PENNSTATE

MRI

FOCUS on MATERIALS

MATERIALS RESEARCH INSTITUTE BULLETIN

SPRING 2015

MATERIALS FOR HUMANITY

PENNSTATE

MRI

MATERIALS RESEARCH INSTITUTE

Focus on Materials is a bulletin of the Materials Research Institute at Penn State University. Visit our web site at **www.mri.psu.edu**

Clive A Randall, *Director of the Materials Research Institute and Professor of Materials Science and Engineering*
N-221
Millennium Science Complex
University Park, PA 16802
(814) 863-1328
car4@psu.edu

Robert Cornwall, *Managing Director of the Materials Research Institute*
N-319
Millennium Science Complex
University Park, PA 16802
(814) 863-8735
rgc5@psu.edu

Walt Mills, *editor/writer*
N-358
Millennium Science Complex
University Park, PA 16802
(814) 865-0285
wem12@psu.edu

Mark Passmore, *graphic design*
Passmore Design
(814) 353-8853
passmoredesign@comcast.net

This publication is available in alternative media on request.

Penn State is an equal opportunity, affirmative action employer, and is committed to providing employment opportunities to minorities, women, veterans, individuals with disabilities, and other protected groups. Nondiscrimination: http://guru.psu.edu/policies/AD85.html

U.Ed. RES 15-23

Message from the Director

Clive A Randall

The topic of this issue, which can best be described as cultural and humanitarian materials science, is one of the key areas of our new strategic plan for MRI. We realize that MRI has the capabilities to make a profound impact on the programs Penn State has already pioneered in student engagement and socially responsible engineering in the developing regions of the world. By adding our expertise in testing and characterization, we can help reduce the time to market of products that must be able to perform for extended periods in harsh environments and in resource limited locations. As this program ramps up, we will be bringing you further news of our collaborations with the likes of the Colleges of Arts and Architecture, Engineering, Agricultural Sciences, the Huck Institutes, and Penn State Institutes of Energy and the Environment (PSIEE) to provide a materials component to their humanitarian and cultural projects.

With the appointment of Adri van Duin as director of the new Materials Computation Center (MCC), we are moving ahead with our plan to create a Three Labs, One Integrated Solution approach to both faculty driven discovery and industry needs. By integrating the MCC with the Materials Characterization Lab and the Nanofabrication Facility, MRI will be able to provide one-stop solutions that integrate theory, simulation, fabrication, and evaluation.

A third key strategy for MRI is the establishment of centers for the study of biological and soft materials (biomaterials, polymers) and for a sustainable digital future that builds on Penn State's considerable strengths in electronics, energy, and photonics technology.

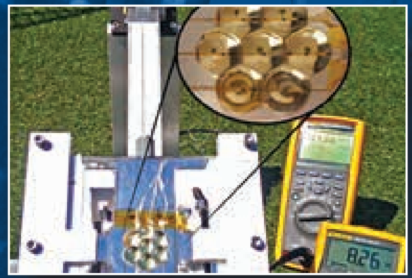
In each of these areas discussed, MRI will encourage and support entrepreneurial efforts by MRI researchers with the goal of developing a thriving start-up community that will transfer our most promising discoveries to the marketplace.

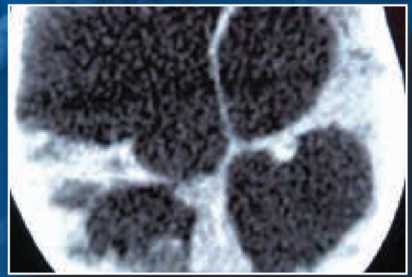
To help implement our ambitious goals, we have restructured MRI management with a Board of Directors drawn from diverse disciplines across the university to broaden our perspective, enhance our knowledge base, and distribute our responsibilities. In addition, I am pleased to announce that Joan Redwing, professor of materials science and engineering and electrical engineering, has agreed to accept the new position as the Associate Director of MRI. Joan is not only a world's expert in chemical vapor deposition in compound semiconductors, but she also brings over a decade of industry experience to this position. Welcome, Joan.

Sincerely,
Clive A Randall
Director of the Materials Research Institute
And Professor of Materials Science and Engineering

To access the materials expertise at Penn State, please visit our Materials Research Institute website at **www.mri.psu.edu** or the Office of Technology Management website at **http://www.research.psu.edu/offices/otm**

CONTENTS





IN THIS ISSUE:
MATERIALS FOR HUMANITY

COVER: Employees of Mavuuno Greenhouses with a fresh harvest of organic bell peppers. Vegetables produced in the greenhouses tend to be much bigger in size and have almost no blemishes.

Clive Randall speaks at Materials Day 2014.

Clive Randall to Lead Materials Research Institute

Vice President for Research Neil Sharkey has named noted Penn State electroceramics scientist Clive Randall as the new director of the Penn State Materials Research Institute, effective March 1, 2015. After serving as interim director since September, Randall, who is a professor in the Department of Materials Science and Engineering, becomes only the second MRI director in the institute's 16-year history.

Vice President Sharkey said this about Randall's appointment: "I am absolutely thrilled with Professor Randall's decision to become the permanent director of MRI. Clive's impressive research credentials, his intellectual firepower, and his practical management skills will surely serve him well in this new capacity. Adding to Clive's stellar academic record is his intimate knowledge of the Materials Research Institute and its many faculty. He has already done a phenomenal job of grabbing the reigns in his short time as interim director, leaving no doubt that he will effectively build upon the solid foundation laid by his predecessor Carlo Pantano. We are most fortunate to have landed a director who will continue to ensure that Penn State maintains its leadership in materials science."

The Materials Research Institute undertakes world-class interdisciplinary scientific and engineering research with global impact. MRI cuts across the boundaries of traditional fields of study to push research at the leading edge of emerging fields. With more than 250 materials-related faculty across multiple science and engineering disciplines, Penn State has been ranked by the National Science Foundation as the nation's leading materials research institution based on annual expenditures. MRI provides state-of-the-art characterization and nanofabrication facilities for the research community and hands-on training to thousands of students.

"It has been an honor to serve as MRI's interim director, and I look forward to engaging with the university administration in a way that enables MRI to make real progress on our strategic goals," Randall said. "I want to thank Carlo Pantano for leaving this institution well prepared to meet those goals."

By partnering with the College of Medicine, the Huck Institutes for the Life Sciences, Randall plans to increase interactions at the intersection of the life sciences and materials research, for example, by developing new devices for early diagnostics and therapeutics of diseases and also applying advanced materials characterization imaging techniques to the study and processing of biological materials. Along with the Penn State Institutes of Energy and the Environment, and the colleges, he plans to advance the transition of Penn State's expertise in electronics, energy, and photonics to industrial partners. And with the creation of MRI's new Materials Computation Center under the leadership of Adri van Duin, associate professor of mechanical engineering, Randall intends to make a computation and modeling component more available to materials researchers on campus to aid characterization and processing. His long-term goal is to apply a materials science philosophy to the cause of global humanitarian engineering and social entrepreneurship to benefit society.

In his announcement, Sharkey noted that "Dr. Randall has authored/co-authored over 330 technical papers, with over 10,000 citations. He also holds 13 patents (with 3 pending) in the field of electroceramics. He was Director for the Center for Dielectric Studies between 1997 and 2013, and in 2014 formed a new Center as Co-Director, the Center for Dielectrics and Piezoelectrics. Clive received a B.Sc. with Honors in Physics in 1983 from the University of East Anglia, and a Ph.D. in Experimental Physics from the University of Essex in 1987.

Van Duin Named Director of New Computation Center in the Materials Research Institute

Adri van Duin, associate professor of mechanical engineering , has been named the director of the newly created Materials Computation Center (MCC) in the Penn State Materials Research Institute. Van Duin is best known as the inventor of the ReaxFF reactive force field method. The goal of the new center is to help make computational methods available to experimentalists both in the university community and in industry.

"I want to make sure that our theory capability is more visible to the university and the outside world," van Duin said. "In the long run, I want the MCC to be as integrated into research as the Nanofabrication Laboratory and the Materials Characterization Lab are now."

A new MCC website is now available to connect researchers with potential collaborators in several modeling and simulation techniques. The website will allow visitors to interact with MCC, discover the available materials computation methods, and learn about the work of Penn State's active community of theorists and modelers.

Clive Randall, the new director of the Materials Research Institute, has made the MCC and the "three labs, one solution" concept an integral part of MRI's strategy for future research excellence and for a unified approach to industry needs.

Contact Adri van Duin Email: acv13@psu.edu

Web: www.mri.psu.edu/facilities/mcc

Snapshots are brief summaries of significant materials-related breakthroughs by MRI researchers. More information is available by visiting the links at the end of each summary.

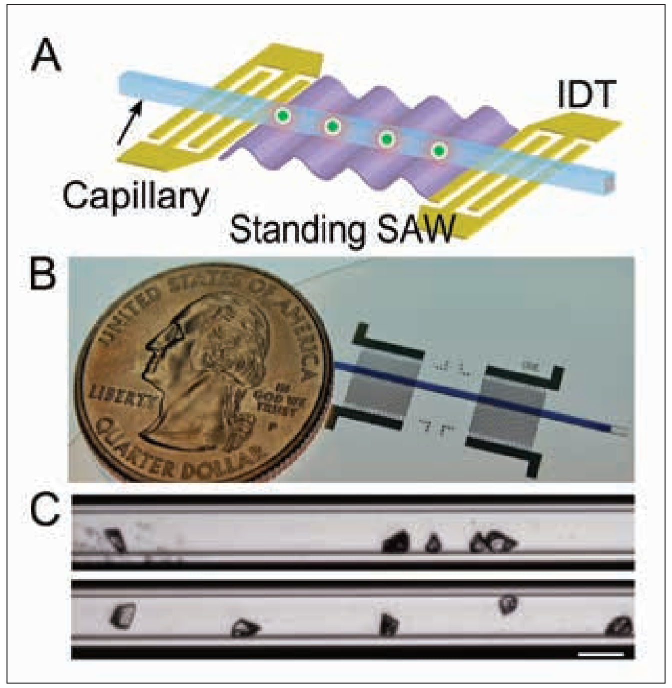
ACOUSTIC TWEEZERS DEVICE EXPANDS THE RANGE OF X-RAY CRYSTALLOGRAPHY

A device for precisely positioning small objects using acoustic waves has now been used to position fragile protein crystals a few micrometers or less in size in the path of a crystallography X-ray beam. This technique will make it possible to collect data on previously intractable samples and will expand the scope of what is now possible with X-ray crystallography.

"X-ray crystallography has the capability to characterize the atomic-level details of molecules and complex structures. It enables discoveries in virtually all fields of chemistry, biology, and medicine," said Tony Jun Huang, professor of engineering science and mechanics at Penn State. "But the biggest issue today with the technique is finding a way to handle these small and delicate crystals."

Recent advances in modern X-ray sources and detector technology have made it possible to collect usable data on these tiny crystals. But the manipulation and mounting of crystals in the beam has traditionally been done by hand under a microscope with small needle-like cryoloops. This process is not only slow and inefficient, but is extremely difficult or impossible for very small crystals.

"The lack of robust, automated sample handling techniques prevents crystallographers from fully realizing the power of these technological advances. Our new device, which enables the precise manipulation and patterning of protein crystals using surface acoustic waves, is a transformative technology for structural biologists," said Jarrod French, an assistant professor of biochemistry and cell biology at Stony Brook University. "This acoustic tweezers technology is a significant boon to the field of X-ray crystallography. It overcomes a significant barrier in the field by enabling the manipulation and patterning of micro- or nanometer sized protein crystals using low power, biocompatible acoustic waves."



(A) Schematic of an acoustic tweezers device used to manipulate protein crystals (B) A photograph of the device compared to a US quarter (C) Clusters of crystals (top) can be separated and patterned (bottom). The inter-crystal distance is equal to one half-wavelength of the input acoustic waves. Scale bar = 100 μm   Credit: Feng Guo

French and Huang's collaboration began while French was a postdoctoral scholar in the lab of Stephen Benkovic, Evan Pugh Professor of Chemistry at Penn State. The pair are corresponding authors on a paper appearing online on Feb. 2 in the journal *Small* titled "Precise Manipulation and Patterning of Protein Crystals for Macromolecular Crystallography Using Surface Acoustic Waves." The lead author is Feng Guo, a Ph.D. student in Huang's group.

Neela Yennawar, director of the Huck Institute's Macromolecular X-ray Facility at Penn State and a co-author on the paper in Small, said "Crystallographers are pushing the boundary of biological samples being studied and moving towards more difficult targets of higher molecular weight and complexity. Acoustic tweezers will be extremely important to handle nano sized and fragile crystals of such targets. It will maximize the quality and quantity of X-ray diffraction data collected using the recently established femtosecond serial crystallography approach. This exciting field often requires vast quantities of crystals owing to the low efficiency (hit-rate) of the crystal delivery system to the X-ray beam. Acoustic methods developed in our paper promise to significantly increase the efficiency and throughput of both serial crystallography methods as well as the more conventional screening and data collection approaches."

Acoustic tweezers is a microfluidic device that utilizes ultrasound waves produced by piezoelectric transducers to gently and precisely position biological samples without damage. The device has been used to separate different blood components, to separate cancer cells from blood and to manipulate nanorod motors inside living cells, to name only a few research areas.

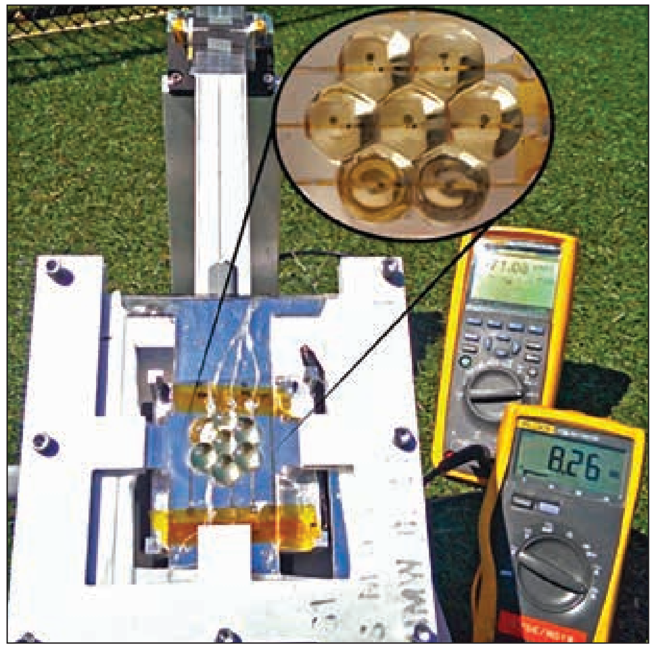
Other authors on this paper are Weijie Zhou, a Ph.D. student in chemistry at Stony Brook, Peng Li, a postdoctoral fellow and Zhangming Mao, a Ph.D. student, both in engineering science and mechanics at Penn State.

This work was supported by the National Institutes of Health, the National Science Foundation and the Penn State Center for Nanoscale Science (an NSF Materials Research Science and Engineering Center).

Contact Tony Jun Huang at juh17@psu.edu

http://dx.doi.org/10.1002/smll.201403262

HIGH-EFFICIENCY CONCENTRATING SOLAR CELLS MOVE TO THE ROOFTOP



Photograph of the prototype panel being tested outdoors. The small black squares seen under each lenslet in the close-up are the solar cells. Image: © Nature Communication

Researchers at Penn State, University of Illinois, Urbana Champaign, and LUXeXcel Group B.V., The Netherlands, have developed a concentrating photovoltaic system with an inexpensive solar tracking system that can be mounted on a rooftop and deliver more than twice the solar efficiency as standard rooftop silicon solar cells.

To enable CPV on rooftops, the researchers combined miniaturized, gallium arsenide photovoltaic cells, 3D-printed plastic lens arrays and a moveable focusing mechanism to reduce the size, weight and cost of the CPV system and create something similar to a traditional solar panel that can be placed on the south-facing side of a building's roof. They reported their results Feb. 5 in *Nature Communications*.

"We partnered with colleagues at the University of Illinois because they are experts at making small, very efficient multi-junction solar cells," said Noel Giebink, assistant professor of electrical engineering at Penn State. "These cells are less than 1 square millimeter, made in large, parallel batches and then an array of them is transferred onto a thin sheet of glass or plastic."

To focus sunlight on the array of cells, the researchers embedded them between a pair of 3D-printed plastic lenslet arrays. Each lenslet in the top array acts like a small magnifying glass and is matched to a lenslet in the bottom array that functions like a concave mirror. With each tiny solar cell, sunlight is intensified more than 200 times. Because the focal point moves with the sun over the course of a day, the middle solar cell sheet tracks by sliding laterally in between the lenslet array.

Because the total panel thickness is only about a centimeter and 99 percent of it – everything except the solar cells and their wiring – consists of acrylic plastic or Plexiglas, this system has the potential to be inexpensive to produce. Giebink cautions, however, that CPV systems are not suitable for all locations.

"CPV only makes sense in areas with lots of direct sunlight, like the American Southwest," he said. "In cloudy regions like the Pacific Northwest, CPV systems can't concentrate the diffuse light and they lose their efficiency advantage."

Others working on this project include Jared Price, graduate student, Penn State; Xing Sheng, postdoctoral fellow; John A Rogers, professor of materials science and engineering, University of Illinois, Urbana Champaign; and Bram M. Meulblok, technical representative, LUXeXcel Group B.V., The Netherlands.

The U.S. Department of Energy funded this research.

Read the complete article by A'ndrea Elyse Messer and see a video about the research at mri.psu.edu/news/.

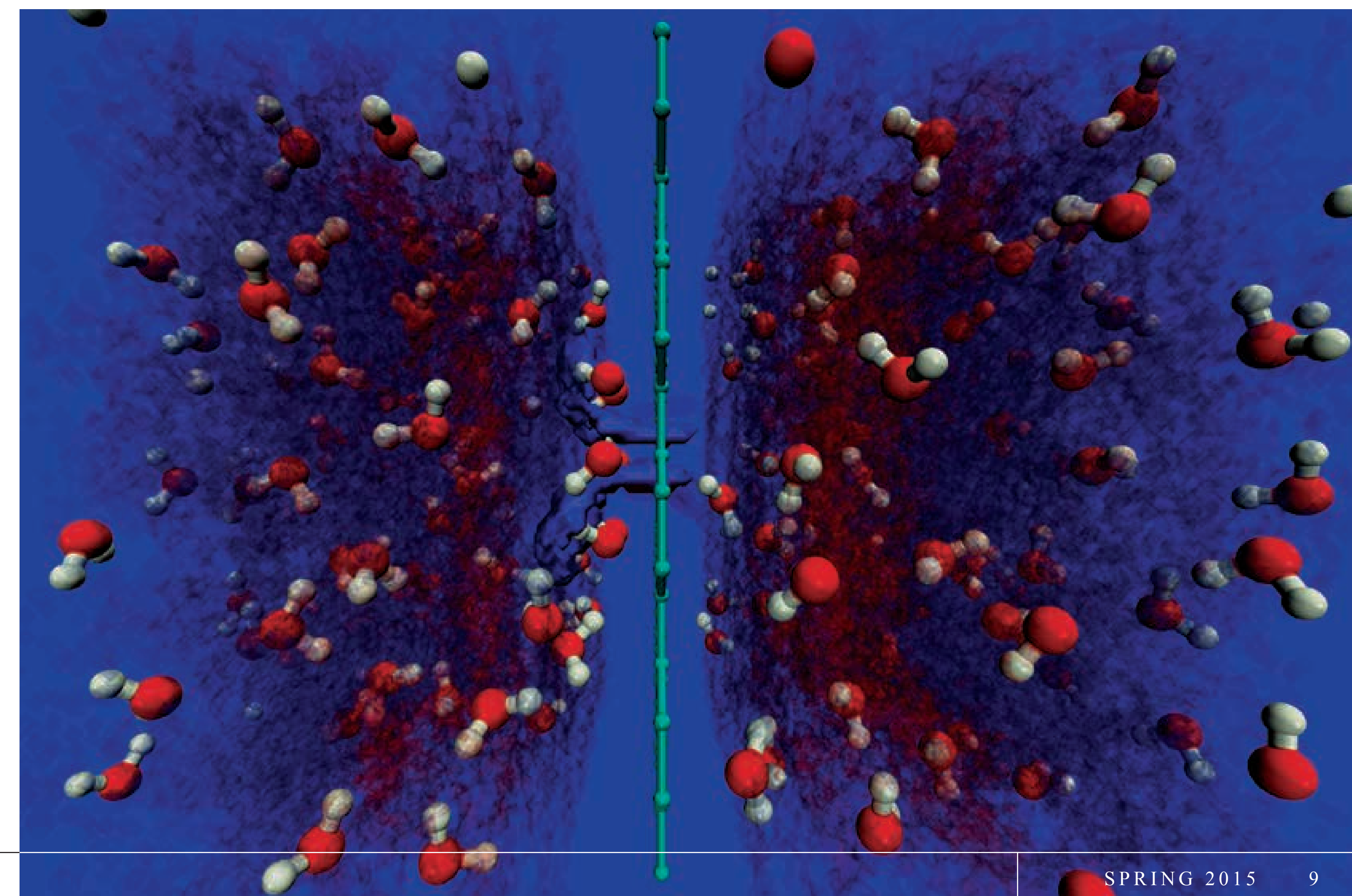
GRAPHENE MEMBRANE COULD LEAD TO BETTER FUEL CELLS, WATER FILTERS

An atomically thin membrane with microscopically small holes may prove to be the basis for future hydrogen fuel cell, water filtering and desalination membranes, according to a group of 15 theorists and experimentalists, including three theoretical researchers from Penn State.

The team, led by Franz Geiger of Northwestern University, tested the possibility of using graphene, the robust single atomic layer of carbon, as a separation membrane in water and found that naturally occurring defects, essentially a few missing carbon atoms, allowed hydrogen protons to cross the barrier at unprecedented speeds. Whereas many researchers strive to make graphene defect-free in order to exploit its superior electronic properties, Geiger's team found that graphene required the vacancies in order to create water channels through the membrane. Computer simulations carried out at Penn State and the University of Minnesota showed the protons were shuttled across the barrier via hydroxyl-terminated atomic defects, that is, by oxygen hydrogen groups linked at the defect.

The paper, titled "Aqueous proton transfer across single-layer graphene," will be published March 17 in the journal *Nature Communications*.

A figure showing the proton transfer channel across a quad-defect in graphene, as obtained from a ReaxFF molecular dynamics simulation. Credit: Murali Raju/Penn State



"Our simulations and experiments showed that you need to have at least four carbon vacancies and some sort of channel to overcome the energy barrier that would normally prevent the protons from crossing to the other side," says Adri van Duin, associate professor of mechanical and nuclear engineering at Penn State, who used reactive force field calculations to do dynamical, atomistic scale simulations of the process. "If we can learn how to engineer the defects and the defect size, we could make an effective separation membrane. Although it still requires a lot of design work, clearly this looks highly attractive for many applications, including desalinization."

It may also work for a new, less complicated design for fuel cells in the future, Geiger believes. "All you need is slightly imperfect single-layer graphene," he says.

Penn State co-authors are former Ph.D. student Muralikrishna Raju, now a post-doc at Stanford, post-doc Weiwei Zhang and van Duin.

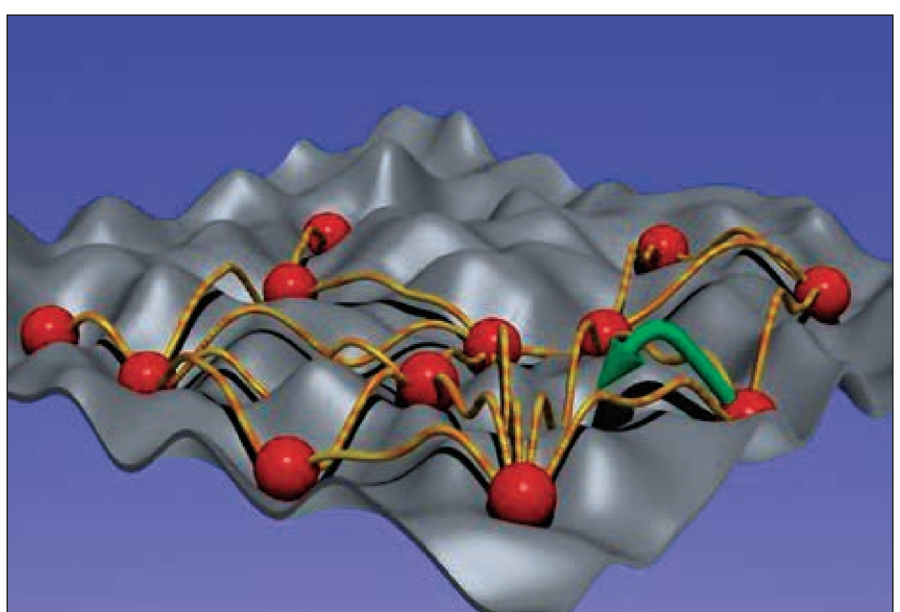
Other co-authors include Oak Ridge National Laboratory's Raymond Unocic, Robert Sacci, Ivan Vlassiouk, Pasquale Fulvio, Panchapakesan Ganesh, David Wesolowski and Sheng Dai; Northwestern University's Jennifer Achtyl and Geiger; and University of Virginia's Lijun Xu, Yu Cai and Matthew Neurock (all three now at the University of Minnesota).

This work was supported by the FIRST Center, an EFRC funded by the US Department of Energy, Office of Science, Office of Basic Energy Sciences. Microscopy was conducted as part of a user proposal at the Center for Nanophase Materials Sciences, an Office of Science User Facility at ORNL.

For a video simulation of the transport process, visit https://www.youtube.com/watch?v=of-tmv05vw0&feature=youtu.be

Penn State contact: Adri van Duin at acv13@engr.psu.edu

MATHEMATICAL APPROACH PROVIDES A NEW STEP IN RESOLVING THE MYSTERY OF GLASS



Unlike crystals, whose particles line up into long-range repeating structures that allow them all to be equally energetically happy, the particles in glasses are disordered and their ground state is frustrated – the forces that determine their configuration are in conflict with each other such that the arrangement that is most advantageous with respect to one of them leaves the others energetically unhappy. The disordered, irregular structure of glasses results from competition between the interactions among their constituent particles and from the forces exerted on them by the structural disorder of the materials. Frustration is the technical term describing the fact that the forces are competing and not all of the particles can find a resting state that minimizes their energy at any one time. Because of this frustration, there is no single ground state in glassy systems that would allow for a straightforward computational description of their properties, but instead a multitude of energetically equal possibilities.

Leonid Berlyand, professor of mathematics at Penn State University, and Valerii Vinokur, Argonne Distinguished Fellow in the Materials Science Division of the Argonne National Laboratory in Illinois have developed a new quantitative approach to understanding the mysterious properties of the materials called glasses. The study is described in a paper in the Nature Publishing Group journal *Scientific Reports* on January 16, 2015.

"The approach we developed provides a launching point for further studies of glasses, whose properties have been too complex for mathematical treatment until now," said Berlyand.

The key insight made by the researchers was the realization that, given certain constraints, the electrons in a two-dimensional Coulomb glass interact with each other in the same way as the vortices of magnetic force that form in superconductors interact. The behavior of superconducting vortices is well understood and is described by the Ginzburg-Landau equation, one of the most well-known and universal equations in modern physics that has also led to new fundamental insights in mathematics. The researchers therefore described the ground state of the Coulomb glass by adopting the Ginzburg-Landau equation.

Their approach could provide insights into phenomena such as high-temperature superconductivity and the metal-insulator transition.

In addition to Berlyand and Vinokur, the research team included Shawn D. Ryan, a Penn State graduate student, and Vladimir Mityushev, professor at the Pedagogical University of Krakow.

The work at Penn State was supported by grants from the National Science Foundation (NSF-DMS-1106666 and NSF-DMS-1405769). The work at Argonne National Laboratory was supported by the U.S. Department of Energy, Office of Science, Materials Sciences and Engineering Division. Vladimir Mityushev was partly funded by Pedagogical University in Poland and by NSF-DMS-1106666.

For the complete article from the Eberley College of Science, see mri.psu.edu/news/.

LATEST NSF RANKINGS: PENN STATE SCORES HIGH IN BROAD RANGE OF RESEARCH FIELDS

By David Pacchioli

In the most recent institutional rankings released by the National Science Foundation of total research expenditures for science and engineering, Penn State stands second in the nation, behind only Johns Hopkins and tied with the Massachusetts Institute of Technology, in the number of fields in which it is ranked in the top ten.

The rankings, released in February 2015, are for the 2013 fiscal year. Overall, Penn State ranked 17th nationally in total research expenditures across the board. In 12 individual fields, however, the University achieved rankings in the top ten nationally. Only Johns Hopkins, with 15 top-ten rankings, had more.

"This is testament not just to our overall strength, but to the extraordinary breadth and variety of Penn State's research enterprise," said Neil Sharkey, Vice President for Research. "Very few other institutions can demonstrate such a high level of achievement in fields as disparate as materials science and psychology."

The fields and sub-fields in which Penn State ranked in the top ten are materials (1st), psychology (2nd), mechanical engineering (3rd), sociology (3rd), electrical engineering (4th), total engineering (5th), aerospace engineering (8th), computer science (8th), agricultural sciences (8th), civil engineering (9th), atmospheric sciences (9th), and earth sciences (9th).

In eleven of these fields, moreover, the University has repeated top-ten status every year since at least 2008.

"This consistent record of excellence is a credit to our hard-working faculty, and shows the remarkable balance that Penn State enjoys," said Sharkey. "That balance, in turn, is the basis for our interdisciplinary strength, which is crucial to solving the complex challenges of the 21st century."

TWO-DIMENSIONAL METAMATERIAL SURFACE MANIPULATES LIGHT

A single layer of metallic nanostructures has been designed, fabricated and tested by a team of Penn State electrical engineers that can provide exceptional capabilities for manipulating light. This engineered surface, which consists of a periodic array of strongly coupled nanorod resonators, could improve systems that perform optical characterization in scientific devices, such as ellipsometers; sensing, such as biosensing of proteins; or satellite communications.

"We have designed and fabricated a waveplate that can transform the polarization state of light," said Zhi Hao Jiang, a postdoctoral fellow in electrical engineering and lead author of a recent paper in *Scientific Reports* explaining their invention. "Polarization is one of the most fundamental properties of light. For instance, if we transform linearly polarized light into circularly polarized light, this could be useful in optical communication and biosensing."

Optical waveplates with broadband polarization conversion over a wide field of view are highly sought after. Conventional waveplates, made from multilayer stacks of materials such as quartz, have difficulty achieving both broadband and wide-angle conversion. Thin waveplates have been demonstrated, but their efficiency was low, with an average power efficiency of less than 50 percent. The team's nanofabricated waveplates achieved measured polarization conversion rates higher than 92 percent over more than an octave bandwidth with a wide filed-of-view of around 40 degrees.

"In this paper, we demonstrated with simulation and experiment both quarter-waveplate and half-waveplate metasurfaces, which are thin artificial surfaces that operate both in the visible spectrum as well as in the near infrared," said Jeremy Bossard, a postdoc who is a member of the team but not an author on the paper. "It also has a wide field of view, which means that if you illuminate the surface from a wide range of angles, it would still give the same reflective performance."

As a component in an optical setup, the nanostructured waveplate offers a thinner form factor and reduced weight for space applications, a wider field of view, which can reduce the number of optical components in a system, and can achieve very wide broadband functionality in the visible to near infrared wavelength range. This represents a new state-of-the-art for optical meta-surface based devices and will enable other types of ultrathin highly efficient optical components, the authors said.

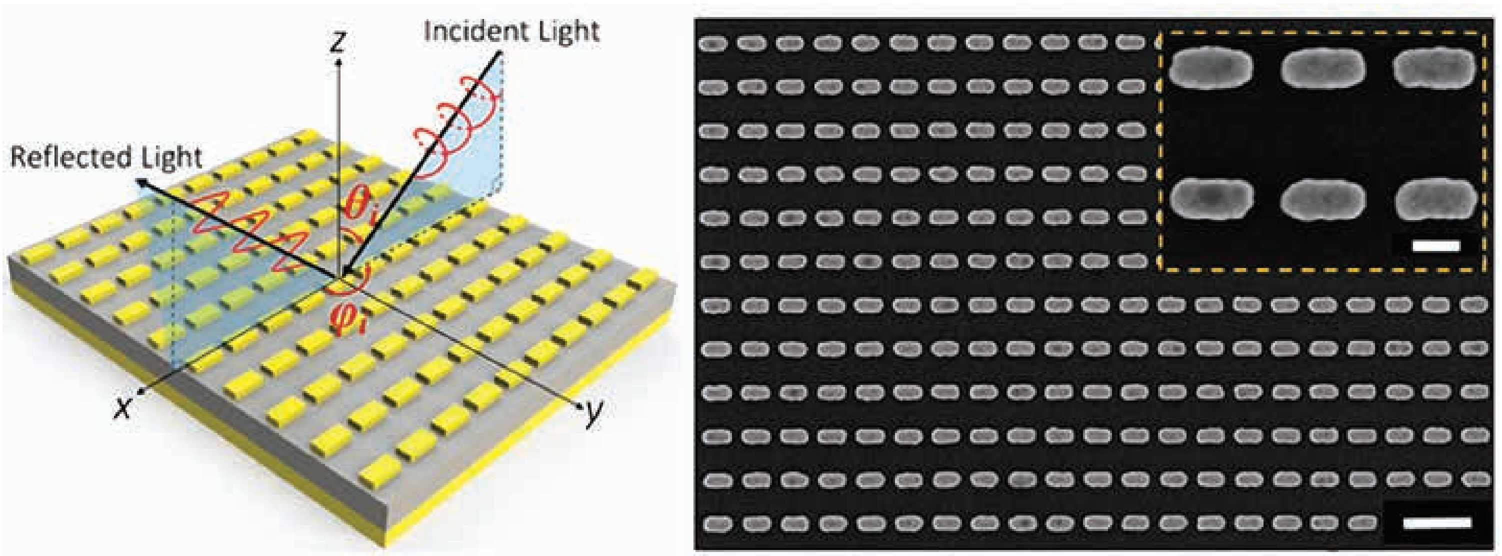
The waveplate was designed by Jiang using global optimization methods. It was fabricated in the Penn State Nanofabrication Laboratory by doctoral student Lan Lin, and characterized by doctoral student Ding Ma. Co-authors include Seokho Yun, a former postdoctoral scholar in the Penn State Electrical Engineering Department, Douglas H. Werner, John L. and Genevieve H. McCain Chair Professor of Electrical Engineering, Zhiwen Liu, associate professor of electrical engineering, and Theresa Mayer, Distinguished Professor of Electrical Engineering. The paper is titled "Broadband and Wide field-of-view Plasmonic Metasurface-enabled Waveplates." This work was supported by the National Science Foundation through Penn State's Center for Nanoscale Science.

Contacts:

Douglas Werner
Email: dhw@psu.edu

Zhiwen Liu
Email: zliu@engr.psu.edu

Theresa Mayer
Email: tsm2@psu.edu



On the left, circularly polarized light is converted to a linearly polarized wave upon reflection in a metasurface-based quarter-wave plate. On the right, a top-view FESEM image of the fabricated nanostructure showing the nanorod array. (Bottom scale bar - 400 nm. Top scale bar – 100 nm) Credit: Werner Group, Penn State

MATERIALS ON A MISSION:

GLOBAL HUMANITARIAN ENGINEERING

Khanjan Mehta is a man with a mission – solving the problems of providing energy, clean drinking water, food security, and health care to some of the poorest nations on Earth.

2014 HESE Fellow Jerrel Gilliam meeting with VISECO, a women's farming cooperative, on the outskirts of Xai-Xai, Mozambique.

As the founding director of HESE – Humanitarian Engineering and Social Entrepreneurship – in the College of Engineering, Mehta leads a group of engaged undergraduates who are designing new technologies, and equally important, designing how to get those technologies into the hands of the people who need them.

"It's not all about the technology," says Mehta, who is an assistant professor of engineering design in the College of Engineering's School of Engineering Design, Technology, and Professional Programs (SEDTAPP). "Designing the technology and saying 'Here it is' doesn't solve the problem. Well, windmills existed 300 years back, and all over Africa people have no power and no windmills either."

That's where the social entrepreneurship part of the name comes in. Unlike many aid projects that provide donations of money or food, HESE uses a market-centric approach, turning technologies into local, self-sustaining business opportunities.

One example of HESE's market-based approach is the design of low-cost greenhouses for East Africa. The greenhouses allow farmers to grow crops year round, while improving yields and preserving scarce water resources. The technology was developed at Penn State, and then licensed to a company called Mavuuno Greenhouses in Kenya and The Greenhouse Center in Cameroon.

"We were in rural Kenya working on telemedicine systems and talking to all these people about their health, and all they kept talking about were greenhouses," Mehta recalls. If they had a greenhouse, they told him, we could make extra money and then we could afford to make the journey to visit a doctor.

"We were in rural Kenya working on telemedicine systems and talking to all these people about their health, and all they kept talking about were greenhouses,"...

Khanjan Mehta founding director of HESE Credit: MRI

Building greenhouses in Mozambique and Kenya
Credit: HESE, Penn State

There were greenhouses in the area, but they cost over $2500, far more than what most farmers could afford. Mehta and his students did their research, talking to many farmers and a number of agribusiness firms. They then came back to Penn State and designed a greenhouse that they tested in parts of Kenya, Rwanda, and Tanzania under varying climates while at the same time determining the availability of local materials and studying the supply chain logistics.

"We have over 100 greenhouses out there in 10 countries," Mehta continues. "The materials to make them cost $350 and they sell for $600 to $1000. A small farmer can have a return on investment in four to six months."

Materials join the mission

The greenhouse project was the impetus for a new collaboration between HESE and the Materials Research Institute. The glazing for the greenhouses is sourced from Israel, and the HESE team wanted to see if a cheaper, local material could replace the Israeli glazing, saving about $100 on each greenhouse and avoiding the complicated import issues. One local material that was in large supply were sturdy sacks that contained rice shipped from China. Once emptied, the sacks would seem to be a cheap and endless resource after applying a UV resistant coating.

One of Mehta's students approached Josh Stapleton, director of the Materials Characterization Lab (MCL) to see if MCL could evaluate the transparency of the material and how long the material would stand up to the harsh conditions in East Africa.

"Khanjan's student, Shayne Bement, contacted me about doing optical transparency tests and accelerated aging analysis," Stapleton explains. "They don't want to be materials scientists; they want to link up with the people who already have the expertise. And I like working on this kind of stuff. It gives me a high level of satisfaction."

It turned out that the rice sacks didn't pass the requirements for greenhouse glazing, but they showed potential as shade nets for farmers. "Which is great, because they don't have local shade netting over there. We came to him for results. It cost us $150. It was the best money we ever spent," Mehta remarks. "We have lots of ongoing projects where Josh's expertise and resources will let us quit supporting the airline industry by not needing to make multiple trips overseas."

The greenhouse project continues in East Africa in collaboration with their partner, World Hope International. Recent funding from USAID, the federal agency that funds international development efforts, will help get two more greenhouse businesses up and running in Sierra Leone and Mozambique. They have been so successful that in Kenya some of the bell peppers and tomatoes were growing so big that his students had to assure people that they were safe to eat and there was no witchcraft involved.

"By the way, when we license this we don't just sign on the dotted line and collect our money, that's just the beginning. My student, Shayne, who worked with Josh, spent four months in Cameroon where he built the first set of greenhouses, trained their staff, and established market linkages. Now he is back in Cameroon as a Fulbright scholar."

"Everything we do has to be ruggedized to survive under harsh conditions. MRI could play an important role in helping us understand if a product will stand up under temperature swings, harsh UV radiation, people dropping it," Mehta says.

A test kit made of paper

HESE has a telemedicine system up and running in central Kenya that employs seven full-time employees and is built on a self-sustaining model that creates jobs and provides accessible healthcare in rural areas. They have trained a network of over 1,000 community health workers who check on the health of their community members.

"They don't want to be materials scientists; they want to link up with the people who already have the expertise. And I like working on this kind of stuff. It gives me a high level of satisfaction."

Shayne Bement drinks tea by candlelight in Cameroon
Credit: HESE, Penn State

HESE has been working on a set of low-cost diagnostic and screening devices, including a paper-based test kit to screen women for urinary tract infections and everyone for diabetes. One of the MRI faculty, Jim Adair, professor of materials science and engineering and biomedical engineering, is working with HESE on the simple paper sensor that changes color if there is infection or glucose in the urine. The strips will be printable on an inkjet printer, 100 test strips per sheet, Mehta says. "There are already so many questions emerging on the chemistry, the life span, and how to make the product usable under pretty harsh conditions. There are many questions on this project where MRI can help us."

Test strips can be printed on an inkjet printer.

Or a pulse oximeter

HESE has also designed a pulse oximeter, a small boxlike device that is put over a finger to measure oxygen saturation in blood. These devices can cost from $100 to $500 in a hospital setting, but HESE's design can be mass marketed for under $10. Now, in order to make sure their design is rugged enough they have to take it to Africa for testing. "If we could just send it across campus and get good data back, that would cut down the number of iterations and speed up time to market," Mehta says.

They have trained a network of over 1,000 community health workers who check on the health of their community members.

Mashavu health workers with HESE students, Kenya Credit: HESE

Partners with e-NABLE community to make 3-D printable hands in Africa

One of the most exciting projects HESE is working on involves a network of volunteers who use 3D printers to build custom made mechanical hands for amputees and children born without hands. Mehta was contacted by the e-NABLE community (enablingthefuture.org) about adapting their partial hand technology for Africa, where the legacy of the 11-year civil war in Sierra Leone and other wars across the continent have left many thousands of survivors with one or both hands amputated.

"This is not our innovation, it's theirs, but they reached out to us and said 'We know this works. We need you to get it to the people in Africa who need it,'" Mehta explains.

The costs involved are not exorbitant, less than $5,000 for a 3D printer, infrastructure, and employee training. The hands can be printed for around $15 each. e-Nable has printed over 200 hands for people in the U.S., primarily children, and has trained medical practitioners in Haiti to size and print hands.

With the exception of the printing, these hands are low tech. They are designed to grasp and hold objects, but there are no electronics. Mehta is beginning to work on details of how the hands will hold up in various climates, how much load they can carry, how much abuse they can withstand, and more. "There are 50 little questions here I'm going to send over to Josh by the end of the semester," Mehta says. "Then we can say should we focus on Sierra Leone, where it's incredibly hot through the year? Or should we focus on Kenya? Then we need to find out what people want to use this for and use MRI's characterization results to say if they can or can't do those things."

Engaged scholarship

This semester, Mehta has 50 students as the core workforce for all of the ventures HESE is involved in. But the involvement goes far beyond those students. Mehta is involved in what he calls "a pretty big experiment" this semester that involves outsourcing parts of the projects to 1,100 students in 21 different courses, including three sections of a freshmen design course, a biomedical engineering class, a chemistry class working on test strips, all of them engaged in work that can make a difference in people's lives.

The larger involvement of 1,100 students is part of the Engaged Scholarship Initiative which engages students with real world problems without their necessarily having to travel to Africa the way the HESE students do each summer. The initiative is a university-wide effort to give undergraduates out-of-the-classroom experiences that complement their in-class learning.

Mehta proposes a national center for characterization

"If we could create a national center here, which I would really push for, this would be a huge resource for programs of this nature that are cropping up across the country. Because I don't think that many of them, or any of them, have the ability to do this kind of testing very quickly that could speed up their product development process. Design teams don't want to do testing - they want to outsource it. Those guys are going to love sending a sample over to us and getting the results in a week's time," Mehta believes.

"Khanjan says there is an ongoing need for materials expertise in his area," Stapleton, the lab director, says. "They have a need and we can help. We do this for industry all the time."

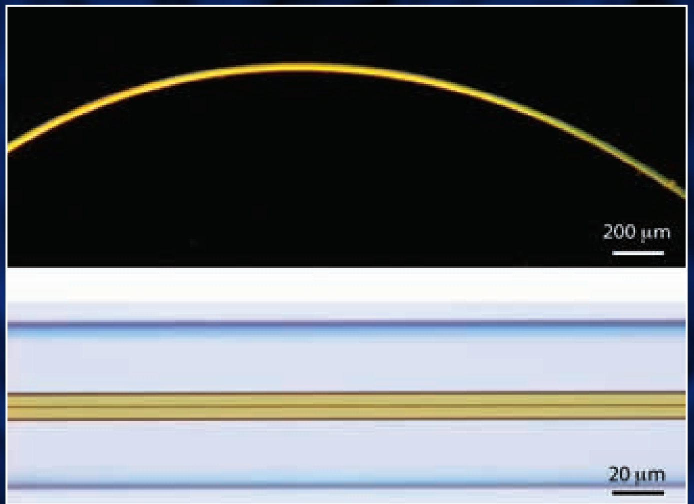
Stapleton pointed out that MRI and his laboratory are already engaged in a number of nontraditional areas of materials testing and characterization, from food science to archeology and the environment. "This is an opportunity to see MRI and the MCL as having a completely different skill set. How can we support the work others are already doing? It may not require a lot of new lab space and people," he concludes.

Clive Randall, MRI's new director and a professor of materials science and engineering, is enthusiastic about supporting a strong materials involvement in HESE. He notes that MRI has worked with Stephen Carpenter, professor of art education at Penn State, on improving his water filtration system based on clay pots and silver nanoparticles. "Having a materials viewpoint on materials selection for robustness in harsh climate conditions is one possibility where I would like to see MRI take leadership," Randall says. He foresees co-funding a faculty position in conjunction with one of the colleges to jumpstart this idea.

"We don't want to learn how to do what Josh and his lab can do," Mehta concludes. "We don't want a drill bit, we just want the hole. That's where MRI can be a game changer."

Contact Khanjan Mehta at khanjan@engr.psu.edu.

NSF AWARDS $15 MILLION TO PENN STATE CENTER FOR NANOSCALE SCIENCE



IRG3 exploits unique synthetic capabilities in high-pressure infiltration of semiconductors into diverse 3D nanotemplates to create new materials in which electronic, magnetic, and vibrational degrees of freedom interact with well-ordered nanometer-scale 3D structural modulations. Credit: Badding Group

The Center for Nanoscale Science, a National Science Foundation-funded Materials Research Science and Engineering Center (MRSEC) at Penn State, has been awarded a six-year, $15 million grant to continue research on materials at the nanoscale.

MRSECs are funded to support materials research that would be beyond the scope of one or a few investigators. By funding long-term multi-investigator projects, NSF promotes an interdisciplinary approach to address fundamental problems in science and engineering. In Penn State's Center for Nanoscale Science, four distinct interdisciplinary research groups (IRGs) will develop new classes of materials through predictive modeling, newly developed methods of synthesis at the nanoscale, and advanced methods of testing and characterizing materials and devices.

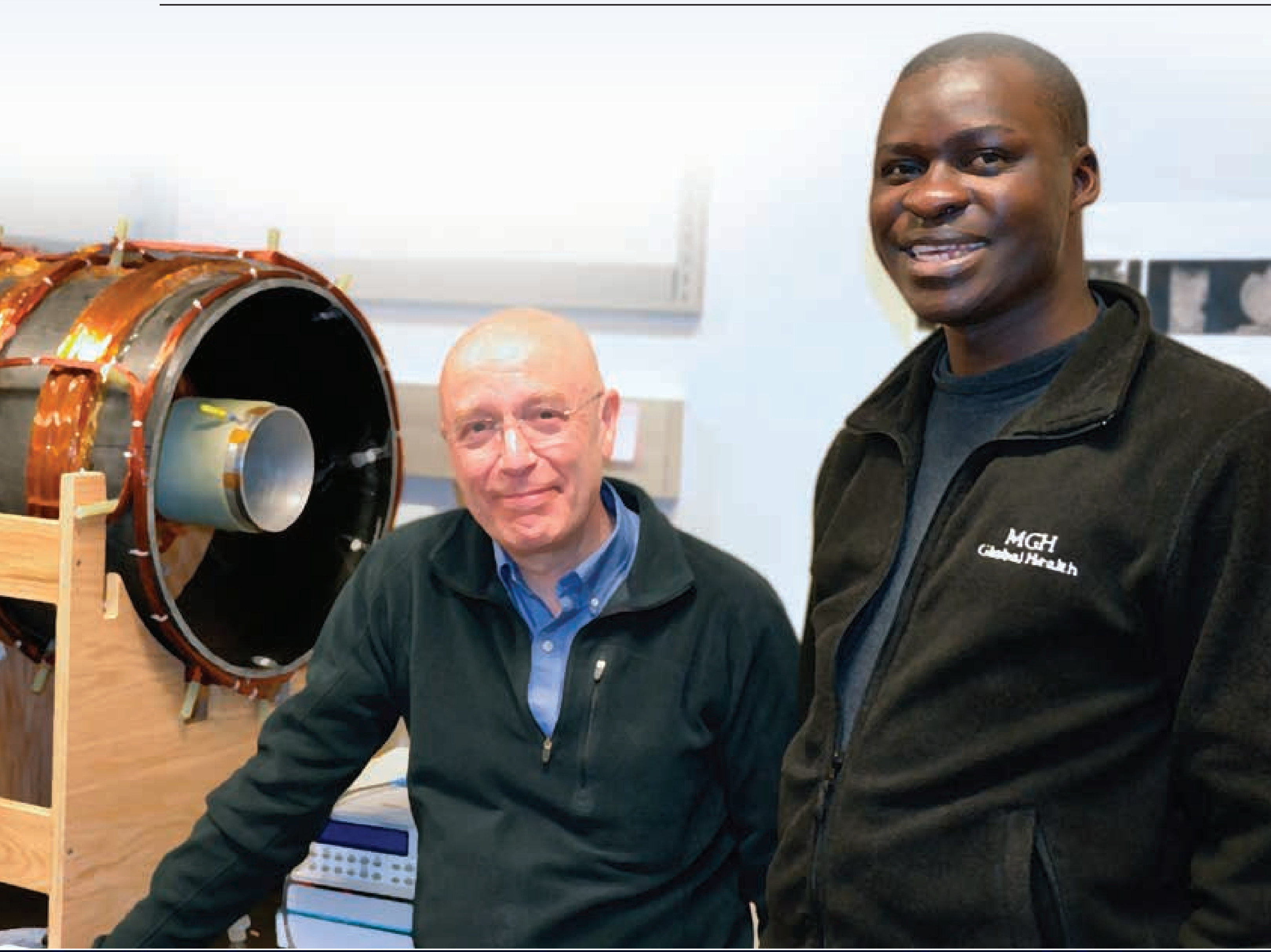
The four topics to be addressed include designing functionality into a class of materials called layered oxide ferroics, which can change shape in response to electrical signals and could be used for tunable microwave devices, energy storage, piezo-transistors, and high-temperature magnetoelectrics; new types of autonomously powered nano- and micro-motors that can sense their environment and react in a collective fashion that mimics living microorganisms; high-pressure enabled electronic metalattices that can squeeze electrons into new forms of behavior for solar cells, light-emitting devices, and improved thermoelectrics; and electrically and optically active particles organized into materials that guide light and electrons to create lasers, tiny antennas, and the building blocks for next-generation computer vision.

"Thirty seven faculty members across seven departments and three colleges at Penn State, plus eight faculty members at partner institutions around the world will join their diverse backgrounds in pursuit of these ambitious goals," said Vincent Crespi, director of the Center for Nanoscale Science and Distinguished Professor of Physics, Chemistry and Materials Science and Engineering. "The Center for Nanoscale Science also supports high-risk, high-reward seed projects from faculty across the University. Seed projects have continuously rejuvenated and redirected the mission of the MRSEC."

Projects sponsored by industry partners build on and extend Center research in each of the four IRGs, with sponsored projects contributing around $500,000 annually. Research in the Center has resulted in more than 450 publications and patents since 2008, when the previous group of IRGs was funded. The Center also develops educational programs in collaboration with the Franklin Institute that have reached over 100,000 museum visitors and thousands of elementary age students and science campers. These science outreach projects involve all Center students and postdocs, giving them valuable skills in communicating their research to inspire future scientists and engineers and educate the general public in the importance of science to society.

Contact: Vincent Crespi
Phone: 814-863-0163 Email: vhc2@psu.edu

INVENTING A LOW-COST **MRI SCANNER** FOR THE DEVELOPING WORLD



Steve Schiff and Johnes Obungoloch with a prototype low-field MRI under construction

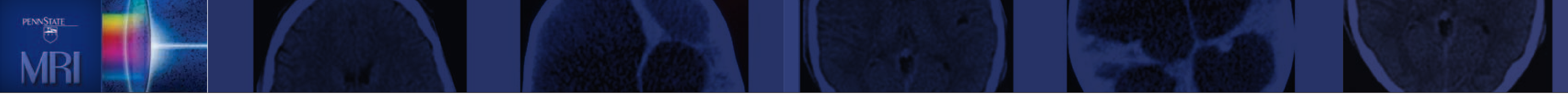
Infant hydrocephalus is an abnormality that has devastating effects if untreated. Often called "water on the brain," the malady develops when the cerebrospinal fluid that normally protects the brain increases as a result of a blockage in the normal flow of fluid to areas where it can be absorbed. The increasing pressure of the fluid expands ventricles that push against the brain tissue, causing brain damage, blindness, and eventually, in many cases, death. One of the first signs of hydrocephalus in infants and young children is swelling of the head to an abnormal size. Around 400,000 infants around the world will develop hydrocephalus in any given year, and in developing countries, many of them will go untreated.

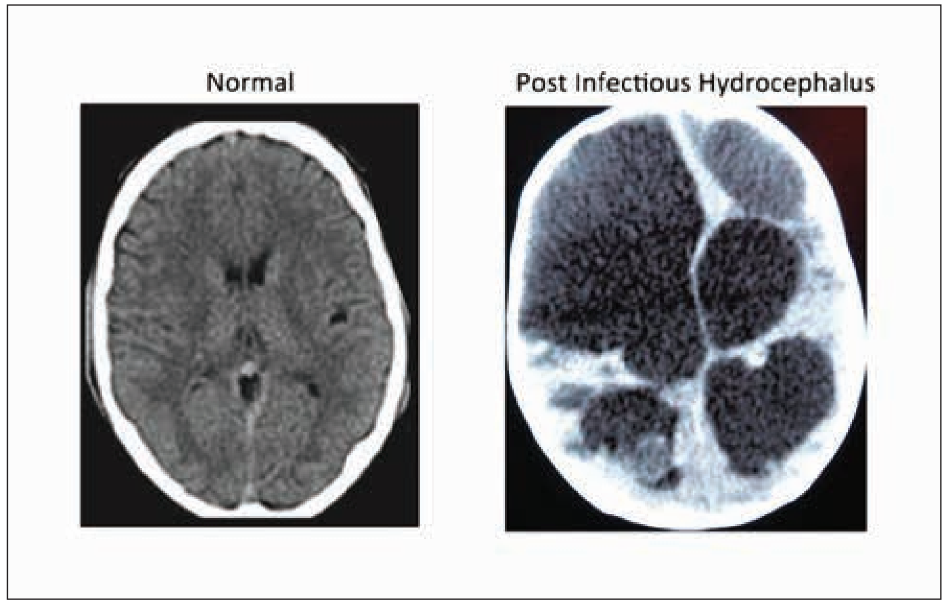
Steven Schiff, MD, Ph.D., is working with engineering colleagues at Penn State to develop an inexpensive, portable magnetic resonance imaging scanner for use in developing countries to help make the diagnosis and treatment of infant hydrocephalus available and affordable in the remote regions where a majority of the untreated children live.

"Our goal right now is to get to the point where we can make surgical decisions in order to treat hydrocephalic infants, whether we are putting in a shunt or using a scope to redirect fluid," said Schiff, who is the director of Penn State's Center for Neural Engineering and Brush Chair Professor of Engineering. "Once we have that, we are accomplishing 99 percent of what we would accomplish with a three-million-dollar scanner."

Although the concept of an ultra-low field device has been around for over 20 years, no one has yet developed a low field scanner with a bore large enough to scan a human brain. The typical MRI found in a hospital uses a high magnetic field, typically 1.5 Tesla or higher (about 30,000 times the Earth's magnetic field). These devices require some form of very active cooling, including a bath of liquid helium and liquid nitrogen. Schiff's device will operate at a field strength in the milliTesla range, a thousand times weaker. Because a fair amount of electricity will still be pushed through coiled copper wires, some form of air or water cooling will likely be required. But without the complexity and expense of superconducting magnets and liquid helium, Schiff believes his MRI scanner can be built for $30,000 to $50,000 and run off a marine battery or diesel generators, in some cases from the back of a truck.

MRIs work by aligning hydrogen atoms within the body in an up or down direction. About half point one way and half point the other way, with a few





A normal brain on the left and a post infection hydrocephalic brain on the right

Image: Penn State

unmatched atoms that provide the image. When the atoms are pinged with a radio frequency pulse, the unmatched atoms are forced to spin with a frequency that matches the type of tissue. When the pulse ends the atoms spin back and release energy as a radio frequency pulse of the same spin frequency. That energy provides the signal that is captured by a sensor and turned into an image on a computer. The stronger the magnetic field, the more detailed the image.

"What we bring to the table at Penn State are the kinds of novel MEMS-based technologies that we are customizing to enable such devices to get to a level of signal-to-noise that has just been infeasible in the past," Schiff remarked.

Schiff is working with two engineering faculty to improve the image quality of their room temperature ultralow field system. Srinivas Tadigadapa, an electrical engineer, is working on ways to sense the magnetic fields the MRI produces.

"In the last two to three years, my group has started developing MEMS magnetometers," Tadigadapa said. "We are working to achieve room temperature sensitivities in the picoTesla to femtoTesla range (trillionth to a quadrillionth of a Tesla). We have already created devices that get to the around a nanoTesla (billionth of a Tesla), and we have a couple of designs in testing that might be lower than 100 picoTesla at this point."

To the best of his knowledge theirs are the first MEMS magnetometers using chip technology and a nanofabrication process. Because they are small and cheap, they should be able to use multiple sensors to get resolution that will be good enough to meet the needs of surgeons in the field.

NIH

NIH DIRECTOR'S PIONEER AWARD

On April 24, Steve Schiff learned his proposal had received the NIH Director's Pioneer Award to control neonatal sepsis and infant hydrocephalus. "Our work in the developing world will get some desperately needed strong support now," he wrote.

"In principle, it should be possible to make a technology that is simple, effective, and easy to maintain," Tadigadapa said.

"And they have to be extremely safe," said Schiff, when I visited his Center for Neural Engineering. "If we are using this on young babies who can't say 'It's too hot in here,' it has to be robustly safe."

Schiff, who along with his engineering and physics appointments is also a pediatric neurosurgeon at Penn State's Milton S. Hershey Medical Center, understands the requirements of surgeons in developing countries. He has a medical license to practice in Uganda, where there is currently only one neurosurgeon for every 10 million people, and he has done extensive field work tracking down the conditions that lead to so many cases of hydrocephalus in Sub-Saharan Africa.

"Another thing we bring to the table is a lot of disease expertise for situations where scans of much lower quality than we are accustomed to can be highly diagnostic," he said.

Schiff's doctoral student, Johnes Obungoloch, is returning to Uganda to establish the Department of Biomedical Engineering at Mbarara University of Science and Technology after he receives his degree in 2016. The MRI research will continue there and other sites in Uganda where he intends to do clinical trials and evaluations of the technology.

"Having Johnes return as department head in the same country where we are running these trials also gives us a lot of in-country expertise," Schiff said. "Not only to maintain and operate such devices, but to give us the feedback we need to work our African colleagues as partners and make the devices appropriate for the environment. Unless it fits in that environment, it will end up in a shed somewhere with a padlock."

Why hasn't anybody done this before?

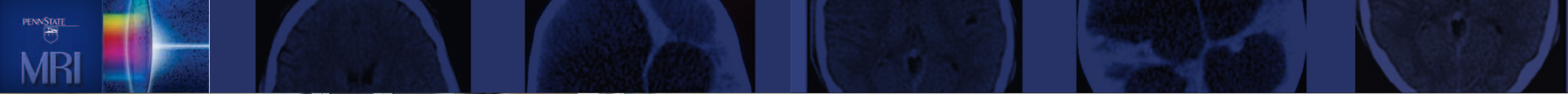
The idea for a practical low field MRI was proposed by a Stanford scientist named Steve Conolly in the early nineties, Tadigadapa told me. At some point, probably because the sensor technology was not well enough developed at the time, he moved on to other areas. Following Conolly's work, a group at Los Alamos National Lab took up the challenge. They used a SQUID, a superconducting quantum interference device, which is the world's most sensitive magnetic detector, inside a magnetic field coil. They showed they could get high contrast images, but they required liquid helium temperatures around the sensors to achieve this. This was followed up by work with atomic magnetometers at Los Alamos, a promising technology that is still not widely available. Then, in the last two to three years, Tadigadapa's group started developing their MEMs magnetometers. Tadigadapa's answer to why nobody has developed commercial low field MRI devices is a story of overcoming technological challenges. Schiff's explanation is somewhat different.

In clinical medicine, he told me, you need an entrance point where you can show it is a viable alternative to current technology. Can you show you can make the technology safer or cheaper? At present, with no application in clinical medicine in the U.S., there is no foothold. "We're hoping with our collaborations with physicians at Harvard and the University of Toronto, with our combined expertise in hydrocephalus and collaborations with African hospitals, that we can show where that entry point is," he said.

Tadigadapa thinks there are even potential applications for a low-cost MRI system in the U.S. "I'm not sure that every ailment requires the resolution of a $1-3 million dollar MRI device," he said. "A reasonably high resolution machine that doesn't feed off liquid nitrogen may help tell us a lot of basic things. In the U.S., a $50,000 instrument for a clinic or doctor's office might be feasible. So there is a market opportunity, which we are looking at."

A materials approach could help

A new approach to enhancing low resolution MRI comes from research on dielectric materials. Dielectrics are insulators that are widely used in electronics in the form of capacitors and actuators. Mike Lanagan, a professor of engineering science and mechanics at Penn State, has formed a startup company with two Hershey Medical



From left to Right: Graduate student Nishit Goel (Tadigadapa group), graduate student Johnes Obungoloch (Schiff group), Igor Savukov from Los Alamos National Lab, Srinivas Tadigadapa, and graduate student Gokhan Hatipoglu (Tadigadapa group)   Photo provided

Center researchers to fabricate conformable dielectric pads that can wrap around the patient's head to enhance the magnetic signal.

These pads have already been tried out successfully at several university hospitals using high resolution MRI systems, the main commercial target for their company. "It's not a huge market. There are probably a couple of thousand MRIs produced per year."

Lanagan believes that he can engineer the dielectric constant of the material, which will need to be increased by two to three orders of magnitude for Schiff's device in order to be effective. The dielectric constant indicates the amount of electric charge a material can hold.

"Depending on the frequency, the dielectric constant for the high resolution MRI is on the order of 100. For

Schiff's machine, the dielectric constant would need to be 10,000 to 100,000. I would say realistically we could get up to 20,000. Is that going to be good enough? I don't know," Lanagan said. "If we can improve the image or shorten the time an infant has to lie still in the machine, that's heading in the right direction."

The material he has in mind is called a boundary layer dielectric, and it has been studied in the Materials Research Institute for years as a material for capacitors, primarily in professor of materials science and engineering Clive Randall's lab. However, it is more complex than just filling some kind of bag with a dielectric material. The electromagnetics need to be designed in such a way that the waves propagate through the pad and into the head. That requires good computer models of the interaction of materials and electromagnetic (EM) fields.

"I've seen a really big change recently in EM models," Lanagan said. "Because the models are so good, you can predict how they will operate in a material, within reason. It's an iterative process where you design it, make it, and tweak it. But with the newest models, we can put in the materials parameters and a geometry and have a really good idea of what's going to happen before we build it."

The hope for a cure

The founding director of CURE International's Children's Hospital of Uganda in Mbale was Dr. Benjamin Warf, now at Harvard Medical School and Boston Children's Hospital. It was Dr. Warf who developed the minimally-invasive, shuntless treatment for hydrocephalus that is increasingly used by surgeons when treating infants and children in Africa. It was Warf who convinced Schiff to work in Africa, and they have coauthored papers in medical journals about their successes treating infant hydrocephalus without shunts. They are presently running an NIH sponsored clinical trial in African comparing shunts versus shuntless treatment on the cognitive outcome in infants with hydrocephalus in Uganda.

Shunts, the standard treatment in the U.S., are dangerous in the developing world because of the need for multiple shunt replacements as the child grows and the danger of the shunt failing after the patients return to their often distant villages. Traveling back and forth to the CURE hospital in Mbale for diagnosis is beyond the means of most subsistence Africans. Schiff's portable MRI could help solve this problem by bringing diagnostic facilities to remote Ugandan hospitals.

It was Warf, along with Schiff and a number of students and faculty from Penn State, who are unraveling the link to hydrocephalus in the blood and meningitis-type infections that infants developed in the first month of life in Uganda and other African countries, known as neonatal sepsis. If an infant survives neonatal sepsis, the damage to the lining of the brain can often result in hydrocephalus. Using DNA sequencing on bacterial remnants from the infants' cerebrospinal fluid, and comparing it with bacteria found in the huts in the remote villages, the team determined that the local environment, such as farm animal dung used to line the walls of the huts to keep out insects and rain, may be a major source of infection. Prevention of infections by changing hygiene in the home environment may be the single best cure for the hydrocephalus epidemic.

Cheap, easy to maintain, and robust

"I've seen examples in African hospitals where an expensive CT scanner arrives and no one is quite sure why it never worked. A hospital gets a lot of monitoring equipment donated from U.S. and European corporations, and it works until it needs repair," Schiff said. "So, we need to make equipment that's very robust, contains high quality electronics but with minimal expense for the quality, and when a part needs to be replaced, you can pull it out and either fix it onsite or have a replacement part shipped in the mail. But none of this is easy. I tell people there are enormous engineering challenges in doing really simple things."

This is also an example of a project that no one could do on his own, Schiff believes. A new convergence of life sciences and physical sciences is underway that this work highlights. At the Millennium Science Complex at Penn State, engineers and materials scientists from one side of the building can work intensively with life scientists and physicians from the other side to form a working group with their students that can produce the next generation of such device technology. With their students from overseas, they can build capacity in-country in Africa to insert such cutting edge technology into both clinical and academic centers with the goal of sustainable long-lasting health benefits.

To find out more about CURE's hydrocephalus program, visit the website at https://cure.org/hydrocephalus/

Steven J. Schiff is the Brush Chair Professor of Engineering in the departments of Neurosurgery, Engineering Science and Mechanics, Physics, and Bioengineering. Contact him at sschiff@psu.edu.

Michael Lanagan is professor of engineering science and mechanics. Contact him at mlanagan@psu.edu

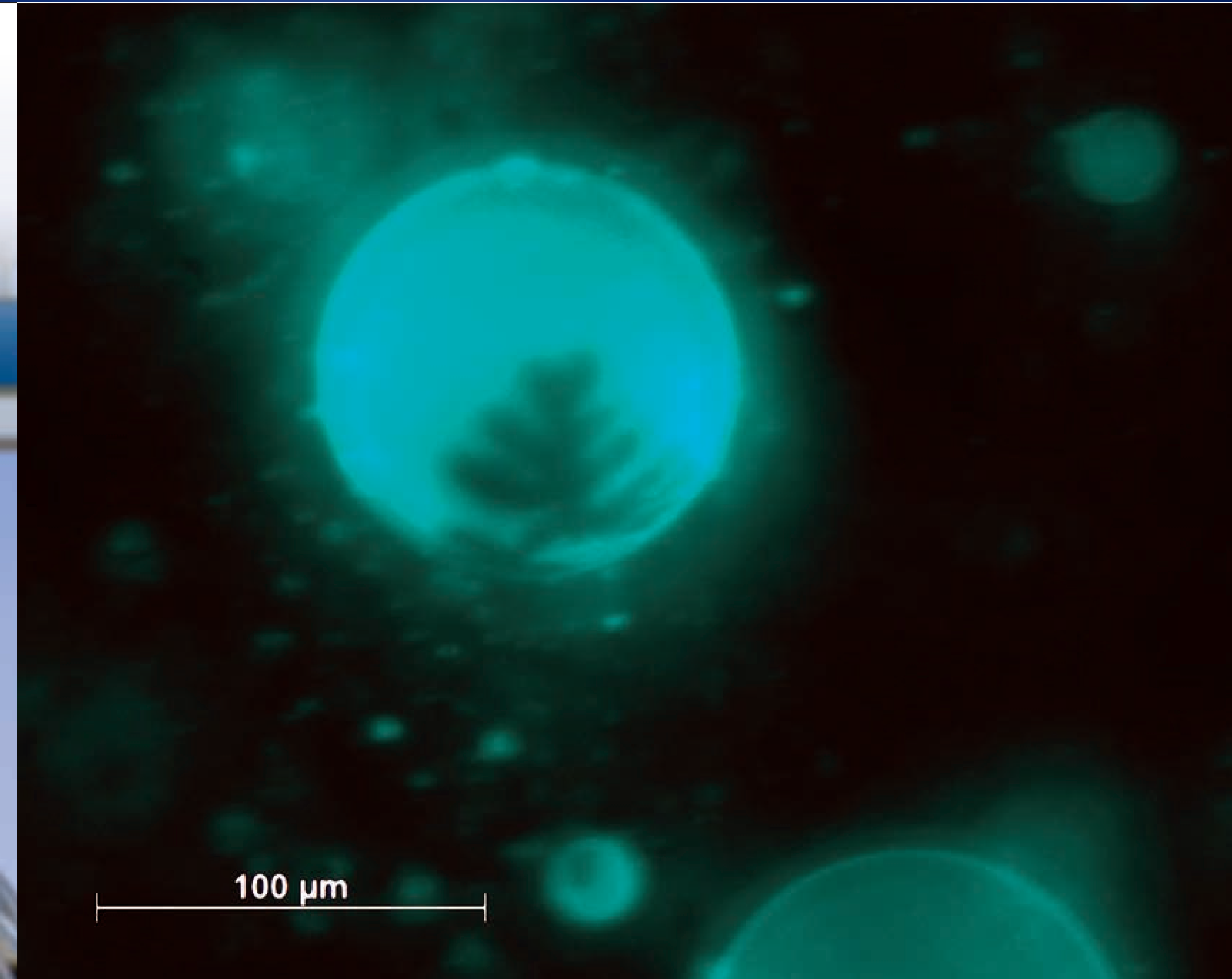
Srinivas Tadigadapa is professor of electrical engineering. Contact him at sat10@psu.edu.

FACULTY SPOTLIGHT

SHEEREEN MAJD

SHEEREEN MAJD STUDIES THE GATEKEEPERS OF THE CELL

Every cell in our body has a cellular membrane that keeps the inside of the cell separated from the outside. The membrane is made up of fatty material called lipids, one end of which is attracted to water and the other end of which is repelled by water. Two rows of lipids with their water-loving heads facing both out toward the external world and in toward the cell and their water-hating tails facing each other make up the cellular membrane. These same types of membranes wrap around all mammalian cells.



The image shows a cell-sized lipid vesicle displaying micron size lipid domains that are formed due to the interactions between a negatively-charged lipid, phosphatidylserine, and calcium ions. Credit Majd Lab

"Membranes are interesting because they not only define the shape of the cell, like a sack that keeps everything within the sack together, but they are also like gatekeepers that control tightly what comes in and goes out of the cell," says Sheereen Majd, who is an assistant professor of biomedical engineering whose group is studying the complex structure of cellular membranes.

Studded throughout the membrane like raisins in a croissant are proteins that are critical to the functioning of the cell. Some of the proteins act as gates, others as sensors, and through these proteins, cells signal to each other and the surrounding support system called the extracellular matrix. Majd and her students build cell-mimicking liposome vesicles that are spherical capsules with water on the inside and outside with a membrane made of lipids and proteins. Their size and composition closely resemble actual cell membranes.

"We started from something very simplistic, just the lipid, but we are trying to make it more and more complex," she says. "As we throw in proteins, it becomes a more realistic model."

Majd's group focuses on a very important group of proteins called multi-drug resistant transporters. These proteins, which sit on the cell's membrane, are involved with the drug resistance that develops in cells of cancer patients being treated with chemotherapy. Although these proteins are typically found in cells, in cancer cells they are overexpressed, there are many more of them. Their role is to pump out anything that they identify as not belonging inside the cell. As the concentration of the chemo inside the cell is reduced, the cell becomes resistant, and even the most effective chemotherapy won't kill the cell.

The way that the proteins can recognize the alien chemo molecule, along with a wide range of other drugs that are not even structurally similar, remains something of a mystery. In order to help understand the process, Majd's group uses micro- and nanofabrication techniques to make platforms on which they study these proteins at a level that was not possible before, that is, the single protein level. At the level of one or a few proteins, they hope to gain information that otherwise would be averaged out over multiple dissimilar proteins.

Multi-drug resistant transporter proteins, and one in particular called p-glycoprotein, or Pgp, are major obstacles to cancer treatment. Pgp has become a necessary step in testing potential cancer drugs, and the FDA requires testing all drugs against this protein to determine whether it will pump the drugs back out of the cell or not. The normal way of doing tests, which involves traditional assays using lots of cells with the protein in their membrane and seeing whether or not they survive, is time consuming, labor intensive, and costly, Majd says.

"We hope to be able to replace that system with a much simpler model system that mimics the cell membrane very well in an environment similar to the cell environment," she says.

Finding some way to inhibit Pgp and other proteins won't be an easy matter. For one thing, these proteins are important in protecting the nervous system. She hopes to find a way to fine-tune the physiological function of the protein in cancer cells, without damaging healthy cells. Also, the proteins are hard to handle. She is collaborating with Frances Sharom, a molecular biologist at University of Guelph in Canada, to provide Majd with highly purified proteins to incorporate into vesicles. Majd's Penn State collaborators on this project include Peter Butler in biomedical engineering and Manish Kumar in chemical engineering.

Membrane drug delivery and hydrogel stamping

In addition, Majd's group is developing nanoparticle drug delivery systems based on the same components as their cell membranes but loaded with toxic drugs. In this project, she and several of her students are working with James Connor, a Penn State neurosurgeon, with support from a Woodward Award. Their target is a deadly brain cancer called a glioblastoma. While there are many groups working on drug delivery systems for cancer, using membranes to target brain cancers is relatively new.

"It's exciting to work with neurosurgeons, and if I'm making something that is useful to them, I see that as progress," she says.

A third collaboration is with Mohammad Abidian, also in biomedical engineering, in which she is using soft lithography to create surfaces functionalized by biomolecules on conductive polymers and using gradients to control the growth of cells. Abidian is using her substrates to guide neuron growth. "We're using some relatively novel tricks and tweaks in hydrogel stamping to create the substrate," she says. They use a novel approach for patterning conductive polymer film using a hydrogel stamp to deposit multiple bioactive molecules in precise patterns using a one-step process.

A little background

"I grew up in Tehran, Iran, and went to Amir Kabir Institute of Technology in mechanical engineering. I got interested in mechanical engineering because I was good in math and physics. When I was younger, I watched my older brother, who was in university studying electrical engineering, solving problems, and that excited me. I wanted to solve math and physics problems too. And while I loved studying dynamics, in the end I became more interested in working on health-related issues," she says.

Arriving in the U.S. in 2003, she switched gears in order to study biomedical engineering at the University of Michigan, where she earned her Ph.D. and did a short post-doc. "That was the most exciting turn for me. I used a lot of the analytical skills from my rigorous mechanical engineering training and applied them to a more health-related field."

Asked if STEM education is encouraged in Iran, Majd lights up. "I'm really pleased with the number of women in STEM fields in Iran. We have a national exam for university entrance each year. The past few years you will see more and more females in the top rankings, and they will end up in the top public universities. I believe that today more than 60 percent of university students are women. It is an exciting time in Iran."

Although the schools are highly competitive, once students gain entrance, their four year education is completely paid for, she adds.

Majd joined Penn State in 2011 as assistant professor in the Department of Biomedical Engineering. In 2012, she also joined the Department of Engineering Science and Mechanics.

Teaching philosophy

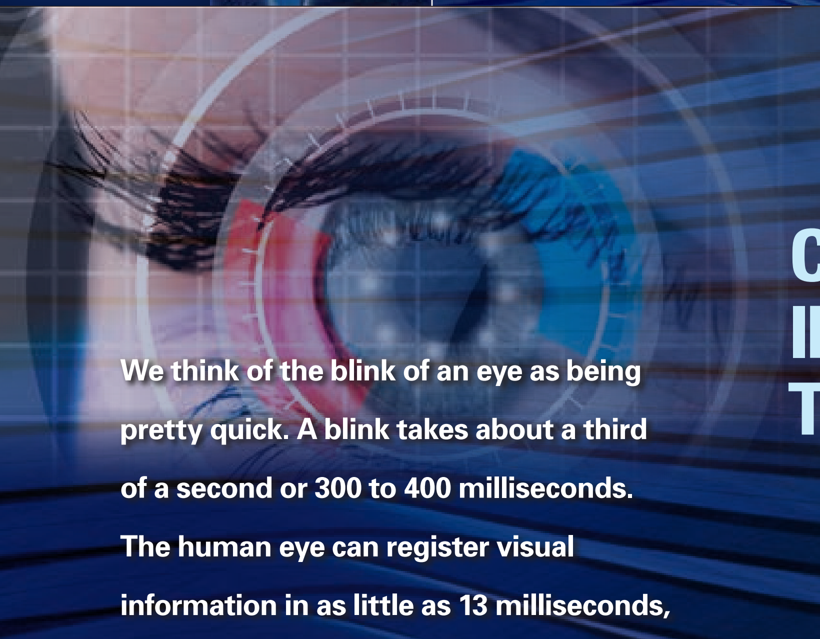
Hers is a diverse group, with several undergrads in various departments, including biomedical engineering, chemical engineering, mechanical engineering, physics, and biochemistry and molecular biology. Her graduate students are all from biomedical engineering. In group meetings, she has noted, questions that arise that are outside of one student's field are often background knowledge for another student. The diversity extends to their nationalities – Korean, Chinese, and American, with a near equal distribution of males and females.

"One thing that I really like about my group is that they have a very good relationship, and support one another," Majd says, noting that during her recent maternity leave this support kept the group functioning in her absence.

"I try to give my group a lot of space in their research," she says. "I do guide them and advise them in what direction to take or in how to design their experiments, but I try to give them space to struggle with their challenges, come up with their own solutions, and only give them feedback after they have thought the issues through. I tell them I don't care how many hours you put in, I want to see you are making progress and learning."

With her students, Majd hosted a biomedical engineering workshop in her lab this past February for about 70 female middle school students who were interested in exploring STEM careers. To see photos of the workshop and learn more about her research, visit the Majd Research Group website at http://www.bioe.psu.edu/labs/Majd-lab/.

Majd's funding is provided by The Pittsburg Foundation, Grace Woodward Grants, the Materials Research Institute, and the College of Engineering. Contact her at sum30@psu.edu.



CAN WE TURN ORANGES INTO APPLES ON FAST TIME SCALES?

We think of the blink of an eye as being pretty quick. A blink takes about a third of a second or 300 to 400 milliseconds. The human eye can register visual information in as little as 13 milliseconds, according to neuroscientists at MIT. That's much faster still, but we can't get anywhere close to seeing the movements of atoms with our naked eye – that takes place at one trillionth of a second time scale, called the picosecond. What could we learn if we could see electrons leaping across energy barriers? Perhaps something new about the many intermediate states of matter during the jump.

Venkat Gopalan in his laser lab at Penn State Credit: Penn State

Recently, the Department of Energy put out a special call for new ideas on ultrafast phenomena. Because of recent advances in laser technology, the DOE believed there were untapped fields of science to be explored at time scales on the order of femtoseconds, or 1/1000 of a trillionth of a second or less.

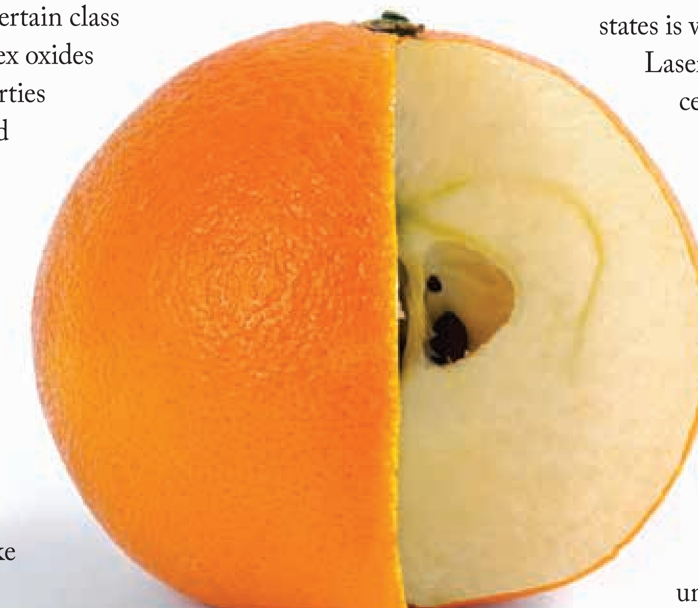
"All these cool tools are out there now, these lasers," explains Venkat Gopalan, Penn State professor of materials science and engineering. "DOE asks what can we do on these time scales? They are looking for exciting science. What are the most exciting things that you want to know about materials and phenomena?"

Gopalan and his Penn State colleague Roman Engel-Herbert put together a proposal with an interesting premise. It suggested that when viewed on ultrashort time scales, a certain class of materials called complex oxides would have hidden properties that could be revealed and even controlled by using ultrashort laser pulses. They suggested that by moving atoms around with a pulse of light, they could transform the properties of matter. It was not unlike the old alchemical idea of the philosopher's stone that could turn base metals like lead into gold.

Gopalan illustrated the concept with a small orange left over from a hurried lunch. "Here is an orange. The reason you saw an orange 10 minutes ago when you came in, see it now, and you will see it tomorrow is because it is in what physicists call a ground state. In that state it is rather stable. It won't last forever, of course, but we can call it metastable."

A ground state is an object's lowest energy level, and things tend to seek their lowest energy level. Most scientists like to look at things in the ground state because in that state they are stable and predictable, Gopalan said. However, things with high energy change quickly, and so they must be studied with very high speed equipment.

Going back to his example of the orange, Gopalan explained: "This orange, it looks pretty still. But if you keep zooming in and in, eventually you will come to atoms. Maybe if I wasn't looking at this at its lowest energy state, but on a faster time scale where the atoms are moving and things are happening, I might see that halfway through the motion of atoms, there is a transient hidden state that is more like an apple instead of an orange. It sounds crazy, but how do you know it isn't happening inside? You can only see the final stable state. What if there are hidden states of matter you can't see on your macroscopic time scales? Those states may be just as exciting, but you don't even know that they exist. Discovering such hidden states is what our proposal is about."



Phil McDonald/Shutterstock.com

Lasers were invented in the mid-20th century based on an idea proposed by Albert Einstein in a paper in 1917. He proposed that by stimulating atoms with a certain frequency of light, a cascade of atoms would emit photons of the same frequency and direction, lining up like soldiers marching in unison. The laser, which stands for light amplification by stimulated emission of radiation, was not invented for another 40 years. The key to the laser is that unlike normal light such as sunlight, which is disorganized, every photon of laser light is identical to every other photon in amplitude, in color, and in phase.

"You have to have a pool of atoms. And you have to excite them somehow, apply a voltage or UV light. You need a lot of energy, and yet you only get a little back. It's not like you get more light than you put in," Gopalan explained. "You just get special kind of light."

After the first laser was invented, based on Einstein's idea of stimulated emission, lasers quickly became a part of everyday life – laser pointers, laser eye surgery, laser

Roman Engel-Herbert with student adjusts the hybrid molecular beam epitaxy instrument in the Millennium Science Complex. Credit: MRI

printers, and CD and DVD players. There have also been recent advances in ultrashort pulse lasers, which have given rise to the research areas of ultrafast laser physics and ultrafast optics. Keep in mind that ultrafast does not imply the light is moving faster in these lasers – the speed of light is unchanged. But the ultrashort pulses work like a strobe light to freeze action at faster and faster time scales.

"We can measure events at femtoseconds scale, no problem," Gopalan said. "The new cutting edge is the attosecond scale, or one millionth of a trillionth of a second."

The DOE call for proposals was an acknowledgement of the fact that although the U.S. is still in the lead as far as laser technology is concerned, the Europeans are pulling ahead in the science, especially materials science, of ultrafast phenomena. This program was meant to push U.S. scientist to regain the lead.

Applying ultrafast phenomena to complex oxides

Gopalan and Engel-Herbert's program is called "Dynamic Visualization and Control of Emergent Phases in Complex Oxide Heterostructures." "That sounds complex, but what it means is – dynamic visualization is like watching things in action. And control – not only do I want to watch stuff, but can I actually make something happen? An electron is jumping up. Can I make it go the other way on that fast time scale?" Gopalan asked.

He proposes to apply the tools of ultrafast lasers on a large family of materials called complex oxides. (Most rocks are oxides.) Complex oxides are widely studied for their many unusual properties – some are insulators, some are dielectrics that can be used as capacitors, some are ferroelectrics, others ferromagnetic, and some are even superconductors. Gopalan has recruited a group of top U.S. scientists to be part of his team.

The experts include three leaders in the thin film growth of complex oxides – Roman Engel-Herbert at Penn State, Lane Martin at UC Berkeley, and Jak Chakhalian at the University of Arkansas. Once the films are made, they will be studied using a variety of tools. With each spectrum of light, from x-rays to infrared, a new piece of the puzzle will be revealed.

"With hard X-rays you are looking at electrons, electron states, crystal structure, and how the electrons are moving," Gopalan said. "When you go to softer X-rays, you can study things like magnetism."

Infrared is the frequency that makes atoms vibrate, while the visible spectrum is where many electronic processes take place. The femtosecond timescale is the correct one for looking at atoms in the visible frequency, he continues. Two colleagues at Argonne National Lab near Chicago, John Freeland and Hayden Wen, will do the X-ray work at the X-ray synchrotron source in conjunction with a post-doc from Penn State. Other X-ray work will be done at the Stanford Linear Accelerator Laboratory in Menlo Park, CA.

At the University of California, San Diego, two scientists, Dimitry Basov and Rick Averitt, will look at atoms with a unique kind of microscope invented by Basov that uses different color frequencies to look at the materials with both high resolution and at fast time scales, a combination which can be challenging to accomplish.

Two theorists, James Rondinelli at Northwestern University and Andrew Millis at Columbia University, are experts in techniques for predicting states of matter both dynamically (Millis) and at ground state (Rondenelli). "The combination of these two people is perfect for us," Gopalan remarked. His own group has expertise in ferroelectrics and also in X-ray synchrotron techniques. He is also upgrading his laser lab with much more powerful lasers. His group will look at complex oxides that have built-in polarization as well as study materials that can transition from metal to insulator, something of a magic trick with possible applications for very fast switching in transistors. By this summer, he will also have the first terahertz spectroscopy setup on campus. Terahertz is a very long wavelength that is useful for vibrating atoms. None of the new instruments are funded through the DOE grant.

Finding hidden phases

One technique they will use for finding hidden phases in matter is called a pump-probe. The material is first hit with a laser pulse that excites the electrons – this is the pump – which is followed with a weaker pulse – the probe – that will give information about the transition as the electrons fall back into the ground state. Rick Averitt at UCSD used this technique on a complex oxide called lanthanum calcium manganese oxide that has an insulator-to-metal transition under a high magnetic field at low temperatures. What Averitt found was that the material could be made to do the same thing at room temperature using a laser pulse.

"If you wanted to make a very fast switch that goes from conducting to non-conducting at room temperature and without applying a magnetic field, what our phase diagrams say is you can't do it," Gopalan said. "At room temperature it is always going to be an insulator. But when Rick hits it with a laser light with 1.5 electron volt photons, it turns into a metal and it's magnetic. When he hits it again, it's an insulator and it's no longer magnetic. It's changing two properties at the same time. It's like a magic wand, like me changing this orange into an apple and back."

Intel, for one, is looking for metal-insulator transitions to make their transistors go even faster than silicon switches can. But with so many materials to look at, which ones should they try? That is what Gopalan and colleagues will explore using both theory and experiment.

They will be probing a range of oxides – titanates, manganates, vanadates, ferrites, cobalites, and nickelates – with a rich range of phenomena such as ferroelectricity, magnetism, metal-insulator transitions, and charge ordering, which is a uniform arrangement of electrons related to superconductivity. "How can we dramatically change these materials just by exciting them?" he asked. That is the question his team will be looking to answer.

The DOE grant is for ~ $3 million over three years with Penn State as the lead university.

The goal for this program is ambitious. If they can find a way to manipulate the arrangements of atoms in a material, maybe then they can take that orange and move its atoms in a slightly different way until they have an apple.

Contact Venkat Gopalan at vxg8@psu.edu

PENNSTATE

MRI
MATERIALS RESEARCH INSTITUTE

MRI N-317
Millennium Science Complex
University Park, PA 16802

Nonprofit Org.
U.S. Postage
PAID
State College, PA
Permit No.1