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re:search

An inside look at innovation and discovery at Missouri University of Science and Technology // Fall 2013

Mini but mighty metamaterials

On the nano level, some materials
behave oddly.

pg. 4

MISSOURI
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Science & Technology

Fiscal Year 2013 Summary

Proposals submitted

488

Dollars requested

\$140.7 M

Proposals awarded and amendments

265

Dollars awarded

\$51.5 M

Total expenditures

\$42.7 M

Faculty and staff serving as principal or co-principal investigators

234

Invention disclosures

41

Patent applications filed

25

Patents issued

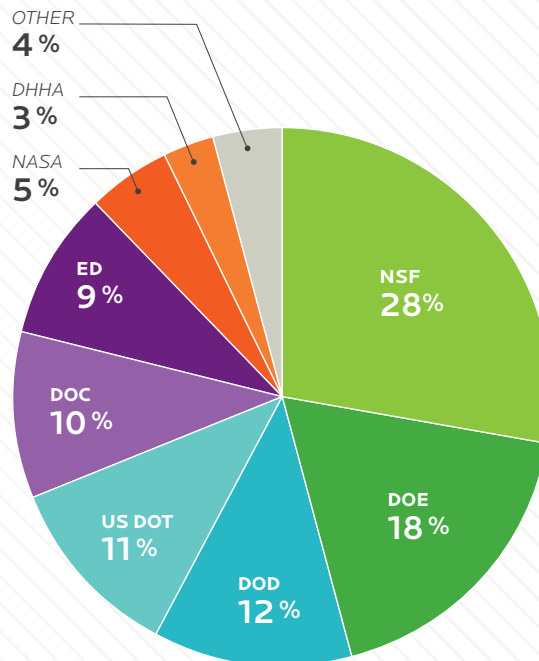
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Licenses/Options signed

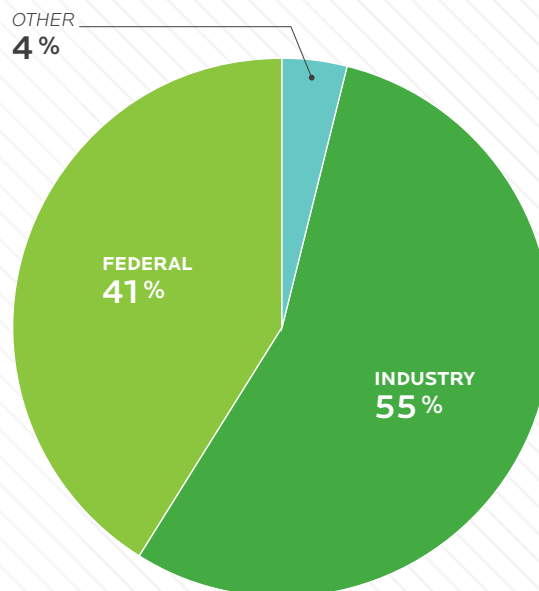
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Licensing income

\$220 K



FY13 federal awards by source (total amount: \$20.9 M)



FY13 sponsored awards by source (total amount: \$51.5 M)



On the cover

An artist interpretation depicting the transverse optical force between two metamaterials. Read about it on page 4.



Dear Colleague,

This has been a significant year for Missouri S&T. After a thorough and comprehensive planning process, Missouri S&T developed a new customer-focused strategic plan. *Rising to the Challenge 2013–2020*, which focuses on providing a top return on investment for six key customer groups. Two of these groups — research-based graduate students and research investors — directly impact Missouri S&T's research mission.

We also made great strides in advancing frontiers of knowledge. In this issue of *re:search* magazine, you will read about tools to study a variety of systems — from aerospace to energy to internet usage, compliant mechanisms, metamaterial slot waveguides, alternative cures to eye disorders, and using lean systems like Six Sigma to help the Veterans Health Administration improve its systems. You will also learn about the latest book by one of the nation's leading experts on the history of Americans in combat during World War II.

Also during the past year, three of our faculty members were honored with prestigious early career awards. Sriram Chellappan and Yew San Hor received the NSF CAREER Award and Richard Dawes received a DOE Early Career Award.

We established two new centers on campus with industry partners. The collaborations fostered here will help develop solutions sought by industry and provide tremendous learning opportunities for our students.

- The Kent D. Peaslee Steel Manufacturing Research Center addresses steel casting and manufacturing issues, including product development and environmental and safety issues. The center was renamed in honor of Kent Peaslee, a metallurgical engineering professor who passed away suddenly this year. He was one of the nation's leading authorities in steelmaking research and was instrumental in establishing the center.
- The Small Modular Reactor Research and Education Consortium in collaboration with University of Missouri-Columbia will develop technology to improve energy security and the environment.

I hope you will take some time to learn more about the innovative research being conducted at Missouri S&T and the impact faculty and students are making through their profound scholarship.

Sincerely,

K. Krishnamurthy
Vice Provost for Research

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re:search is the annual report on research, innovation and discovery activities at Missouri University of Science and Technology, formerly the University of Missouri-Rolla. Published by the Office of Sponsored Programs, *re:search* highlights only a portion of Missouri S&T's vibrant, focused research program. For more information about Missouri S&T's research, contact:

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Mathematically possible

Mathematics is the cornerstone of nearly every academic discipline. Researchers at the Missouri Institute for Computational and Applied Mathematical Sciences (MICAMS) at Missouri S&T are discovering ways that math can improve upon existing research in projects ranging from aerodynamics to geology. Here are three examples of the institute's collaborative projects.

Xiaoming He, an assistant professor of mathematics and statistics, is working with **Runar Nygaard**, an assistant professor of geological sciences and engineering, and **Hai Xiao**, a professor of electrical and computer engineering, to improve monitoring of long-term carbon dioxide storage in geologic formations by optimizing sensor location and

analyzing data collected from the sensors. The researcher will monitor the gas "in-situ," meaning that the gas will be in storage and not extracted. The project is supported through a cooperative agreement with the U.S. Department of Energy.

John Singler, an assistant professor of mathematics and statistics, is working with Belinda Batten, a professor of mechanical engineering at Oregon State University, to help control systems modeled by partial differential equations (PDEs), such as energy consumption in commercial buildings and help control airflows that could reduce fuel costs in planes or lower vehicle noise emissions. His work focuses on algorithms that will improve feedback control in linear PDEs and could also open the door for advances in feedback control to more challenging nonlinear PDEs. Singler's research is funded by a grant from the National Science Foundation (NSF).

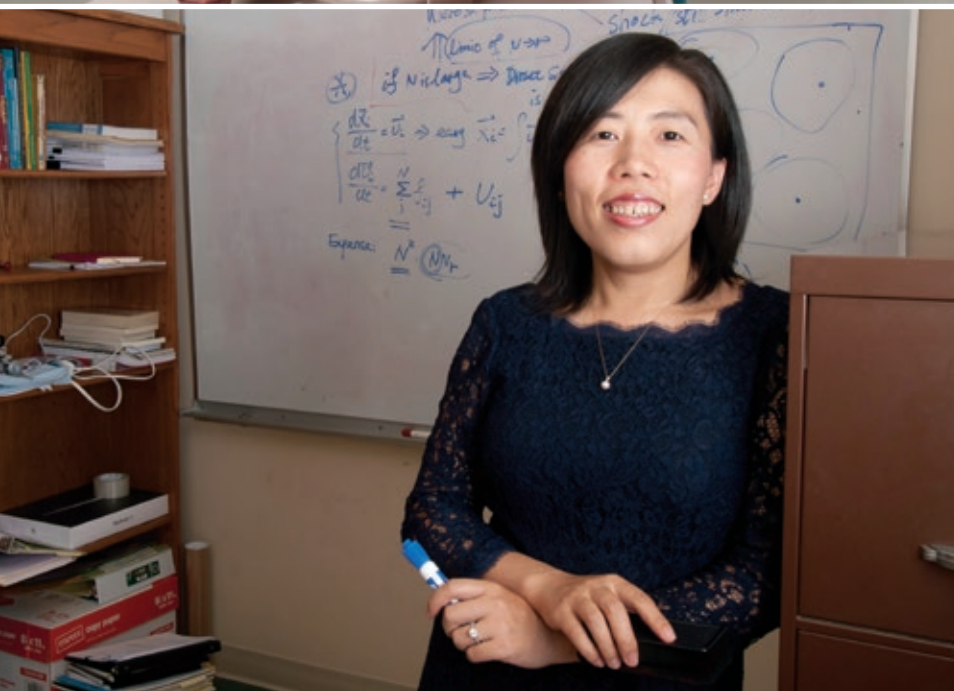
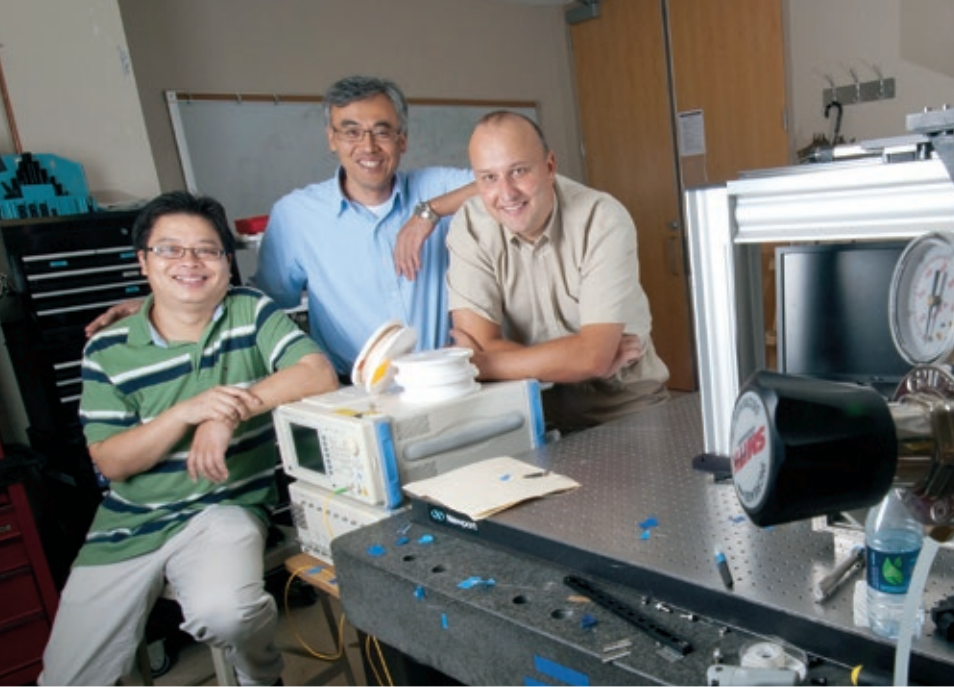
Yanzhi Zhang, an assistant professor of mathematics and statistics, is analyzing the fundamental property of stability in the split-step method that is used to solve partial differential equations. Working with Taras I. Lakoba, an associate professor of mathematics and statistics at the University of Vermont, Zhang focuses on developing improved algorithms to solve problems arising in the materials science field, such as fiber-optic communication systems and low-temperature atomic condensates. Zhang's research touches on the predictive 3-D modeling capabilities of these fields and the electromagnetic behaviors of materials. These advances will lead to improvements in hydrology, heat conduction and chemically reacting flows in energy usage. Her project is funded by a grant from the NSF. ■



Collaboration adds up

Faculty in the Missouri Institute for Computational and Applied Mathematical Sciences, or MICAMS for short, include Xiaoming He, Hai Xiao and Runar Nugaard (top), John Singler (middle) and Yanzhi Zhang (bottom).





Some assembly required

/// **Ashok Midha's quest to teach students about compliant mechanisms began with four Penn State undergraduate students more than 30 years ago. Midha, a professor of mechanical engineering, wanted to create a design approach that integrated form and function with dramatic cost savings.**

Traditional rigid-body mechanisms require mechanical elements like links, joints, gears or bearings to transfer or transform force, motion or energy to perform a task.

Compliant mechanisms do the same thing, but with fewer moving parts. They rely on the systematic deformation of a combination of flexible and rigid segments that offer improved manufacturability and ergonomics, minimized assembly and superior performance, among other advantages. These mechanisms have fewer movable joints, which means less need for lubrication and reduced wear.

In 2012, the American Society of Mechanical Engineers honored Midha's pioneering contributions to the field by naming an annual symposium the Ashok Midha Symposium. This event is held as part of ASME's Mechanism and Robotics Conference.

A rapidly growing field, the compliant mechanisms discipline includes applications in automotive systems, biomechanics and biomedical systems, surgical and space tools, and micro-electro-mechanical systems (MEMS), to name a few. ■

Mini but mighty metamaterials

On the nano level, some materials behave oddly.

Certain structures, when engineered at that scale — a nanometer is just one billionth of a meter — possess properties that seem to defy the laws of physics. Some nanomaterials have been found to both attract and repel light, while metals designed at that scale could form the building blocks of super-strong construction materials because they have fewer defects than bulk materials.

Last fall, a husband-and-wife research team at Missouri S&T demonstrated another peculiar behavior of specially engineered nanomaterials — a quirk that could transform computing and optics. Computer simulations developed by **Jie Gao** and **Xiaodong Yang**, both assistant professors of mechanical engineering, showed that a new class of slot waveguides pack 100 to 1,000 times more transverse optical force than conventional silicon slot waveguides.

Writing in the Sept. 24, 2012, issue of *Optics Express*, Gao and Yang describe the unusual optical and mechanical properties of metal-dielectric structures called metamaterials. The couple developed computer models of metamaterial slot waveguides. (Waveguides are structures designed to channel beams of light from one area to another. They function like tiny filaments or the wires of an integrated circuit, but on a much smaller scale.)

The two identical waveguides designed by Gao and Yang consisted of layered slices of metal (in this case, silver) and a dielectric material (germanium), arranged like the alternating bread and meat of a club sandwich. They stacked the waveguides — each 40 nanometers wide and 30 nanometers tall — but left a tiny air gap between them so they could test the transverse

optical force between the two structures. (Optical force refers to the way beams of light can be made to attract or repel each other, as magnets do.)

They found that “the transverse optical forces in slot waveguides of hyperbolic metamaterials can be over two orders of magnitude stronger than that in conventional dielectric slot waveguides.” Gao and Yang describe that magnitude as “giant” in the title of their *Optics Express* research paper, “Giant transverse optical forces in nanoscale slot waveguides of hyperbolic metamaterials.”

“The calculation on realistic metal-dielectric multilayer structures indicates that the predicted giant optical forces are achievable in experiments,” they explained in the paper. Their finding “will open the door for various optomechanical applications in nanoscale, such as optical nanoelectromechanical systems, optical sensors and actuators.”

Faster than the speed of light?

More recently, Gao and Yang designed a way to engineer materials capable of funneling light through amazingly tiny channels. Yang describes this research, published last spring in the journal *Physical Review B*, as making it possible for light waves to “tunnel through very small holes.”

“It is like squeezing an elephant through an ultra-small channel,” he says.

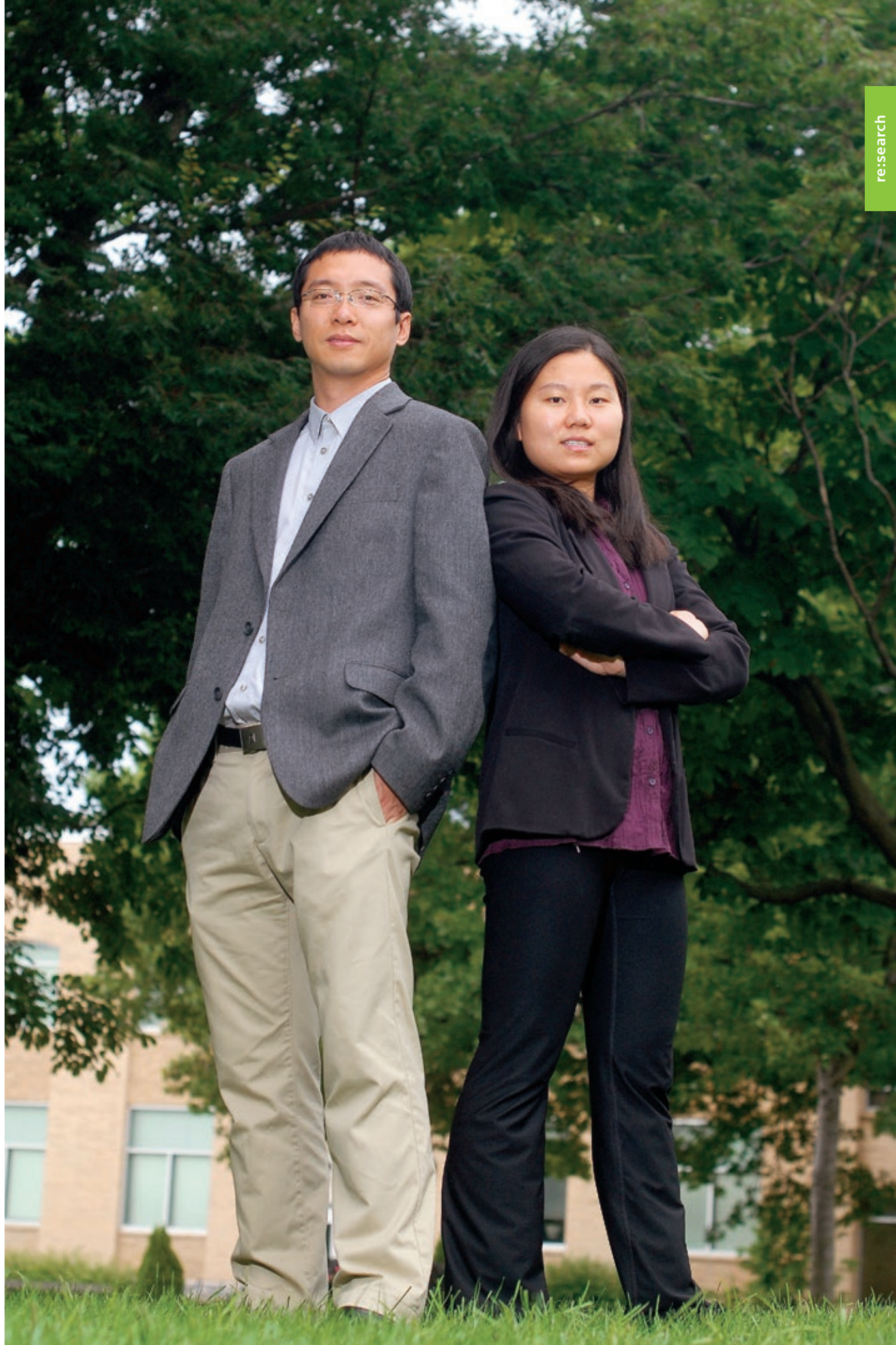
Their research was the first to demonstrate that the material — a specially designed “meta-atom” of gold and silicon oxide — can transmit light through a wide bandwidth and at a speed approaching infinity. The meta-atoms’ broadband capability could lead to advances in optical devices, which currently rely on a single frequency to transmit light.

“The design is practical and realistic, with the potential to fabricate actual meta-atoms,” says Gao. Adds Yang: “With this research, we filled the gap between the theoretical and the practical.”

A not-so-tiny gap at that. ■

**Big ideas**

In a process comparable to squeezing an elephant through a pinhole, Xiaodong Yang (left) and Jie Gao have designed a way to engineer atoms capable of funneling light through ultra-small channels.





A net resource for depression victims

“Internet addiction” is a term tossed about by anti-technologists and armchair psychologists who worry that spending too much time online could lead to serious mental health problems. But what if your Internet usage actually helped health professionals diagnose potential issues? What if your smart phone could alert you to a possible mental disorder?



Detecting depression

Sriram Chellappan used Internet usage data from college students with symptoms of depression to study patterns that could one day help diagnose the disorder.



In the first study of its kind, Missouri S&T researchers led by **Sriram Chellappan**, assistant professor of computer science, analyzed college students' Internet use to see whether the students who show signs of depression used the Internet differently than their counterparts. They first administered a test to 216 Missouri S&T students to determine whether they met the minimum criteria for depression based on the Center for Epidemiologic Studies-Depression scale. They then collected a month's worth of Internet data from the students and analyzed what the students did online. They assigned pseudonyms to keep their identities hidden.

The research group's analysis of the data identified nine fine-grained patterns of Internet usage that may indicate depression. Chellappan and his colleagues found that depressed students tended to use higher "packets per flow" applications, those high-bandwidth applications often associated with online videos and games, than their counterparts.

Students who showed signs of depression also tended to use file-sharing services more than their counterparts and use the Internet in a more "random" manner — frequently switching among applications, perhaps from chat rooms to games to email. Chellappan thinks that randomness may indicate trouble concentrating, a characteristic associated with depression.

The research, published in the Winter 2012 issue of *IEEE Technology and Society* magazine, could lead to new approaches to diagnosing and treating mental illness, says Chellappan. He hopes to put the findings to practical use, perhaps in the form of a smart phone app or software that could be installed on home computers that could warn individuals of worrisome Internet surfing patterns.

The software would unobtrusively monitor Internet usage and alert individuals if their usage patterns indicate symptoms of depression. He also believes the method used to connect Internet use and depression could help diagnose other mental disorders like anorexia, bulimia, attention deficit hyperactivity disorder or schizophrenia.

Chellappan will receive \$428,409 in CAREER Award funding from the National Science Foundation over five years to carry out his proposed CAREER activities.

"The software would be a cost-effective in-home tool that could proactively prompt users to seek medical help if their Internet usage patterns indicate possible depression," he says. "The software could also be installed on campus networks to notify counselors of students whose Internet usage patterns are indicative of depressive behavior." ■



Military History 101

/// Despite the U.S. military's reliance on technology in modern warfare, American troops on the ground — the "grunts" — have proven to be the crucial difference between victory and defeat, says military historian John C. McManus.

McManus, a professor of history and political science, is considered one of the nation's leading experts on the history of Americans in combat, particularly during World War II. He wrote about the ground troops' experience in a 2010 book titled *Grunts: Inside the American Infantry Combat Experience, World War II through Iraq*.

His latest book, *September Hope: The American Side of a Bridge Too Far*, examines the American perspective of "Operation Market Garden," one of World War II's most ambitious and least understood battles.

The author of 10 books on military history, McManus spent the summer researching his next two works: *Hell Before Their Very Eyes*, about the American soldiers who liberated the infamous concentration camps at Ohrdruf, Buchenwald and Dachau, and *The Dead and Those About to Die*, an account of the 1st Infantry Division on D-Day at Omaha Beach.

A member of the editorial advisory board at *World War II* magazine and *Global War Studies*, McManus received the 2012 Missouri Governor's Award for Excellence in Teaching and was named the 2012 Research Fellow by the First Division Museum at Cantigny Park. ■



Preventing cataracts

Using eye drops prepared with the antioxidant N-acetylcysteine amide, or NACA, **Nuran Ercal** and her team are conducting research that could prevent or cure cataracts, macular degeneration and other degenerative eye disorders.

Ercal, the Richard K. Vitek/Foundation for Chemical Research Endowed Chair in Biochemistry, says NACA is better than the experimental treatment N-acetylcysteine because it crosses cell membranes easier and can be used in lower doses.

“NACA eye drops could represent an alternative to costly surgery, while greatly improving the quality of life for those afflicted,” says Ercal, who has been testing NACA on HIV-related problems, lead poisoning and other toxicities for 10 years. About four years ago she began testing it on eye disorders.

Ercal received a three-year, \$378,000 research grant from the National Eye Institute of the National Institutes of Health, using preliminary data based on



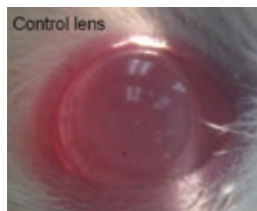
Eyes on NACA

Nuran Ercal, pictured above with Sri Krishna Yasaswi Maddirala, a Ph.D. student in chemistry, is conducting research to see if an antioxidant can prevent degenerative eye conditions like cataracts and macular degeneration.





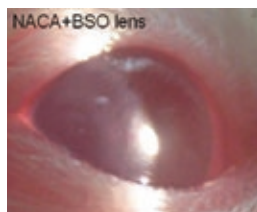
1 (control lens):
The lenses in this group were found to contain no detectable cataracts.



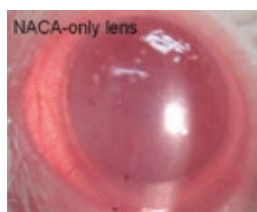
2 (lens treated with BSO, a cataract-inducing solution): All lenses in this group developed distinct cataracts, with most being nearly completely opaque.



3 (lens treated with NACA only): Results were similar to the control group with no detectable signs of cataract.



4 (BSO-treated lens also treated with NACA): Lens has a Grade 1 opacity, which was evident by the amount of scattering light.



research by her former student, **Joshua Carey**, who earned bachelor's degrees in chemistry and physics in 2007 and a Ph.D. in chemistry in 2012.

Carey's dissertation showed how NACA could slow cataract growth on rats that had been given a solution that causes cataracts to form.

"The NACA solution prevented cataracts from forming," says Ercal. "Our research will build on Josh's research, to see if NACA can actually reverse the degeneration as well."

Ercal, who is also an M.D., says further testing will help establish appropriate dosage and frequency, as well as possible side effects and other factors. She says successful results using animal subjects may eventually support the viability of human usage.

Ercal works closely with **Shakila Tobwala**, a post-doctoral fellow in S&T's chemistry department. Others in the research group include the grant's co-investigator, Humeyra Karacal from the ophthalmology department at Washington University in St. Louis, and Missouri S&T graduate and undergraduate students. ■



Lean systems, wider applications

/// In our world of limited resources, organizations continually look for ways to do more with less. Lean systems like Six Sigma improve manufacturing efficiency and reduce waste. Now lean systems expert **Elizabeth Cudney** is using these same methods to help the Veterans Health Administration (VHA) improve its systems.

"Lean principles can be applied anywhere," says Cudney, assistant professor of engineering management and systems engineering and author of four books on the subject. "Lean and Six Sigma tools make it easy to identify the root problem and provide the statistical means to make improvements."

Cudney has received five grants from the VHA for projects that would improve work, staff and patient flow; capture, retain, organize and distribute patient information; and identify, evaluate and reduce risks. One grant specifically addresses patient satisfaction with prosthetics processes.

"These changes directly impact veterans and their families," says Cudney. "Our work is helping the VHA professionals ensure our veterans have access to quality care in a timely manner." ■



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Going with the flow

/// In the only laboratory of its kind in the nation, **Muthanna Al-Dahhan** is leading an effort to understand how nuclear fuel “pebbles” would behave in fourth-generation pebble-bed reactors. He’s developing various methods to measure and track how the materials would move in such a reactor.

He’s also looking at how the pebbles — simulated by marbles — would transfer heat and disperse gas in such a reactor.

“The techniques can show us what is going on inside the reactor and can be used to eliminate a lot of experimental work,” says Al-Dahhan, a professor of nuclear engineering and chair and professor of chemical and biochemical engineering at Missouri S&T.

Not far from Al-Dahhan’s lab sits the university’s nuclear reactor. Commissioned in 1961, it is the first ever built in Missouri. ■

We invite you to take a closer look at Missouri S&T. Start by reading the stories inside this report, then stay connected with us online at research.mst.edu.