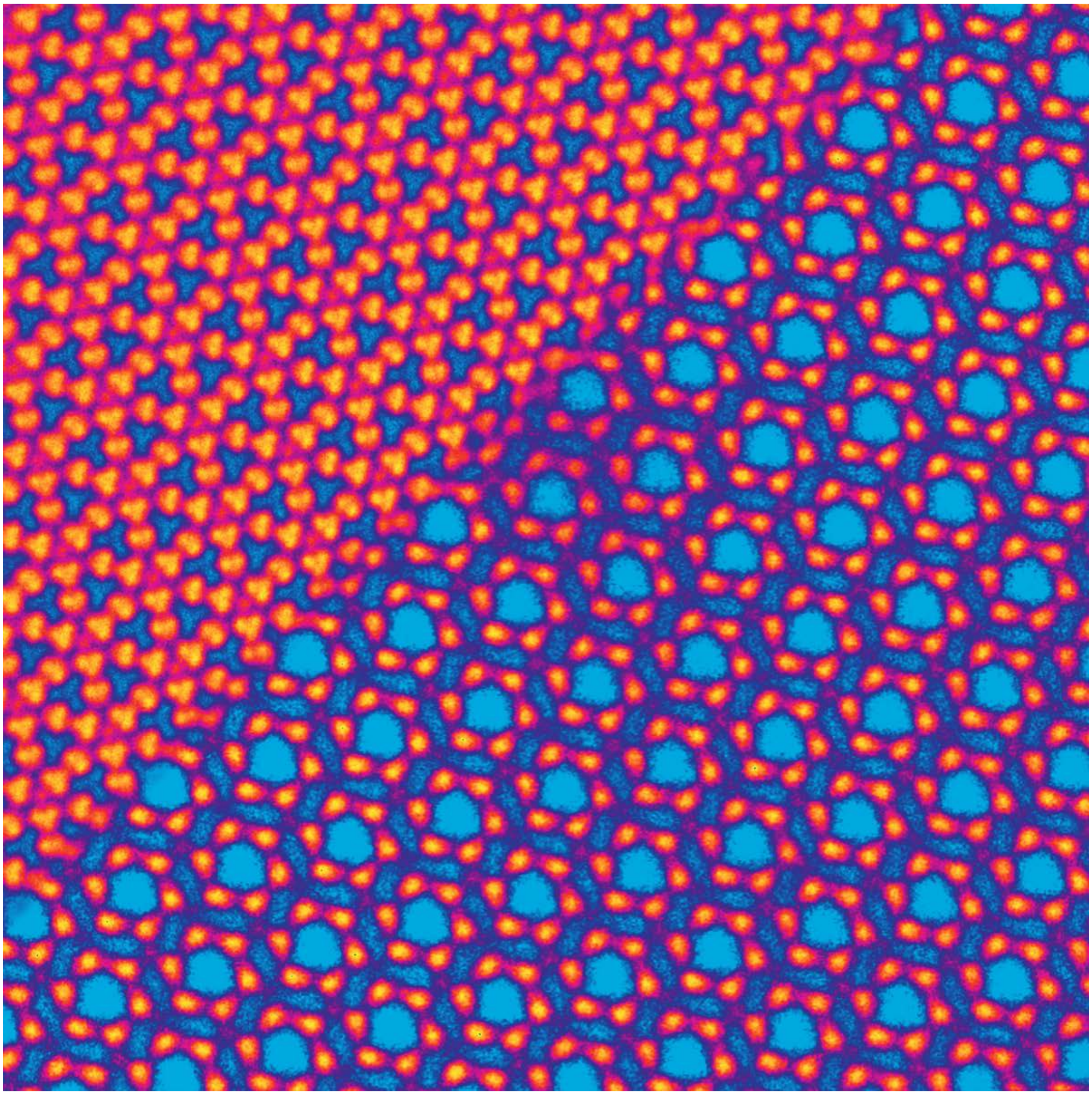
- Jeremy Jordan

ATOMIC RESOLUTION

THE 2016 EXHIBIT CURATED BY NC STATE'S **JIM LEBEAU**, ASSOCIATE PROFESSOR,
DEPARTMENT OF MATERIALS SCIENCE AND ENGINEERING

MUSEUM of LIFE + SCIENCE

LEDs: An unexpected avenue for lower energy demand
(above)
Lighting has had a profound impact on humanity. Many innovations have improved on how we illuminate the darkness. The oil lamp (c 4500 BC) and candle (c 500 BC) came first. Development of the incandescent light bulb (c 1835) greatly improved on light output, and the fluorescent bulb (c 1903) significantly decreased energy usage. Light-emitting diodes (LEDs) are changing the lighting industry again. LEDs last longer, use less energy, and are better for the environment than fluorescent bulbs. LEDs use materials with different bandgaps, which are used to create different colors of light. Gallium nitride (shown here) is used in blue- and white-light LEDs. These types of materials are also used in high-power electronics and high-powered lasers.



EXHIBITIONS

PHASES OF MATERIALS
(left)
Even though one material may have the same type and number of atoms as another, the preparation of the material can have a dramatic impact on how those atoms go together. In this example, silicon (Si) and nitrogen (N) are brought together under different amounts of pressure and temperatures. This results in two very different structures—known as phases. The silicon nitride pattern in the upper left is much harder than the silicon nitride pattern in the lower right. The mechanical properties of these two phases are very different. When these two phases are brought together in a composite (a single material), the resulting material is much tougher than either of the two base phases.

In September 2016, Jim LeBeau, associate professor in the Department of Materials Science and Engineering, curated an art exhibit at the Museum of Life and Science in Durham.

"We want to show people that we are now able to actually see atoms, and the orderly way that atoms are arranged in a material," says LeBeau, an associate professor of materials science and engineering at NC State.

And how those atoms are arranged, the patterns they make, is key to understanding a material's properties – and how engineers can control those properties.

For example, the image above shows silicon nitride, and highlights how differently atoms can organize in a material depending on how it was manufactured. All silicon nitride is composed of the same atoms, but those atoms can be arranged in very different ways.

In this example, the silicon nitride whose pattern is shown in the upper left is much harder than the silicon nitride whose pattern is shown in the lower right.

"Some of my work is supported by the National Science Foundation, and NSF thinks it is important to share our discoveries with the public," LeBeau says. "I agree. By partnering with the Museum of Life and Science, we are able to help people of all ages understand how we can glean insights into what materials look like at the most fundamental level.

"The beauty of these patterns highlights just how amazing nature is. Hopefully, we'll reach young people who may not have otherwise thought about pursuing science," LeBeau says. "Who knows? Maybe I'll see some of them in my classroom one day." ■

JIM **LEBEAU**
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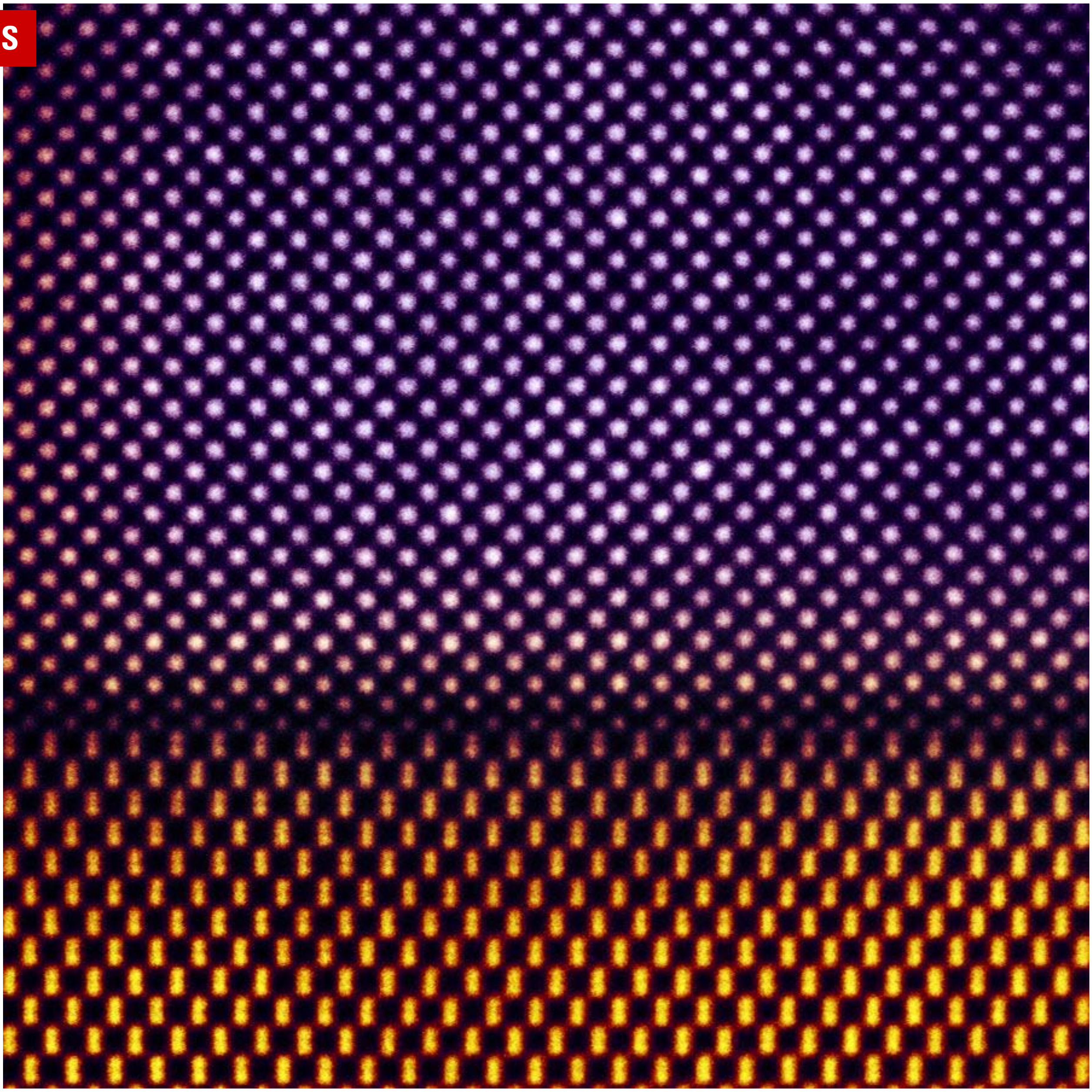
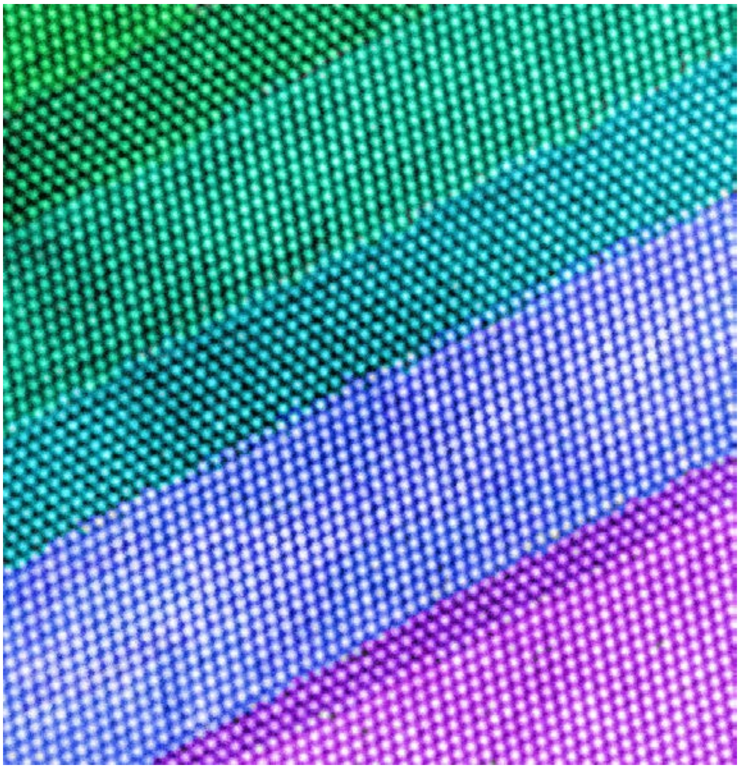
DISORDER UNDER THE MICROSCOPE
(right)
A sheet of aluminum foil, a sheet of plastic, a porcelain dinner plate— all seem pretty homogeneous (continuous) to the naked eye. But at the atomic scale, something that looks homogeneous can appear to have a distorted structure. Oxide materials like these are finding more use in electronic devices. Oxide materials like these are finding more use in electronic devices.

Note how the order breaks between the two regions in the final image: this shows an oxide layer grown on top of a germanium crystal.





SUPERALLOYS: THE METALS OF HARSH ENVIRONMENTS
(left)
Not all metal materials are created equal for every purpose. Some metals are light and some are heavy; some rust and some resist corrosion; some are strong and some are brittle. However, none of the metal alloys we find in everyday life are suitable for airplane turbines. Metals used in turbines must be lightweight, very strong, and capable of withstanding extreme heat and corrosive environments. Scientists have engineered metallic superalloys to be reliable in harsh environments, such as the alloy of nickel and aluminum, shown here. The bonding interactions between the alloying elements, and the ordering and arrangement of the atoms into a specific lattice or crystal structure make these alloys both strong and resilient.

LEW **REYNOLDS**

PRIORITIZING STUDENT SUCCESS

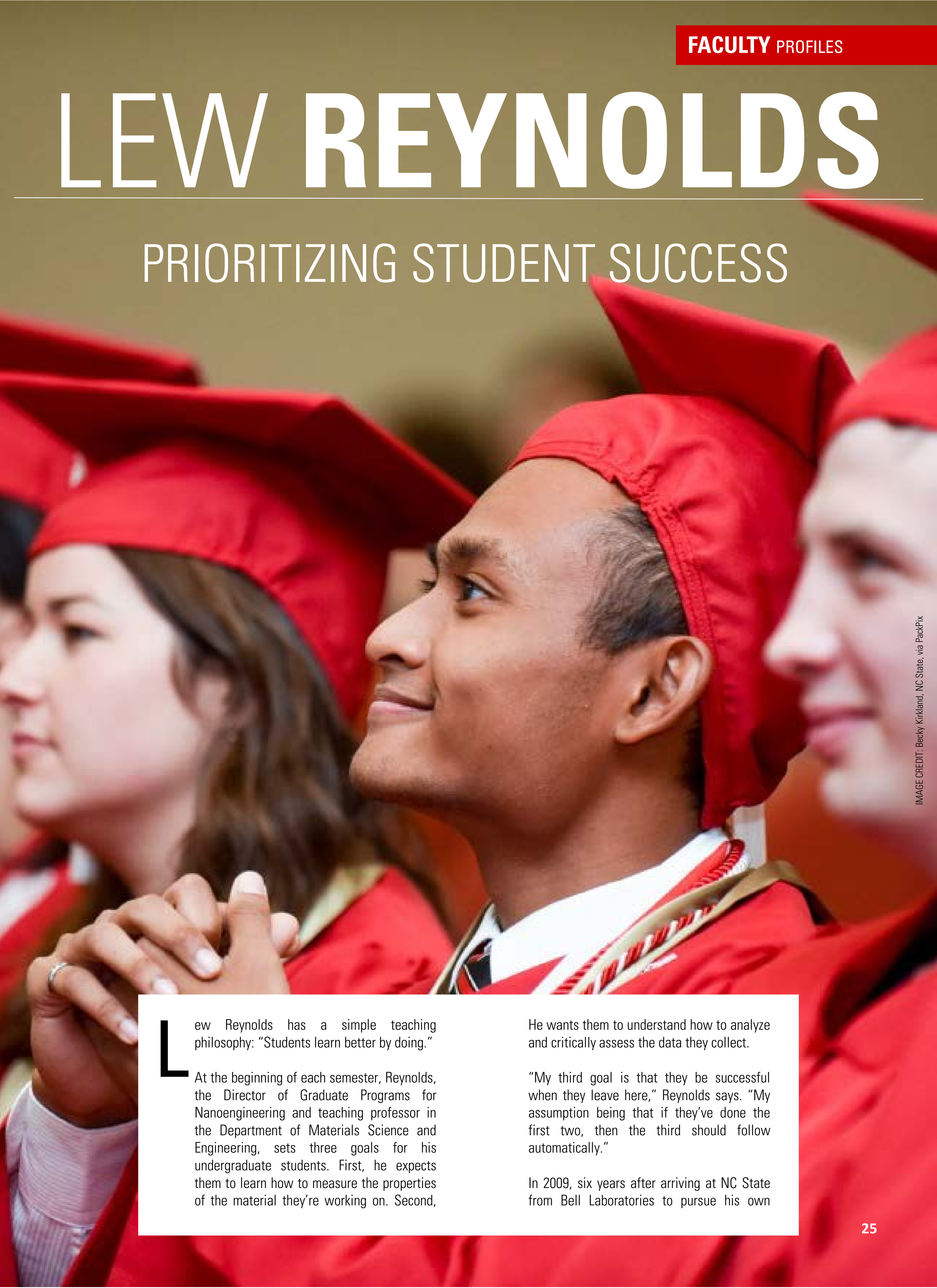


IMAGE CREDIT: Becky Kirkland, NC State, via PackPix

Lew Reynolds has a simple teaching philosophy: “Students learn better by doing.”

At the beginning of each semester, Reynolds, the Director of Graduate Programs for Nanoengineering and teaching professor in the Department of Materials Science and Engineering, sets three goals for his undergraduate students. First, he expects them to learn how to measure the properties of the material they’re working on. Second, He wants them to understand how to analyze and critically assess the data they collect.

“My third goal is that they be successful when they leave here,” Reynolds says. “My assumption being that if they’ve done the first two, then the third should follow automatically.”

In 2009, six years after arriving at NC State from Bell Laboratories to pursue his own semiconductor research, Reynolds teamed up with Justin Schwartz, the newly appointed Department Head, to reformulate the undergraduate laboratory program. The decision coincided with Schwartz's drive to increase student enrollment, which fluctuated between as many as 35 and as few as 8 students per year.

At the time, the curriculum included only one experiment each week that corresponded with the topic of a main lecture course. Since all students had to perform the same experiment, they worked together in large groups, making it easy for some students to fall back and offer minimal input. Observing this pattern, Reynolds realized he could predict which students would stay on the course within the first few weeks of each semester. "It was very obvious to me that different students were engaged at different levels in a given experiment," he says.

To redress this, Reynolds and Schwartz designed a new curriculum, which has significantly improved both student enrollment and student engagement in the laboratory. Small groups of students – no more than four to a group – work on one of five different experiments during three weekly sessions. To supervise and teach five lessons simultaneously, Reynolds assigns teaching assistants to each experiment so that he can circulate through the laboratory and dedicate ample time to each student.

"AS I PROGRESSED THROUGH THE MSE UNDERGRADUATE PROGRAM, I BEGAN TO REALIZE THE **LAB COURSES** BROUGHT TO LIGHT THE THEORY PRESENTED IN THE TEXTBOOKS."

CHRIS **CRUZ**, NC STATE ALUMNUS

With more content covered at a faster pace, he sets a short quiz at the beginning of the laboratory class to check that the students have come prepared; for every new experiment, students must watch a pre-recorded online lecture and read the experimental description before arriving for the session. And at the end of each week, his students are also required to submit a full lab report, which they have told him takes 10 to 15 hours to prepare.

Reynolds is the first to recognize that this is a particularly rigorous course for undergraduates. But with more than 23 years of experience in industry and 30 years' experience in semiconductor research, he knows the intensity is necessary.

"It's intended to reinforce the concepts," Reynolds explains, "so that when they sit down and start putting [the lab report] together, they need to think to themselves: Why is this experiment important? What are we really getting out of it?"

"The lab courses can be difficult because they really force you to dive into new materials concepts that you may have only touched on in the past," says Mary Kasper, one of Reynolds's former students who graduated from NC State in May and just started a Ph.D. in biomedical engineering

A CENTRAL FOCUS OF LEW REYNOLD'S WORK IS TO GIVE STUDENTS THE EXPERIENCE THEY NEED TO EXCEL IN THE WORKPLACE.
IMAGE CREDIT: BECKY KIRKLAND, VIA PACKPIX

at the University of Florida. "Despite how difficult they may be, they really put materials science into perspective."

"When I was in undergraduate school, I always found myself questioning why we needed to do these lab courses, and why the lab reports were so long and tedious," recalls Chris Cruz, who graduated from NC State in May, 2006. He currently works as Quality Lead Auditor in the Nuclear Oversight Division at GE Hitachi Nuclear Energy in Wilmington, North Carolina. "As I progressed through the MSE undergraduate program, I began to realize the lab courses brought to light the theory presented in the textbooks. Throughout my career, I have been able to speak intelligently about material experiments and material degradation issues because of my experience in the lab."

Guided by his own experience, Reynolds reinforces the skills and expertise his students will need when they move into the workplace.

"Lew's class did a good job of showing students the mindset of an engineer in the workplace," says Jacob Majikes, who completed both his undergraduate and graduate degrees at NC State, and

"HE'S CONSISTENTLY WILLING TO SACRIFICE TIME IN ORDER TO **CRITICALLY LISTEN** TO HIS MENTEE'S PROBLEMS, THEN GIVE ADVICE.

LEW HAS BEEN **CONSISTENTLY PROACTIVE** FOR BOTH HIS LAB SPACE AND FOR THE STUDENTS HE MENTORS."

JACOB **MAJIKES**, NC STATE ALUMNUS

graduated in the summer of 2016. He is currently an NRC Postdoctoral Fellow at the National Institute for Standards and Technology. "Engineering doesn't happen in a vacuum. You have to get the best information possible with finite resources to report your findings, and your confidence in them, to non-engineers within a limited amount of time."

The graduate degree course on nanoelectronics, part of NC State's Nanoengineering Master's Degree Program that launched in 2013, also benefits from Reynolds's careful examination of course content and structure. This past fall, at the request of his students, he added an additional three days of lectures on fundamental semiconductor physics. To supplement his own lectures, he also organizes talks from topical experts from outside the department to ensure students receive fresh information from a fast-paced field. "Nanoelectronics is such a dynamic area," he explains. "Things are evolving every day."

LEW **REYNOLDS**, DIRECTOR OF GRADUATE PROGRAMS AND TEACHING PROFESSOR

"ONE'S NEVER SATISFIED WITH THE **STATUS QUO**. ONE MUST ALWAYS LOOK AT WHAT STUDENTS SHOULD BE THINKING ABOUT FOR **THE FUTURE**."

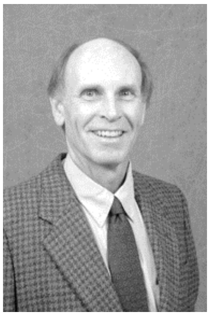
"There are two really notable things about Lew as a teacher/mentor," Majikes adds. "The first is that he's consistently willing to sacrifice time in order to critically listen to his mentee's problems, then give well-thought-out advice. The second is that, in my experience, it's very easy for the demands of the professoriate to isolate the faculty from their labs and their students. Lew has consistently been proactive for both his lab space and for the students he mentors."

Importantly, Reynolds's role as a mentor also extends beyond the undergraduate and graduate degree programs. He keeps his door open to his former students, ready to provide help whenever they need it.

"He really cares about the success of his students… after they leave NC State," says Cruz. "Even today he is quick to respond to his former students to help with recommendation letters, help answer any technical questions, and provide career advice based on his experiences. It's the little things like these that make him such a remarkable teacher and mentor."

By prioritizing the success of his students, Reynolds has guaranteed that his own work at NC State will always mirror the dedication and diligence he expects from his students. If student success equates to a strong career in industry or academia, then the reformulation of undergraduate programs that he began in 2009 is a task that will never end.

"You constantly evaluate: Is this the right experiment to do?" Reynolds says. "One's never satisfied with the status quo. One must always look at what other things are out there, and what students should be thinking about for the future." ■



LEW **REYNOLDS**
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THE **2017 U.S.-CZECH REPUBLIC** IRES PROGRAM

A SUMMER IN **PRAGUE**

IMAGES COURTESY OF HAILEY DAVIS

Each summer, MSE at NC State sends six undergraduate or graduate students to an international institution for the International Research Experience for Students (IRES) program. The program consists of a 10-week research and training experience, and seeks to develop and train globally-engaged scientists and engineers: Students and professionals whose scientific breakthroughs and engineering solutions consider and leverage global resources and are environmentally and socio-economically advantageous on the global scale.

This summer, Nick Blumenschein, Mike Slomski, Patrick Snyder and I visited Prague, Czech Republic, for the U.S.-Czech Republic IRES program, funded by the National Science Foundation, coordinated in part by our supervisors Dr. Albena Ivanisevic from the Department of Materials Science and Engineering and Dr. Tania Pascova from the Department of Electrical and Computer Engineering. This year's international host was the Institute of Physics at the Czech Academy of Science. The main goals of the trip were to create connections, experience living and working abroad, and work with scientists from different cultures in another country. It was an amazing experience, and our colleagues in Prague were incredibly gracious hosts.

At the Institute of Physics, we worked with Alex Romanyuk and had access to the institute's laboratories. We learned about new experimental characterization techniques and performed measurements on various GaN and Al_2O_3 samples using X-ray Photoelectron Spectroscopy, Micro Raman Spectroscopy, Kelvin Probe Force Microscopy, and Terahertz Spectrometry.

Outside the lab, we also had a chance to experience some of Prague's cultural attractions. Among the many activities we participated in, on one weekend our colleague Alice took us to the Karlštejn castle and the Koneprusy Caves, and also to a glass shop to see glassblowing demonstrations. We also spent time with her family. Alice's son also spent an afternoon with us, and took us hiking through the Divoká Šárka nature reserve. On the remaining weekends we also took organized tours to Terezín Camp and the city of Kutná Hora. Each were about an hour outside of the city, allowing us to see as much of Prague and its neighboring towns as possible.

The trip was spectacular, to say the least. Prague's scenery and architecture is absolutely beautiful and we all found it to be an eye-opening to experience. We tasted a way of life very different to our own, and also took our first steps toward becoming global scientists. ■

- Hailey Davis

Nick Blumenschein (*left*), Hailey Davis and Mike Slomski (*right*) in front of Karlštejn castle, Karlštejn. Blumenschein and Patrik Synder (*not pictured*) are graduate students; Davis is a rising senior; and Slomski has just been awarded his Ph.D.

IMAGE CREDIT: Marc Hall via Pack Pix

AWARDS AND PROMOTIONS

On March 1, 2017, Zhu received the **2017 The Minerals, Metals and Materials Society (TMS) Fellow award** at the TMS Annual meeting in San Diego, "for pioneering contributions to the understanding of deformation physics of nanomaterials and the development of nanotechnologies to produce superior nanomaterials." In 2016, he was also among **Thomson-Reuters** most highly cited researchers.

YUNTIAN **ZHU**
DISTINGUISHED PROFESSOR

In 2016, Augustyn was one of 35 nationwide recipients of **the Ralph E. Powe Junior Faculty Enhancement Award**, which provides funding for research by junior faculty at Oak Ridge Associated Universities. In November 2016, Augustyn also received an **NSF Career Award**, and this year, was selected for **NAE/CAE 2017 China-America Frontiers of Engineering Symposium**. This year, she also became a **Research Corporation for Science Advancement Scialog Fellow**.

VERONICA **AUGUSTYN**
ASSISTANT PROFESSOR

Jones is a Professor of Materials Science and Engineering, Director and Principal Investigator of the Research Triangle Nanotechnology Network, Director of the Analytical Instrumentation Facility, and a University Faculty Scholar. In 2016, he received the NC State **College of Engineering George H. Blessis Outstanding Undergraduate Advisor Award**, and was named an **Outstanding Reviewer for Scripta Materialia**.

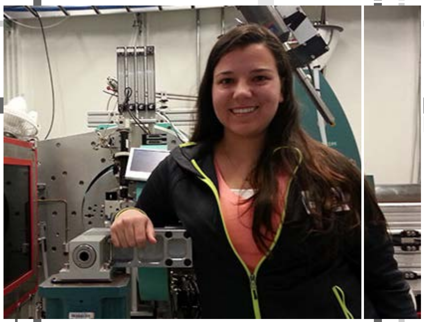
JACOB **JONES**
PROFESSOR

RAMON **COLLAZO**
PROFESSOR

This year, Collazo, has been promoted to **associate professor with tenure**. As well as studying growth and characterization of wide band gap semiconductor thin films, he is interested in control of polarity in III-nitrides, and the development of AlN bulk single crystal substrates, their surface preparation, and further epitaxial thin film deposition for optoelectronics and power device applications.

SHELBY **BOYD**
GRADUATE STUDENT

Boyd is a Ph.D. student in Veronica Augustyn's research group studying layered oxides for energy storage. In November 2016, she won **Best Poster Presentation** at 2016 MRS/ASM/AVS Joint Symposium. In March this year, she was awarded an **NSF Graduate Research Fellowship**.



TEDI-MARIE **USHER**
PH.D. GRADUATE

Usher graduated with her Ph.D. from NC State in 2016, where she worked with Dr. Jacob L. Jones, and in April this year, she received the **College of Engineering Distinguished Dissertation Award** for her dissertation "Local and Average Structures in Ferroelectrics under Perturbing Fields." Usher is currently working as a postdoctoral research associate at Oak Ridge National Laboratory (ORNL) in Oak Ridge, Tennessee.

THOMAS **LABEAN**
PROFESSOR

LaBean, who joined the Materials Science and Engineering Faculty in August 2011, has been promoted to **professor** this year. His current research projects involve the design, construction, and testing of self-assembling DNA nanostructures for applications in molecular materials, nanoelectronics, nanophotonics, molecular robotics, and nanomedicine.

30

AWARDS AND PROMOTIONS

Alhajji is one of 14 students at NC State who has been accepted into the National Academy of Engineers **Grand Challenge Scholars Program** this year. She will be addressing the Grand Challenge of "making solar energy economical" by studying the emerging technology of Na-ion batteries and the development of nanomaterials for supercapacitors, as well as designing flexible and transparent electronics.

EMAN **ALHAJJI**
UNDERGRADUATE STUDENT

Lucas was an undergraduate student participating in Veronica Augustyn's research group. This year, she has awarded an **NSF Graduate Research Fellowship**, and she started her Ph.D. degree at Caltech in September. Lucas has also been named **Top Presenter** at the 2017 NC State Undergraduate Research Symposium, and NC State **MSE Department Outstanding Senior**.

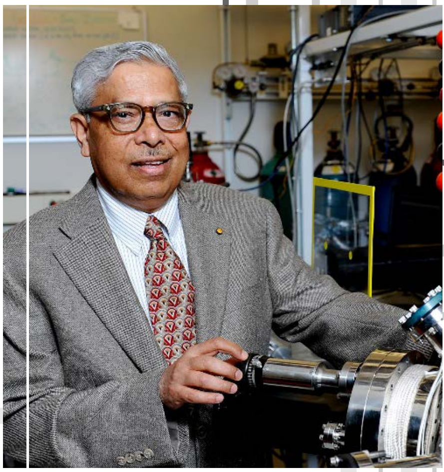
EOWYN **LUCAS**
UNDERGRADUATE RESEARCHER

The TMS Annual meeting in San Diego held a **symposium** in Koch's honor this year. Koch is a Kobe Steel Distinguished Professor at NC State. His recent research has focused on nanocrystalline materials due to special mechanical and soft magnetic properties of these materials.

CARL **KOCH**
DISTINGUISHED PROFESSOR

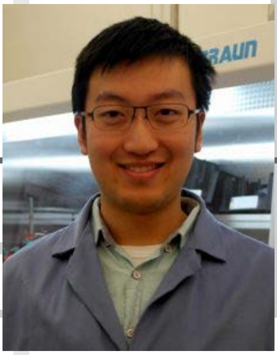
Hsain is an NC State junior majoring in materials science and engineering. She is working under the supervision of Michael Dickey on NC State's Advanced Self-Powered Systems of Integrated Sensors and Technologies Center for two years. In April this year, she was awarded a **2017 Truman Scholarship**.

ALEX **HSAIN**
UNDERGRADUATE RESEARCHER



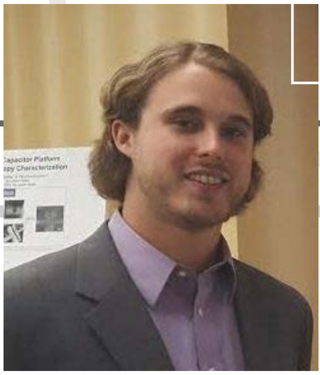
JAGDISH **NARAYAN**
DISTINGUISHED PROFESSOR

This year, Narayan, the John C. Fan Distinguished Chair Professor of MSE at NC State, has been inducted into the **National Academy of Engineers**. His group's current research focus is on novel thin film heterostructures involving epitaxy across the misfit scale of oxides and nitrides and their integration on practical substrates including the (100) Si and sapphire substrates.



RUOCUN **WANG**
GRADUATE STUDENT

Wang is a graduate student in Veronica Augustyn's research group studying *in-situ* electrochemistry platform for transmission electron microscopy and solvated oxides for energy storage. In June this year, he was selected for **2017 UIC Next Generation Electrochemistry (NGenE) Workshop**, and in August this year, was selected for the **2017 WE-Heraeus Seminar on "In-Operando Characterization of Energy Materials**.



JAMES **MITCHELL**
GRADUATE STUDENT

Mitchell is a graduate student in Veronica Augustyn's research group studying hydrated oxides for energy storage. In April this year, he was awarded **Best Poster Award at 2017 MRS Spring Meeting**. In August this year, he was also selected for **MRS/SMM Student Poster Award Exchange Program at the 2017 International Materials Research Congress**.

CHERYL **CASS**
TEACHING ASSOCIATE PROFESSOR

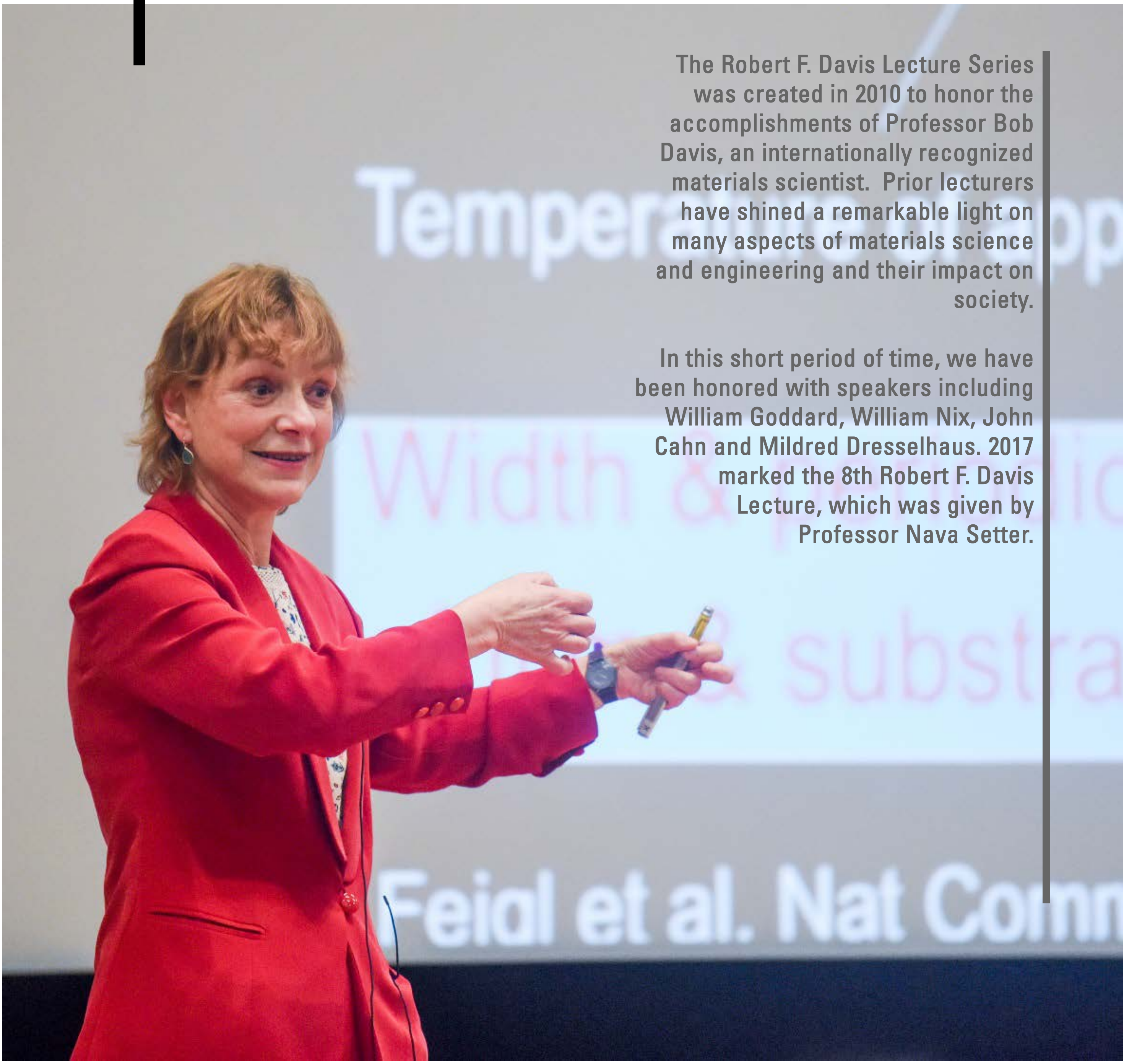
Cass, Director of Undergraduate Programs, has been promoted to **teaching associate professor** this year. Her interests include engineering and science education, STEM identity development, engineering doctoral student experiences, and industry relevance in capstone courses. Her research focuses on the intersection of science and engineering identity and engineering career choice in post-secondary and graduate level programs.

DAVIS LECTURE SERIES

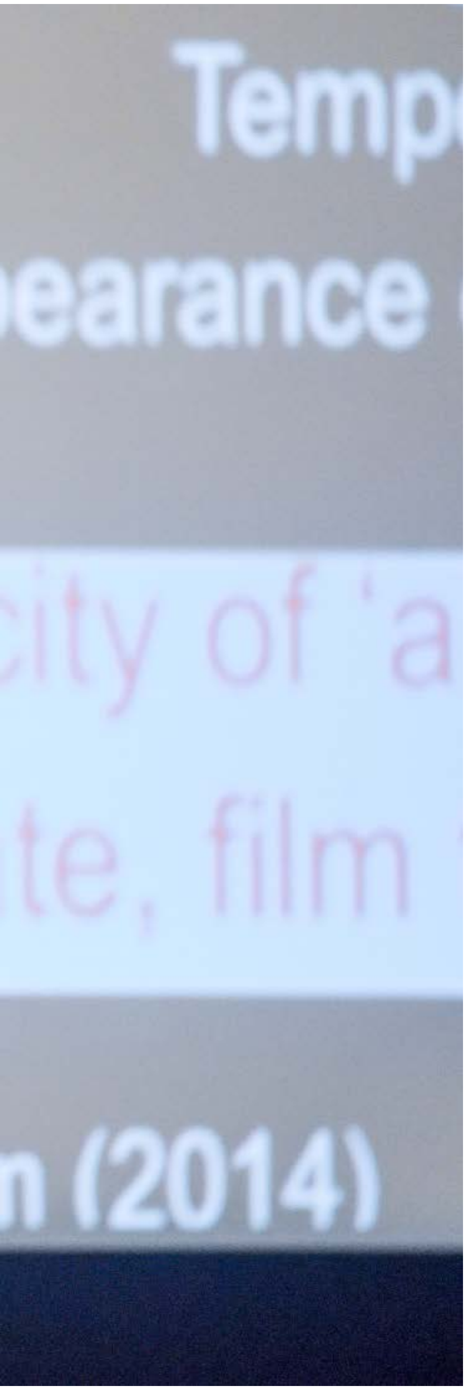
NAVA SETTER

The Robert F. Davis Lecture Series was created in 2010 to honor the accomplishments of Professor Bob Davis, an internationally recognized materials scientist. Prior lecturers have shined a remarkable light on many aspects of materials science and engineering and their impact on society.

In this short period of time, we have been honored with speakers including William Goddard, William Nix, John Cahn and Mildred Dresselhaus. 2017 marked the 8th Robert F. Davis Lecture, which was given by Professor Nava Setter.



THE 2017 LECTURE FEATURED PROFESSOR NAVA SETTER, WHO CURRENTLY SHARES HER TIME BETWEEN EPFL, SWITZERLAND, AND TEL AVIV UNIVERSITY, ISRAEL.



Professor Setter was born in Haifa, Israel, and undertook her master's degree in Civil Engineering at the Technion, the Israel Institute of Technology. Following completion of her MSc, Setter turned her focus to the electrical properties of matter, and moved to the United States to pursue her PhD in Solid State Science at the Pennsylvania State University, which she completed in 1980.

In the following years, she worked as a postdoctoral researcher, focusing on physics and chemistry, at the University of Oxford, United Kingdom, and at the University of Geneva, Switzerland. Between 1983 and 1989 she returned to Haifa to work as a research engineer at the R&D Institute, and eventually became head of its Electronic Ceramics Lab. In 1989, she was appointed professor of Materials Science and Engineering and director of the Ceramics Laboratory of the prestigious Swiss Federal Institute of Technology (EPFL) in Lausanne, Switzerland.

Professor Setter's research interests include ferroelectrics and piezoelectrics, in particular the effects of interfaces, finite-size and domain-wall phenomena, as well as structure-property relations and the pursuit of new applications. She has published over 500 scientific and technical papers with over 17,000 citations.

Professor Setter is a Fellow of the Swiss Academy of Technical Sciences, the Institute of Electrical and Electronic Engineers (IEEE), and the World Academy of Ceramics. She has received numerous award for her research, including the Swiss-Korea Research Award, the Japanese FMA Award, the Ferroelectrics-IEEE recognition award, IEEE-UFFC Achievement Award, the AVS Recognition for Excellence in Leadership, and the American Ceramic Society Sosman Award.

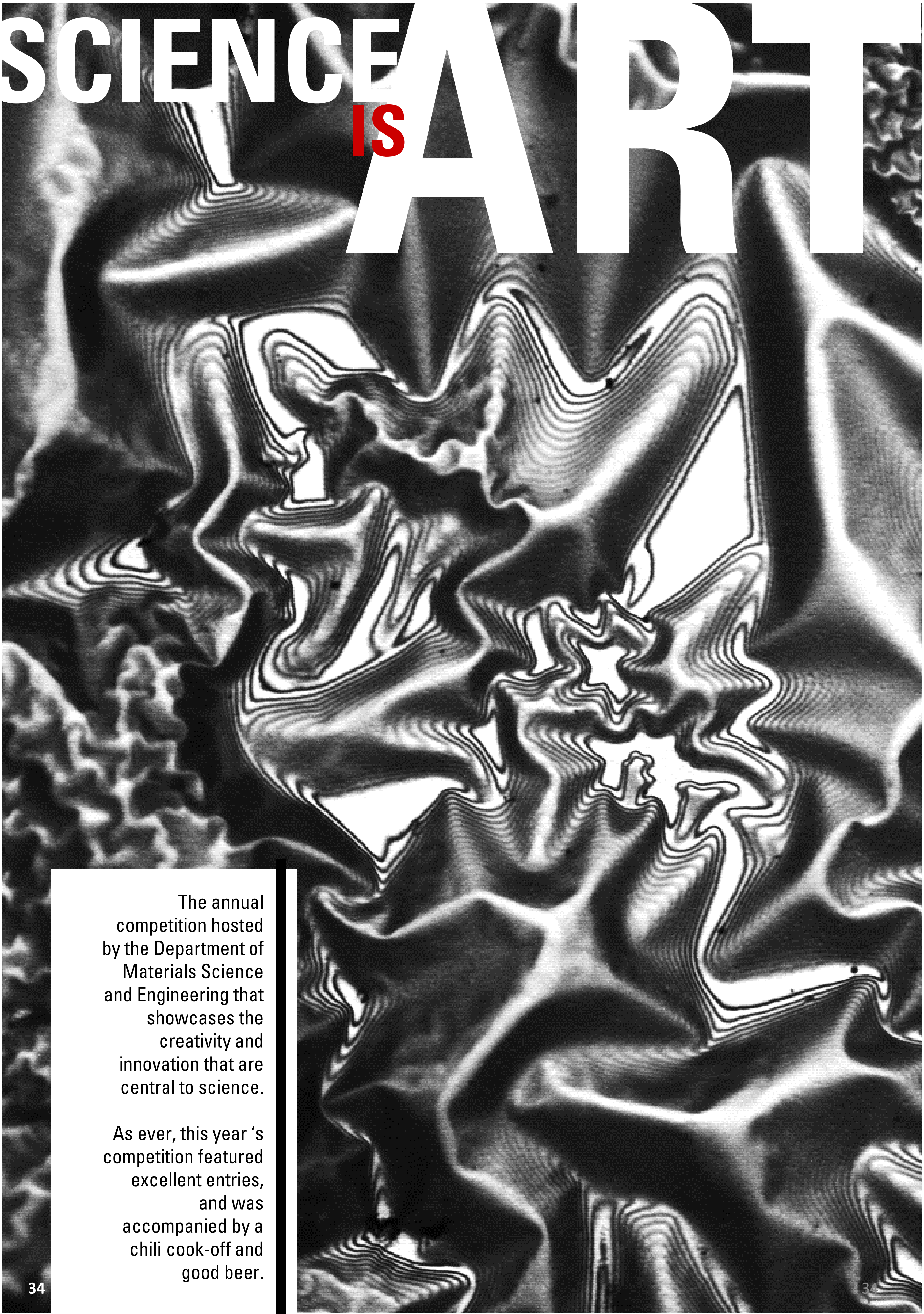
In addition to her outstanding technical contributions, Professor Setter has been an inspiring role model for materials scientists around the world. As a true global citizen, she was responsible for the creation of a high school in a remote, rural location of Tanzania, which is now one of the top schools in science and humanities in the country.

2017 | PROFESSOR NAVA SETTER WITH TWO MEMBERS OF SCIBRIDGE.

This year, Professor Setter met with NC State SciBridge members to discuss the project and its future goals. The SciBridge team hopes to collaborate with Professor Setter, and use her expertise, knowledge and advice to reach their goals as an organization.

Today, Professor Setter shares her time between EPFL and Tel Aviv University, and remains very active in the Ceramics research and education. We were truly honored to have her as the 2017 Davis Lecturer. ■

SCIENCE IS ART



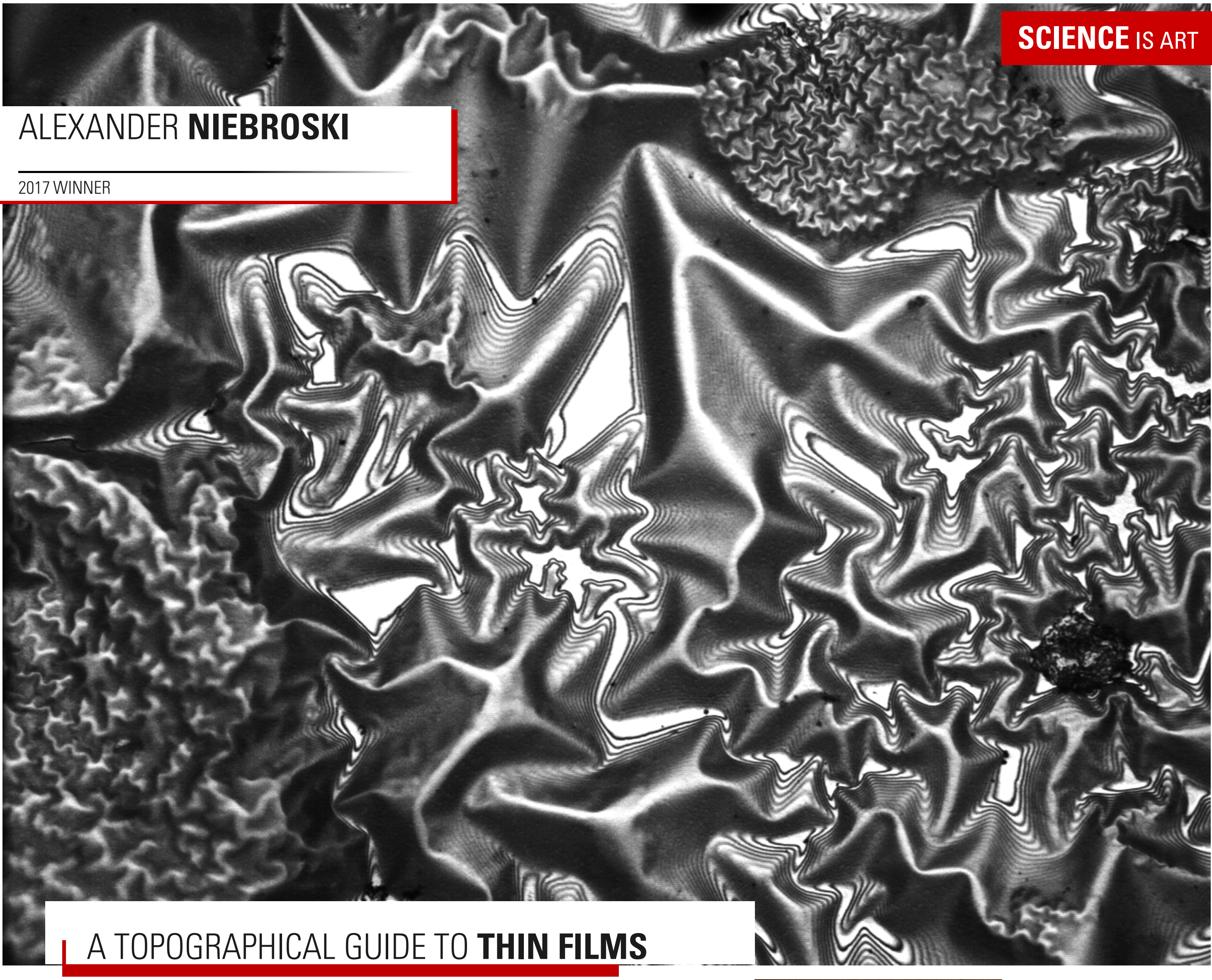
The annual competition hosted by the Department of Materials Science and Engineering that showcases the creativity and innovation that are central to science.

As ever, this year 's competition featured excellent entries, and was accompanied by a chili cook-off and good beer.

34

ALEXANDER **NIEBROSKI**

2017 WINNER



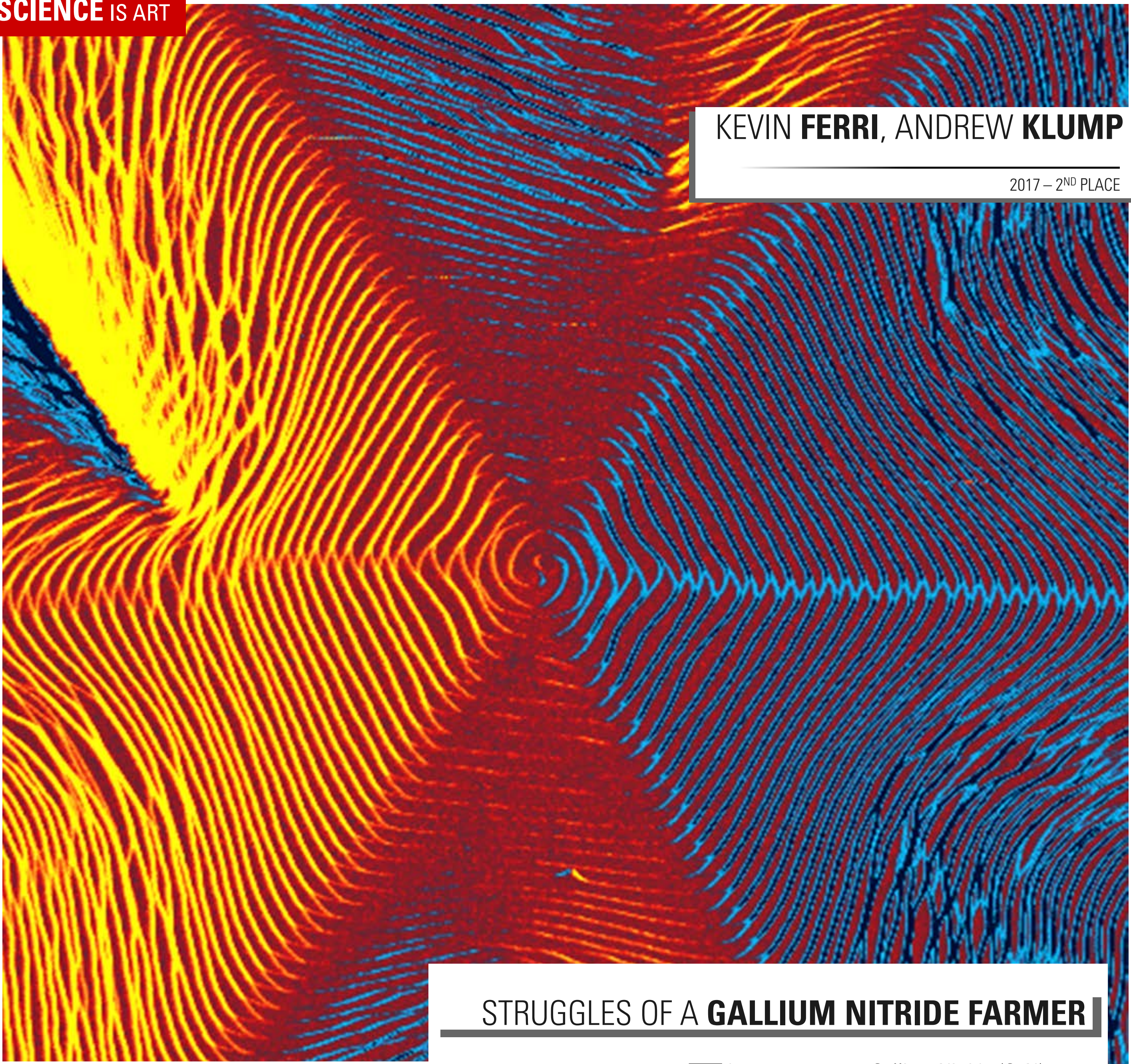
A TOPOGRAPHICAL GUIDE TO **THIN FILMS**

Ridges that appear on a tantalum-doped carbon thin film on a tungsten carbide substrate produced by the pulsed laser deposition technique. These features arise due to internal stresses of the film from a combination of factors such as the differences in both the sizes of the atoms and how much they change size when the temperature changes. Much like a 6’5” tall passenger traveling on an airplane, the film attempts to find a position that minimizes stress.

The image also appears uncannily similar to a topographical map used for navigating the outdoors when hiking – even down to the existence of contour lines depicting where the film has peeled off from the substrate to the same height. However, unlike a mountain range, changes in the topography shift very quickly: ridges are quickly formed and extinguished within a matter of seconds as the film attempts to reach a stable position, leading to a bit of challenge in taking this image. One can imagine being an atom “walking” along a trail in the woods and a second later, suddenly the whole trail is suspended miles up in the air!

Niebroski is a graduate student studying the formation of Q-carbon and diamond films for tribological and electronical applications in Jay Narayan’s group. He recently received his BSE in Materials Science & Engineering at Arizona State University and has been at NC State for one year.

Over the span of his career, he hopes to make quantum computing a reality, leading to the advancement of simulation capabilities and the discovery of new materials, especially for the conversion of energy. For instance, he believes new materials could be developed rapidly to overcome the corrosion and heat transfer hurdles that currently plague nuclear fusion research. Furthermore, Niebroski wants to make scientific discoveries more accessible to those without technical degrees and to foster evidence-based policymaking.



KEVIN **FERRI**, ANDREW **KLUMP**

2017 – 2ND PLACE

STRUGGLES OF A **GALLIUM NITRIDE FARMER**

Andrew Klump (right) has just started his third year as a Ph.D. student in Zlatko Sitar's group, and Kevin Ferri (left) is a second year PhD student in Jon-Paul Maria's group. Klump and Ferri work together to create oxide-nitride interfaces with the same structural and chemical perfection that is typically reserved for lattice-matched systems such as nitride-nitride or perovskite-perovskite stacks.

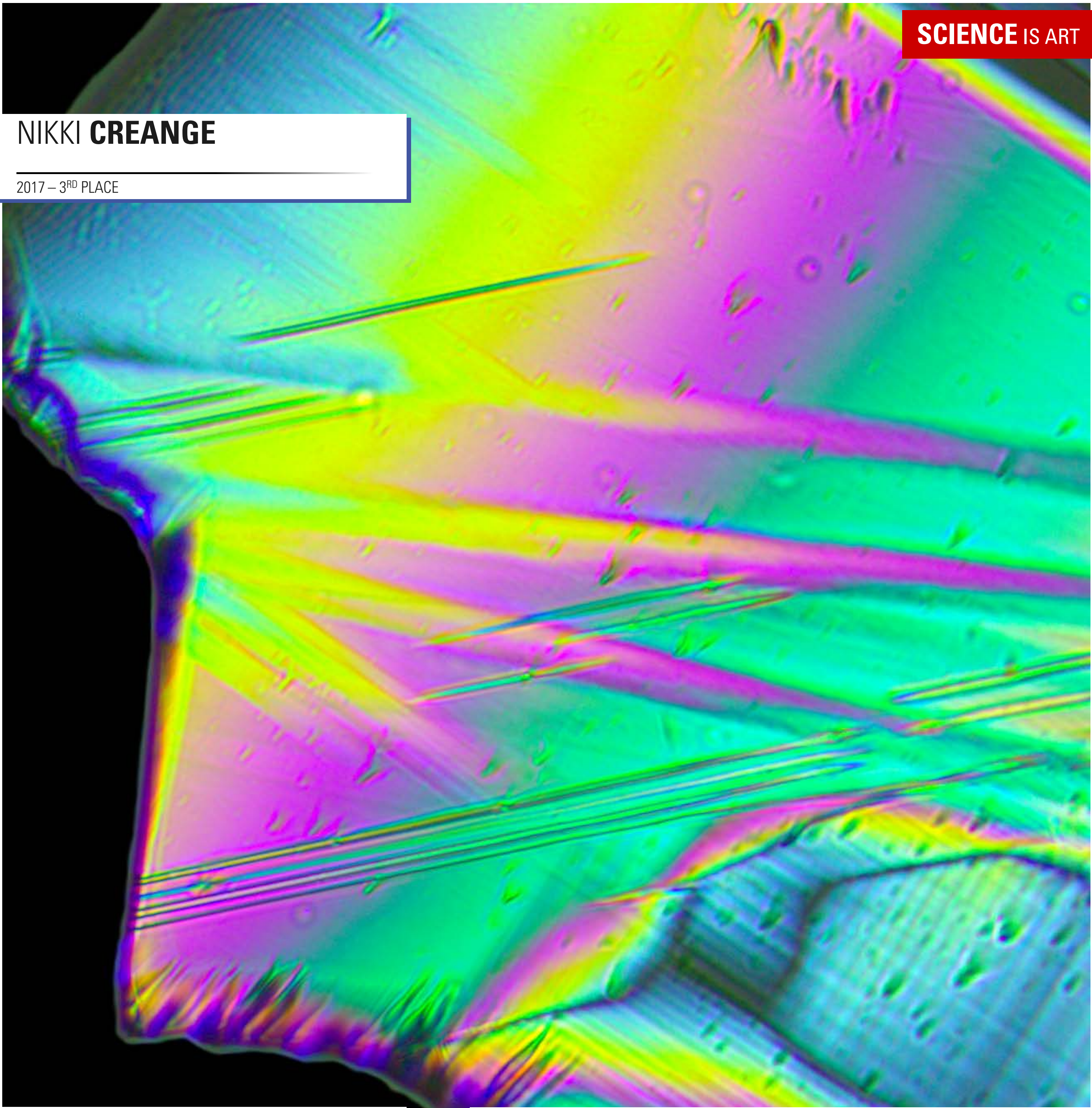
By collaborating, Ferri and Klump are able to investigate both surfactant-assisted epitaxial growth of oxides on GaN (Ferri’s primary focus) as well as optimization of growth kinetics which result in the planarization of GaN (Klump’s focus). This allows both students to grow commensurate lattice matched oxides on GaN surfaces which contain no steps over many microns. The ultimate goal of this research is to create a 2-dimensional electron gas in the GaN which can be modulated by the non-linear properties of the oxide layer.

The sun sets on a Gallium Nitride (GaN) farm. All is still and quiet as the regions of the farm that remain in sunlight shimmer bright, while those still in shadow show only trails of water leading into the valleys below. After a long day of trying to grow flat GaN, the farmers have given up and are nowhere to be found. As the sun sets on a screw dislocation, they hope it rises to step-flow growth tomorrow.

This false color AFM image is of a helical GaN screw dislocation. The step-terrace morphology rising with the dislocation along with the coloration reminded us of the terraces of rice farms.

NIKKI **CREANGE**

2017 – 3RD PLACE



ON THE EDGE OF **SUNSHINE**

Sun rays emerge from the edge of darkness to produce an array of colors. Polarization within this barium titanate sample rotates light to produce these vibrant colors when viewed under a polarized optical microscope.

Note: No color was added to this photo, it was all created through light interacting with the sample.

Nikki Creange is a third year graduate student in Elizabeth Dickey's research group. She received her BS undergraduate degree in physics from James Madison University, Virginia, before coming to NC State. Her research focuses on the structural changes at the metal-metal oxide interface region during resistance degradation, and developing a fundamental understanding of what factors contribute to the degradation process.

Creange is President of the Materials Science and Engineering Graduate Student Association (MSE GSA). She is also a fellow of the Data-Enabled Science and Engineering of Atomic Structure (SEAS) NSF trainee program at NC State, and is incorporating statistical methods into the analysis of atomic structure-generated data. After completing her Ph.D., Creange hopes to obtain a position in an industry or national laboratory with the overall aim of contributing to the advancement of technology.

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