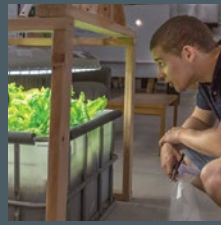




#### ILLUMINATING PLASTIC MOLDS

PMMA allows  
a real-time fix  
for faulty flow  
inside channels.

See page 14



#### THEIR VERY OWN ADVENTURES

Students select  
projects and  
deliverables at  
Mountaintop.

See page 16

# resolve<sup>®</sup>

A FOCUS ON LEHIGH ENGINEERING • VOLUME 2, 2014

## FROM SYNERGY TO INNOVATION

NANO-THEMED RESEARCH CENTERS JOIN FUNDAMENTALS  
WITH APPLICATIONS. SEE PAGE 20

LEHIGH UNIVERSITY

P.C. ROSSIN COLLEGE OF  
ENGINEERING AND APPLIED SCIENCE



# resolve<sup>®</sup>

A FOCUS ON LEHIGH ENGINEERING

VOLUME 2, 2014

EDITOR

Kurt Pfitzer

PUBLICATION DIRECTOR

Chris Larkin

RESOLVE ADVISORY COUNCIL

Daniel P. Lopresti, interim dean

John Coulter, associate dean for graduate studies and research

Martin P. Harmer, senior faculty adviser for research initiatives

DESIGNER

Linda Gipson

ILLUSTRATORS

N.R. Fuller, Sayo-Art LLC

James Provost

CONTRIBUTING WRITERS

Robert W. Fisher '79

Richard Laliberte

Chris Quirk

William Tavani

Manasee Wagh

PHOTOGRAPHERS

Douglas Benedict

B. Findley

Ryan Hulvat

John Kish IV

Christa Neu

RESOLVE is published semiannually by the P.C. Rossin College of Engineering and Applied Science and the Office of University Communications and Public Affairs at Lehigh University.  
[www.lehigh.edu/resolve](http://www.lehigh.edu/resolve)

P.C. ROSSIN COLLEGE OF ENGINEERING AND APPLIED SCIENCE

Lehigh University

19 Memorial Drive West

Bethlehem, PA 18015

610-758-4025

[www.lehigh.edu/engineering](http://www.lehigh.edu/engineering)

OFFICE OF UNIVERSITY COMMUNICATIONS AND PUBLIC AFFAIRS

Lehigh University

125 Goodman Drive

Bethlehem, PA 18015-3754

610-758-4487

SUBSCRIBE OR SEND COMMENTS:

[engineering@lehigh.edu](mailto:engineering@lehigh.edu)

# LEHIGH

UNIVERSITY

## Departments

- 1 LETTER FROM THE DEAN**  
A new leader takes the reins
- 6 BIO BRIEFS**  
Greener molecular separations... A smarter sequence for data processing... A CNT/DNA wrap to detect cancer
- 8 NANO BRIEFS**  
Simulating unobserved droplet behavior... Thinner, better plasmonic color filters... 3D assembly in a soft gel
- 10 SYSTEMS BRIEFS**  
Sharpening transactional memory... A hybrid testing method is validated... Recycled CO<sub>2</sub> boosts geothermal
- 12 Q&A**  
Taking the measure of time and light, a physicist freezes the speeding electron and takes its snapshot
- 28 RISING STARS**  
A superlattice generates coherent THz light



### ON THE COVER

*Collaboration between two interdisciplinary nanotechnology research centers is fueling a growth in discovery and innovation.*

## Features

- 2 RELATING TO A BIGGER PICTURE**  
His students live out David Wu's legacy
- 14 NO MORE MYSTERY TO THE MOLD**  
Opening a window on molten polymer flows
- 16 UNENCUMBERED BY CLASSROOMS**  
Students convert passions into projects
- 20 NANOSCALE COMPLEMENTARITY**  
Research centers share similar missions
- 26 ALL ASPECTS OF ENGINEERING**  
A STEM camp surprises high schoolers

## A rare privilege and a new challenge

Welcome to the 16<sup>th</sup> issue of *Resolve*, a magazine dedicated to research and educational innovation in the P.C. Rossin College of Engineering and Applied Science at Lehigh University.

It is a distinct honor to have been selected last spring as interim dean of the P.C. Rossin College of Engineering and Applied Science. I am focused on upholding and amplifying the achievements of our community of world-class faculty and students; together, we will continue to lead transformation in engineering education while exploring new solutions to society's most pressing needs.

I joined the Lehigh faculty in 2003 and have served the university in various capacities since then, most recently as department chair of computer science and engineering. I have come to respect greatly the heritage of our institution—from its earliest days as an industrial powerhouse to more recent developments that place us in the vanguard of integrated learning and research.

I would like to take this opportunity to thank our former dean of engineering, S. David Wu, now provost at George Mason University, for helping to set us on a course that is well aligned with the modern realities of our discipline. I plan to continue the many fruitful initiatives that have emerged with David's support, and to explore new ways to improve our educational and research profile.

On the next four pages of this issue of *Resolve*, you will find an article about the legacy that David built in his 10 years as dean of engineering. This article examines several of the interdisciplinary programs that David helped create, as seen through the eyes of the students who graduated from those programs.

The article on page 18, "The Freedom to Ask Their Own Questions," illustrates

how engineers are finding new ways to collaborate with their peers in science, business, the humanities and the arts. In our new Mountaintop Initiative, undergraduates from a wide variety of majors are working in teams on open-ended projects of their own choosing, from combating vitamin A deficiency to developing prosthetic hands.

The cover article, "Overlapping Opportunities," on page 16, examines new endeavors in our two nanotechnology research centers—the Center for Advanced Materials and Nanotechnology, led by Richard Vinci, and the Center for Photonics and Nanoelectronics, led by Nelson Tansu.

The goal of the two centers is to channel Lehigh's intellectual and physical resources to achieve breakthroughs that can be applied in energy, sustainability and the environment; and in health, bioengineering and medicine. To do this, the centers are leveraging success in specific areas where Lehigh

***"Our two nanotechnology research centers are leveraging success in specific areas where Lehigh has developed an international reputation."*** —Daniel Lopresti

has developed an international reputation—the use of state-of-the-art facilities in electron microscopy and spectroscopy to characterize properties at the nanoscale and to analyze and manipulate surfaces and interfaces.

The Q&A on pages 12-13 features Paul Corkum, one of the world's leading physicists. Paul, who earned his M.S. and Ph.D. from Lehigh, is a pioneer in ultrafast laser spectroscopy who generates attosecond laser pulses that take photographs



of electrons orbiting inside atoms.

An article on page 14 describes how John Coulter and his students use video equipment and optically polarizing films to observe the flow of molten polymers through the channels of injection molds and to judge the performance of channel designs. And on page 26, you'll find an article about the Pennsylvania Governor's School for Science, Engineering and Technology, held at Lehigh last summer for high school students considering STEM careers.

I hope you enjoy this issue of *Resolve*. Please drop me a line with your thoughts and comments.

A handwritten signature in dark ink that reads "Daniel Lopresti". The signature is fluid and cursive.

**Daniel Lopresti**  
Interim Dean  
P.C. Rossin College of Engineering and  
Applied Science  
lopresti@lehigh.edu





# EVERYTHING RELATES TO A BIGGER PICTURE

*A dean's legacy shines in the lives and careers of his students.*

During his decade as dean of engineering, S. David Wu championed a vision of the engineer as “Renaissance person for the 21st century” and of engineering as a way of thinking that benefits leaders in many spheres of the economy.

STORY BY ROBERT W. FISHER '79

WHEN HE LEFT LEHIGH IN JULY 2014 to become provost of George Mason University, Wu left a powerful legacy founded upon a belief in collaboration.

In his 27-year career at Lehigh, he devoted significant effort toward the development of cutting-edge multidisciplinary programs at the graduate and undergraduate levels, and played a key role in the creation of the university-wide Global Citizenship program. He was co-founder of the Center for Value Chain Research, a joint initiative of Lehigh's business and engineering colleges.

Wu championed a team-based research model—“clustered” initiatives and resources that elevate the institution's approach to solving grand societal challenges. His partnerships with key alumni and business-community constituents channeled energy and expertise into exciting opportunities for generations of faculty and students to come.

The following article examines Wu's impact as dean through the eyes of a handful of young alumni who've flourished, in part, through their experience in some of the programs Wu helped to put into place.

These and countless others exemplify a principle Wu often shared with friends and colleagues among the Lehigh community: “Engineers educated at Lehigh,” Wu said, “are not pocket protector engineers; rather, they are well-balanced individuals who are trained to think rigorously and imaginatively and who use engineering as a platform to bigger and better things.”

## IDEAS

MICHELE SPICER '12, M.S. '14



Michele Spicer brought her passions for music, languages and the environment to a freshman engineering course taught by IDEAS director Bill Best.

“He said I was an ideal candidate for the IDEAS program,” Spicer recalls. “He told me, ‘You might come back to us one day.’”

Two years later, after stretching the limits of her chemical engineering curriculum, “taking Spanish classes and environmental science any time there was a tiny free moment,” Spicer knocked on Best’s door.

As an IDEAS student, Spicer took courses in engineering, environmental sustainability and Spanish. For her senior thesis, she studied a small town in Scotland where wind energy had succeeded because the nearby turbine gave people a social rallying point. Social acceptance, she learned, is critical in introducing renewable energy sources.

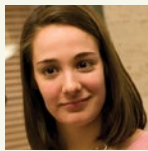
“You can’t decide the best place to install wind energy based just on the science. Just because we have massive wind in a wind belt doesn’t mean that’s where we should put turbines. What I loved about IDEAS is that you take a holistic view. I looked at what works and doesn’t work societally, and at the technological barriers and political and economic impacts.”

After completing her degree, Spicer spent two months in Costa Rica as an Iacocca Intern. To incorporate sustainability principles into the curriculum for fourth graders in a low-income area, she used everyday objects to illustrate environmental concepts.

Spicer earned an M.S. in environmental science from Lehigh and is now a Ph.D. student in forest ecology at the University of Pittsburgh. “I’m so glad I did an integrated degree,” she says. “The same math and science concepts engineers use to explain industrial processes—heat transfer, mass transfer, fluid dynamics—help explain the natural world, too.”

## David and Lorraine Freed Research Symposium

CAROLYN SCOTT '10



Carolyn Scott was excited when Sabrina Jedlicka, assistant professor of materials science and engineering, encouraged her to enter the Freed Undergraduate Research Symposium in her senior year.

Scott’s poster won first prize in the competition. Her research involved taking an adult stem cell and making it a functional neural cell by designing peptides that would trigger development in the precursor cells. The goal was to determine which protein segments spurred development, and then to design peptides, which are smaller, more easily manipulated molecules, to mimic this action.

“We were looking for specific markers for the neural cell we were trying to develop, and we started to see expression of the proteins we would expect to see from those cells,” she says.

Scott, now a Ph.D. candidate at the University of Minnesota, says

her Lehigh education gave her more than a research focus. “Prof. Jedlicka exposed me to working in a wet lab and showed me how to ask the right questions and design an experiment to answer them.”

The Freed symposium, which requires students to make presentations to judges, boosted Scott’s confidence in her ability to communicate.

“Working in a close lab group it can be easy to forget that there are people outside who don’t understand what you are doing,” she says. “I have to be able to think about my work on different levels and explain to people why they should care about it.”

The field of stem cell research, says Scott, is temporarily stalled.

“When we declare that we’re successful and that we’ve produced, say, a liver cell, what we mean is we have cells that behave like liver cells in a very immature liver. We have not gotten to developing full adult cells.” “It’s a field-wide question we’re asking: What are we missing?” she says. “We don’t know yet. That will be my next few years, I guess.”

---

## M.Eng. in Energy Systems Engineering

ROBERT SMITH '14



Robert Smith says ESE’s project focus and breadth—covering energy economics, the environment and technology—set him on the correct career trajectory.

“I developed my program and technical electives to meet the need I saw in the electric utility industry,” he says. “I knew smart grid technology was being deployed more than ever before, and the data that it generated was substantial.”

The ESE degree helped Smith land a job as lead energy research analyst with Colorado Springs Utilities, where he leverages data to gain insight into demand-response, renewable energy and other initiatives. He beat out 200 candidates in a process that required him to develop a long-term projection incorporating socioeconomic and demographic data.

“They gave me three days,” he says. “I spent 40 hours on it, the weekend before [ESE] finals.”

At CSU, Smith continues to develop detailed predictive models that “give us a strategic vision of what we should expect to see happening on our electric system over the next 20 years.

“We’re in a period of transition in our industry away from a top-down framework,” he says. Power is generated not just by large coal plants but by homeowners’ solar arrays. The distribution of electricity is being increasingly monitored by sensors throughout the grid.

“The days of big coal and gas plants are largely behind us. We’re moving to a more decentralized generation system.” Smart grid technologies, and attendant data flows, will continue to expand.

Smith works with CSU’s Eco-Saver Program, which paid 600 customers to install a remote-controlled smart thermostat in their homes.

“On a really hot day we can save you money if we ratchet your thermostat up a few degrees,” he says. While customers can choose to override the utility’s request, such demand-response programs can help utilities shave peak demand, saving energy and money.

“If we can put off adding additional generation capacity for a few years,” says Smith, “then ratepayers don’t bear that cost.”



1

2



3

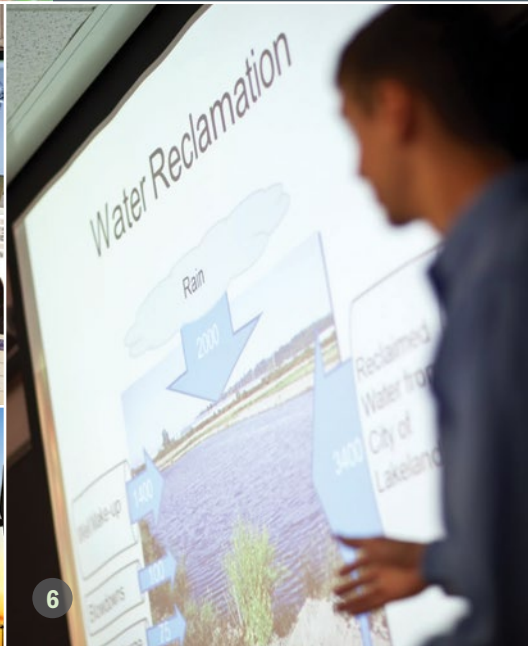
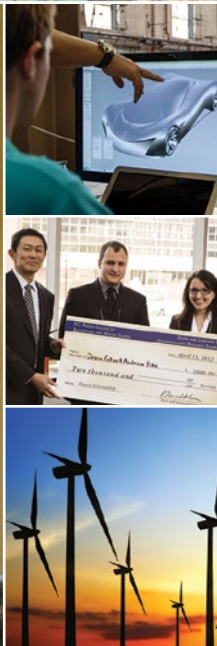


4

1. Carolyn Scott '10 took first prize at the 2010 Freed Research Symposium. 2. In 2013, Lehigh's CHOICES camp for middle-school girls doubled its enrollment. 3. Lehigh's Science, Technology, Environment, Policy, and Society (STEPS) building opened in 2010. 4. Members of Engineers Without Borders assess Honduran villagers' water resources. 5. Dean Wu with former College of Business and Economics Dean Paul Brown at a LehighSiliconValley event in California. 6. Final project presentations by students in energy systems engineering.



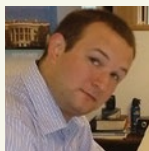
5



6

## M.Eng. in Structural Engineering

VINCENT ANTES '08 '09G



Lehigh's M.Eng. in structural engineering gave Vincent Antes practical experience and industry connections. Much of the program's credibility, says Antes, comes from its director, Jennifer H. Gross, who spent 12 years in industry working on projects such as the Gaylord

National Harbor convention facility in Maryland and a 10-story tower addition to Philadelphia's Children's Hospital.

"In design classes, she discussed real examples, and shared her thinking," Antes says. "She taught that you can't just think about how a structure is going to work, you have to think about how it interacts with all the architectural and mechanical components intertwined with it."

Antes is now a senior structural engineer with Ammann & Whitney, an international practice based in New York. He has worked on airport terminals, parking garages and the Arecibo Observatory radio telescope in Puerto Rico.

"I like to look at the overall picture first, then dissect it into smaller parts," he says. "I rarely deal with a problem that is purely structural. Everything has to relate to a bigger picture."

"I can make a structure strong enough, that's easy: Just pick the biggest beams and columns and it will work. But I also have to think about how much it will cost to build a design, how easy it is to construct it, and how the mechanical, electrical and other systems fit in."

Antes credits his ability to interact with corporate leaders to the structural engineering program's Industry Advisory Council, which includes senior engineers from DeSimone, Clark Construction, WJE and other top firms.

"In project work we had to present our methodology and the reasons we did what we did, and they would critique us," he says. "We also had a chance to sit around and talk and pick their brains. That was a huge advantage."

## M.Eng. in Energy Systems Engineering

KARYS MORENO ARISOHN '11



Lehigh's M.Eng. in energy systems engineering gave Karys Moreno Arisohn a fresh perspective on the energy situation in her native Panama.

"Our classes helped me understand how diversified the energy matrix is in the U.S. If one source fails you can get energy from another," says Arisohn. "In Panama, we are 60 to 70 percent dependent on hydropower. Hydro is very clean, but we can't put our eggs in one basket."

After graduation, Arisohn took a job with Panama's Secretary of Energy. She worked on a project to build a new solar facility and a pilot wind farm and helped draft the nation's first energy efficiency legislation. Her experience collaborating with people from diverse backgrounds in the ESE program, she says, proved beneficial.

"In Panama, I worked with engineers, government officials and

lawyers and met with vendors and manufacturers. Some were angry that their equipment would be disqualified under the proposed law.

"Once the bill passed, the real job started," she says. The energy department had to cooperate with government entities and business to implement the law. Panamanians, who did not yet recycle, had to learn a culture of energy saving.

"I worked with the education ministry to put energy efficiency classes into elementary schools," says Arisohn, "so we could start to change the culture with the children."

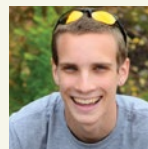
After two years in Panama, Arisohn took a job as project engineer with Energy Resources and Solutions in Troy, N.Y. She advises large corporate clients and determines if energy upgrades and retrofits qualify for state incentives. She has also evaluated the replacement of old heating systems and the installation of insulation in the homes of low-income families to determine if savings are being realized.

"I come from a tropical country," Arisohn says. "I have experience with cooling and refrigeration, but I had never had to deal with heating before."

---

## IDEAS

BRANDON ONOPA '14



Brandon Onopa arrived at Lehigh planning to study civil engineering. In a freshman course, IDEAS director Bill Best encouraged students to delve deeply into various disciplines.

"I knew that was exactly what I wanted," says Onopa, who is now a technology analyst with Deutsche Bank.

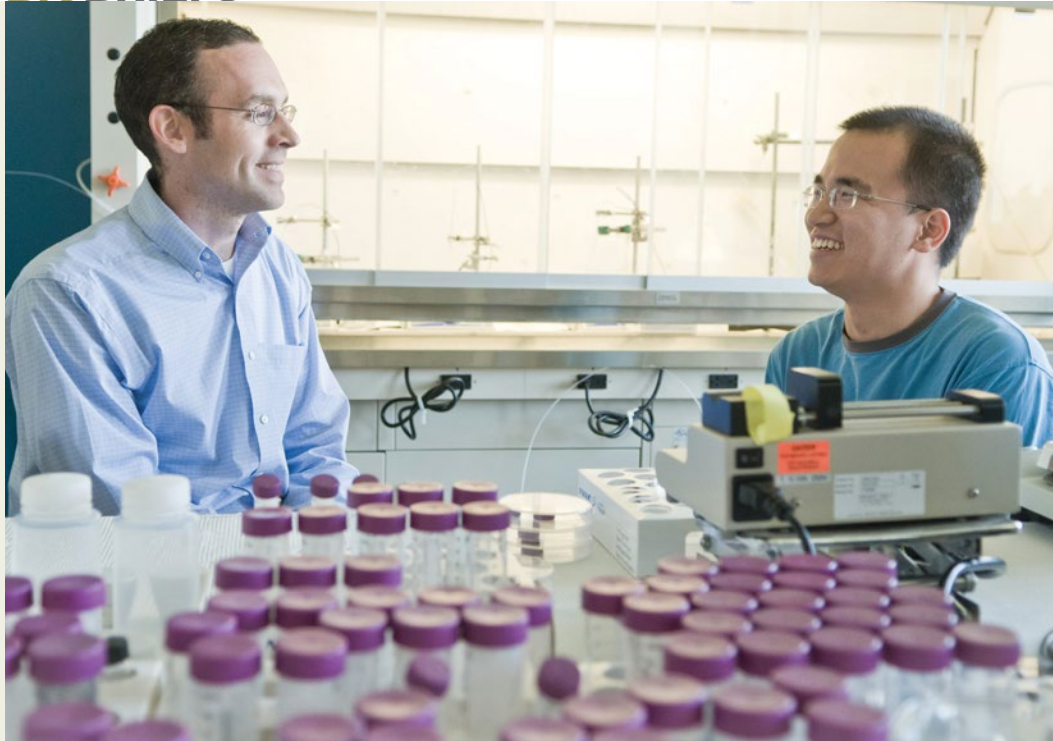
Students in the IDEAS program chart their own curriculum. Onopa had taken Chinese language and culture courses in high school, so Best pointed him to the Chinese Bridge Project, a program led by professors in religion studies, Chinese and architecture in which students studied Chinese culture and Lehigh's 130-year relationship with China. They also built a physical bridge, a pavilion on the South Bethlehem Greenway, with authentic materials and ancient techniques.

The students, says Onopa, sourced all the roof tiles from China and built the structure by hand, following a centuries-old framing technique that does not use nails.

"It was a full-team project, with engineers, science majors, even a math major. We learned there are a number of ways to solve problems that work equally well. That project defined my career at Lehigh."

As an IDEAS student, Onopa chose a specialty in information systems engineering. He said the program taught him "a direct way of problem solving" and helped him see other possibilities.

"I enjoyed looking at an engineering problem and realizing that it isn't a clear-cut path from A to B," he says. "We're all after the same end result. We just get to it in different ways."



## A super highway for the right molecules

*Ultrathin carbon films on porous support promise more energy-efficient separations.*

Energy-intensive separation processes, such as distillation within the petroleum and industrial chemical industries, says Mark Snyder, are responsible for about 15 percent of the energy consumed globally.

If that number seems surprisingly high, the good news is that even modest reductions in the energy inputs required for separations could significantly slice global energy demands.

In a distillation process like the one used in petrochemical refineries, mixtures are heated until the lighter molecular components—the ones with lower boiling points—rise.

“The problem with that technique,” says Snyder, assistant professor of chemical and biomolecular engineering, “is that the energy input required to make that happen is just massive.”

Membrane-based molecular separations offer lower-energy alternatives. Among membrane materials, carbon films can be used to isolate sought-after molecules. The pores on these nanoscale filters, known as carbon molecular sieves,

can be tailored to desired sizes, and can work at the scale of small molecules like CO<sub>2</sub> and methane molecules. But CMS membranes are typically too thick, and the pores too disordered, to be optimal.

“The challenge is speed and selectivity,” says Snyder. “You can create the pores to filter the molecules you want to remove, but it’s hard to get molecules through the membrane quickly, which you need for an industrial process.”

Snyder recently received an NSF CAREER Award, in part for his research into the nanoscale separation of molecules. What makes his work unique is the combination of techniques used to make high-performance CMS films and the potential speed at which the separations can be performed.

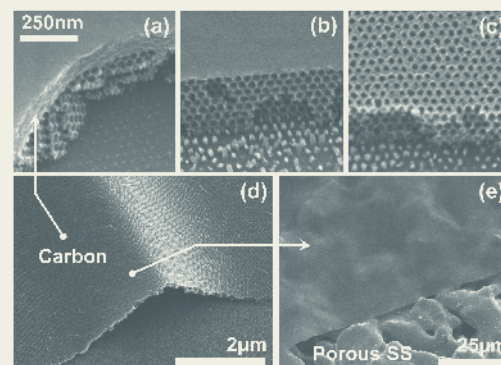
Snyder’s lab creates ultrathin, composite films that promote rapid passage

of molecules. He begins by depositing a thin layer of silica particles, about 10nm in diameter, using a technique that makes the silica self-organize into a regular array. He then introduces carbonized material to fill the spaces between the silica particles, which are then removed.

“You end up with ultrathin carbon layers on a highly porous support,” he says. “These thin films with molecule-selective pores combine with open, ordered mesopores within the support to act like a superhighway for specific molecules.”

In his research, Snyder aims to uncover novel ways to modulate the properties of these materials to create more specific filtering qualities in the membranes.

“You can use the interaction between the materials that are used in synthesizing the carbon thin films or their surface chemistry, for example, to fine-tune the properties of the carbon or activate the pores in the material,” he says.



*SEM images for carbon films/membranes (top row) with intrinsic flexibility (bottom left) enabling mounting on porous substrates (bottom right).*

Snyder, who earned his bachelor’s degree from Lehigh in 2000, returned in 2008 to take his place among the faculty, many of whom had been his professors.

“My teachers are now my colleagues, and they truly welcomed me,” he says. “It’s been really great to come full circle.”



## Sequential processing in the age of big data

Can the flashes of color in thousands of functional MRI (fMRI) scans reveal an invisible coordination between distant regions of the brain? Can patterns in your web clicks give advertisers a better way to target messages to you?

The era of big data is presenting no shortage of machine learning problems. Katya Scheinberg, the Harvey E. Wagner Endowed Chair Professor of Industrial and Systems Engineering, is working to provide faster, more efficient tools to sift through vast quantities of data to reveal nuggets of insight.

“Learning with large data sets requires an optimization problem,” says Scheinberg. Optimization is a numerical method that steps through data to uncover links and patterns.

Large data problems—predicting weather patterns, mapping communities within huge social networks or detecting the synchronized firing of neurons—all rely on a known group of mathematical functions, Scheinberg says. Using the data, algorithms find the value of the function under study and crunch through a data set until the calculations converge to the function’s minimum value.

Optimization tools seek to accurately

model data with the simplest process. “I want to explain the data the best I can,” says Scheinberg, “and with the fewest iterations.

“Any data can be explained well with complex models,” she says. But those models impose a high cost in computational time and resources, and can be tied so tightly to specific data that they break when applied to other data. “They can’t be generalized,” she says.

Optimization approaches data like a climber proceeding step-by-step down a valley to find the bottom—in the fog, Scheinberg says. With each step, data is computed to determine the next step. “In the beginning, crude methods will give you progress,” she says. “As you converge on the solution you have to work harder,” which is where many algorithms grind to a halt.

But what if you could clear away the fog? “If you can see more, you can make adjustments to get to the bottom faster,” Scheinberg says.

The tools she is working on today, in the third year of a DARPA-funded project, exploit the results gained in previous steps so that as calculations approach the lower limit of the function, “the problem space

of models and variables gets smaller,” which reduces the time penalty associated with each step.

Scheinberg’s open-source tool is one of the fastest known that uses sequential data processing. Consider a case analyzing brain scans that contain 10,000 volumetric pixels, or voxels, each representing a 3-D region containing thousands of neurons. Each scan offers 50 million chances of activity in one region corresponding to activity in another.



“We are solving problems of 10,000 voxels in an hour,” Scheinberg says. “We’ve achieved a good balance with relatively ‘cheap’ steps and with relatively rapid progress toward the solution.”

*Scheinberg (right) writes calculations that converge to a function’s minimum value.*

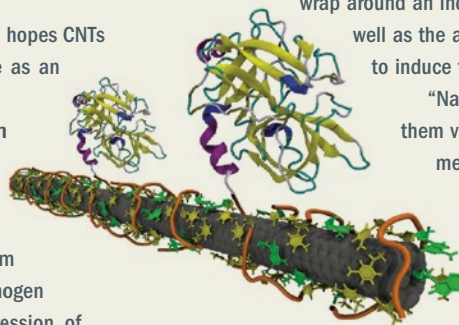
## A tiny weapon joins the battle against cancer

Carbon nanotubes (CNTs) are used in a variety of applications, from clothing and sporting equipment to photovoltaic cells, electronic devices and even automobile tires.

Dan Roxbury '07, '12 Ph.D. (chemical engineering) hopes CNTs can one day be inserted in the human body to serve as an early warning system to detect and treat cancer.

Roxbury recently received a grant from the American Cancer Society to support his work at the Sloan Kettering Institute in New York. According to ACS, Roxbury is building a sensor made of CNTs wrapped with strands of DNA that can detect in the bloodstream the amount of a biomarker called urokinase plasminogen activator (uPA) that signals the presence and progression of some types of cancer.

The sensing agent in Roxbury’s sensor is the uPA binding antibody, which is attached to the CNT-DNA hybrid wrap and detects the uPA. The DNA he uses



is synthetic. The width of each strand is roughly the same as the diameter of the nanotubes, while their length is shorter than that of the CNTs. Several strands wrap around an individual CNT. After modifying the end of each DNA strand as well as the antibody, Roxbury uses a type of synthesis called click chemistry to induce the strand and the antibody to bond to each other.

“Nanotubes are very sensitive to their environment, which makes them very good sensors,” says Roxbury. “The antibody conveys the message to the nanotube and the nanotube gives a readout of how much of the uPA molecule is detected.”

Roxbury is testing his CNT device in water and hopes soon to conduct tests in blood or another complex solution and then in mice. Eventually, he foresees the device being inserted noninvasively under the skin of people who are at risk for cancer or have had the disease. A smart watch or smartphone would pick up signals from the CNT device and monitor the level of the cancer biomarker in the bloodstream.

## A naturally inspired study of nanosuspensions

Researchers advance thermodynamic understanding of liquid-solid interactions.



Lotus flowers do it. So does the Namib Desert beetle. Both have a feature that causes water to gather into tiny balls on their surface.

When rainwater hits a lotus plant, the droplets coalesce on top of micrometer-scale bumps on its leaves, then slide off, picking up dirt particles on the way and leaving the leaves clean.

A similar pattern of hydrophilic bumps on a desert beetle allows it to harvest spheres of precious moisture from its back.

These marvels of the natural world fire Edmund Webb's imagination. An associate professor of mechanical engineering and mechanics, he finds inspiration in the overlap between nature's innovations and human inventions, such as self-cleaning solar panels that use the lotus effect to remove dirt, and potential exoskeleton technology that could collect water in an arid climate.

Webb studies the behavior of liquids when they make contact with solids. His research reveals the intricacies of the wetting and spreading of droplets that are invisible to the naked eye.

Webb's specific focus is nanodroplets, including nanosuspensions, or droplets that contain particles. He uses computer simulations to explore how atoms at the interface of liquid and solid behave as a droplet spreads. Particles suspended in a liquid affect droplet spreading behavior; the coffee cup ring is a classic example.

"When you put down a coffee cup that has coffee all over the bottom," Webb asks, "why does the puddle form a ring-shaped stain instead of a filled-in circle?" Because, he says, all the liquid flows to the edge—where

evaporation is the fastest—and carries particles of coffee with it. Toward the end of evaporation, when the liquid would preferentially retract from the edge, it cannot flow back to the middle, because coffee particles pin the liquid edge to the table's surface.

"All these particles have gathered around the edge, and that's how the final shape, a ring, is achieved," Webb says. He points out that, in some systems, particles flow to the edge but are able to flow back so that a different final pattern emerges. "We can use that natural phenomenon as inspiration for what we can engineer."

*"Nobody had captured the pinning of a precursor film in advance of the contact line in an atomistic scale simulation...We're really excited with our result."* —Edmund Webb

Using a Lehigh Faculty Innovation Grant (FIG), Webb and Ph.D. candidate Baiou Shi have explained a phenomenon of droplet spreading using data not previously observed. Prior experiments showed that the liquid front of a spreading droplet could be pinned, or halted, by the presence of suspended particles; however, the forces involved in the process could only be conjectured and not measured. Simulation results from Webb's group permit the first quantitative extraction of those forces, helping pave the way for more

deterministic engineering of nanosuspension droplet behavior.

"Nobody had captured the pinning of an advancing contact line in an atomistic scale simulation and computed during that process the relevant forces. We're really excited with our result."

Webb's simulations show that a precursor film continues to advance across the surface even when the droplet is pinned in place by the particles within it. However, the rate of precursor advance is significantly reduced by the pinning particles.

Simulations by Shi are also revealing how particle size affects the process, and how the affinity between the particle and the

surface on which the droplet is deposited affects the spreading of the liquid.


"This enables us to advance fundamental thermodynamic theory," Webb says.

Shi's simulations show what happens to atoms along the contact line between a liquid droplet and solid surface as a function of time, which means that she can detect, among other features, specific atomic transport mechanisms associated with contact line advancement.

While computer models are key to revealing fundamental atomic features of droplet behavior, they can create false data if the programmer isn't faithful to the minutiae of how atoms truly behave, Webb says.

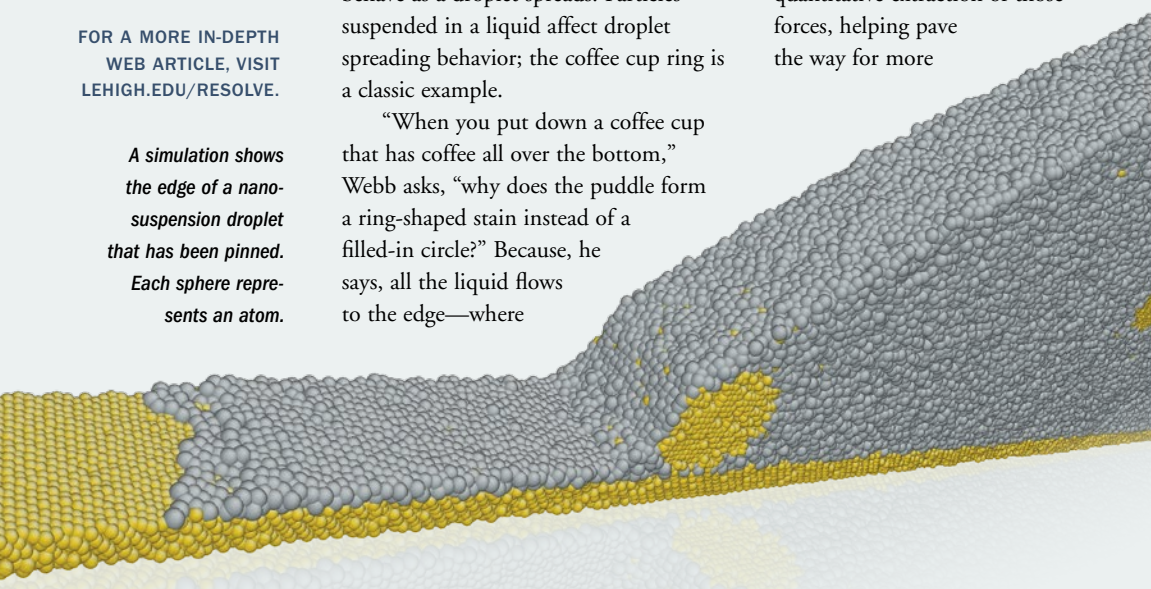
"Without explaining how things behave at the atomic scale, you can't fully understand how the process works at the macro level," he says. "If you don't fully understand it, you can't accurately model it. If you can't model it, you can't engineer optimized applications."

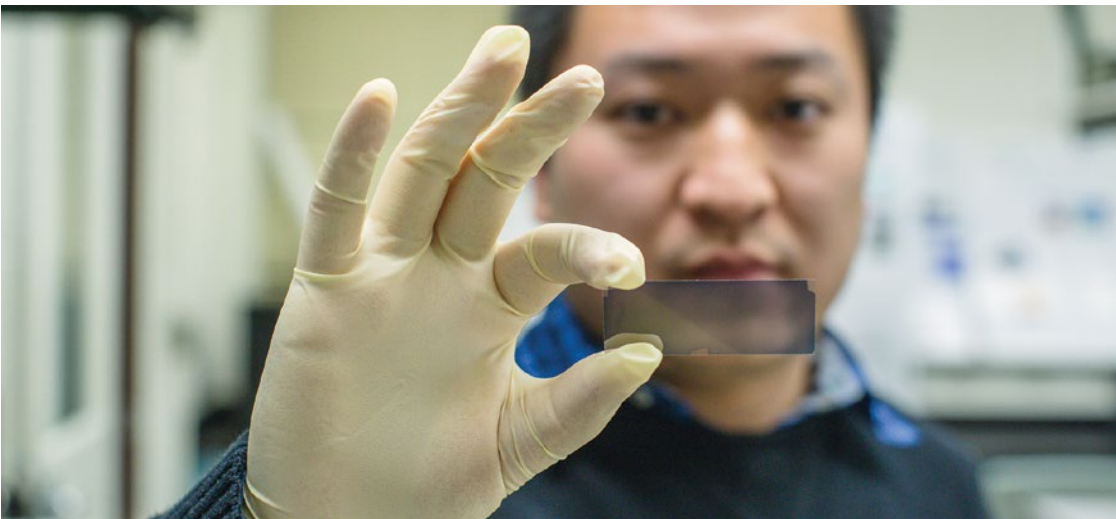
In inkjet printing, particles in the drop are left behind in an ordered array after the ink has been deposited on the surface and the water has evaporated.

"If the particles that you've deposited in this fashion have the right photonic or electronic properties, then you've possibly synthesized a very, very useful device," Webb says. 

FOR A MORE IN-DEPTH WEB ARTICLE, VISIT [LEHIGH.EDU/RESOLVE](http://LEHIGH.EDU/RESOLVE).

*A simulation shows the edge of a nanosuspension droplet that has been pinned. Each sphere represents an atom.*





## A step toward dye- and chemical-free color filters

TVs, iPads and other devices use filters to display the breadth of colors available in the visible portion of the electromagnetic spectrum. Conventional color filters are typically made of organic dyes or chemicals, but they can be damaged by heat and ultraviolet radiation (UVR), and they are costly to make.

For these reasons, says Beibei Zeng, engineers are turning to plasmonic color filters (PCFs), which are based on surface plasmons, or the collective oscillation of electrons at metal/dielectric interfaces. These filters are made by fabricating, on a thin metal film, arrays of holes with diameters of 10nm or less. By varying the geometry of these nanoholes, it is possible to create a broad spectrum of colors for imaging applications.

“PCFs,” says Zeng, a Ph.D. candidate in electrical engineering, “are simple to make and easily tuned over a wide range of colors. They are very stable and they are not vulnerable to damage from heat, humidity or UVR.”

The efficiency with which PCFs transmit light is only about 30 percent—less than half the rate for conventional color filters. Zeng’s team has developed a new PCF scheme that achieves a transmission efficiency of 60 to 70 percent by relying on a subtractive filtering approach.


Subtractive color filters (SCFs) are used in image sensors, says Zeng. They

have advantages over additive filters in color signal strength and light transmission, but researchers have not yet been able to produce high-performance plasmonic SCFs.

Zeng’s group more than doubled the transmission efficiency of PCFs by fabricating the filters onto a 30nm-thick silver film patterned with 1D nanogratings. Additive PCFs are typically etched onto 200nm-thick films.

“The relative thinness of our filters causes a coupling in the electromagnetic resonances at the top and the bottom of the metal surface,” says Zeng. “This does not occur with thicker metal films. Without this coupling, a transmission peak occurs; with it, the peak becomes a valley and causes a transmission dip.

“We can control this transmission dip by tuning the dimensions of the nanostructures on the metal film. Just a few years ago, we could not fabricate such thin structures. Now we can fabricate nanostructures systematically and achieve fine control of the colors transmitted through nanostructured films.”

The group reported its results in a paper titled “Ultrathin Nanostructured Metals for Highly Transmissive Plasmonic Subtractive Color Filters,” which was published by *Scientific Reports*, a *Nature* publication. The paper was written by Zeng; Filbert J. Bartoli, department chair of electrical and computer engineering; and Yongkang Gao ’14 Ph.D. 

*The key to the improved transmission efficiency in Zeng’s plasmonic color filters is the ability to tune the dimensions of the nanostructures on an ultrathin metal film.*

## A unique 3D assembly

It was a straightforward experiment: Aditi Chakrabarti dropped solid spheres of metal and ceramic, 2 to 5mm in diameter, into a gel material. She watched the spheres sink until they became stagnant in the polyacrylamide gel, which is a soft elastic solid. The tiny particles then began to interact with each other, forming close-packed structures, in a process resembling crystallization.


After experimenting further with combinations of copper, steel, glass and ceramic spheres, Chakrabarti discovered that the forces governing the movements of the particles were the result of the cooperative effects of surface tension, elasticity and gravity.

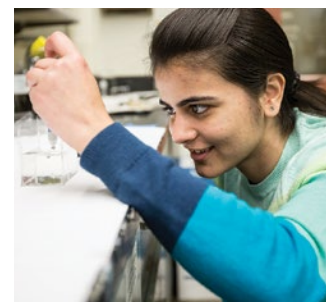
The phenomenon, says Chakrabarti, a Ph.D. candidate, had not been seen or predicted before. She and Manoj Chaudhury, professor of chemical engineering, reported the discovery in *Langmuir*.

Scientists have long known that objects can interact because of the mechanical distortion of the medium that surrounds them as well as physical forces such as elasticity and gravity. A particle inside Chakrabarti’s gel does not displace the gel as it would water. Instead, the tiny sphere experiences not only gravity but also elastic forces as the soft solid of the gel stretches around and over it.

After watching a single, 2mm-sized copper particle sink and reach equilibrium inside the gel, Chakrabarti dropped a second particle a few millimeters away and watched it sink to the same depth and stop. The particle then started moving toward the first sphere until it made contact and created a dimer, a structure of two identical units.

When a third particle was released, it moved toward the dimer and formed a triangular structure. A fourth particle formed a tetrahedron. Chakrabarti continued adding copper spheres, and they formed a large cluster on one side of the gel screen. She then formed a second cluster on the other side of the gel. The two clusters drew together, made contact and reorganized into one close-packed structure.

“They became kind of clenched together,” says Chakrabarti, “almost like crystallization. People have done lots of 2D assembly in liquids. But 3D assembly in this kind of soft gel is new.” 



## A constructed, real-time, hybrid solution to structural testing

Engineers seeking to design structures that withstand earthquakes with minimal physical damage have a valuable new testing tool at their disposal thanks to Lehigh

sustain the complex, dynamic loads of an earthquake.

RTHS, says Ricles, divides a structural system into two parts—an analytical substructure represented by a numerical model, typically using a finite element method, and an experimental substructure that is constructed in a lab.

An RTHS test imposes “displacements” in real time onto both substructures for each time step of a seismic event. The response is integrated to determine the overall system’s dynamic response to earthquake forces.

“At each time step,” Ricles’ group wrote in *Earthquake Engineering and Structural Dynamics*, “the inertia, damping and restoring forces of the analytical substructure are formulated numerically [and] measured physically for the experimental substructure.”

Conventional hybrid tests impose displacements on an experimental substructure in “an extended time scale,” the researchers wrote. An RTHS test imposes them in real time, enabling researchers to obtain more realistic results.

Ricles’ collaborators at Lehigh include

Richard Sause, professor of structural engineering; Ph.D. candidates Karim Kazemi Bidokhti, Chinmoy Kolay, Akbar Mahvashmohammadi and Baiping Dong; Yunbyeong Chae ’11 Ph.D.; and Thomas M. Marullo, NEES IT manager.

The group tested a three-story prototype building made of reinforced concrete and a multistory steel structure with nonlinear viscous dampers. Research partners for the second project included California State University at Northridge, California State Polytechnic University, Penn State University at Erie, Corry Rubber Co. and Taylor Devices. Tests were conducted at Lehigh’s NEES Real-Time Multi-Directional Earthquake Simulation Facility (RTMD), one of the largest of its kind.

Founded by NSF in 2004, NEES is a collaboration of 14 American research institutions. NEES researchers at Lehigh, says Ricles, NEES principal investigator and RTMD director at Lehigh, have completed 20 major RTHS projects and performed more than 2,000 large-scale, real-time tests. An RTHS can be parceled out, with researchers at separate sites conducting different portions of the experiment. **1**



Ricles (center) and his students made three presentations on RTHS at the Sixth World Conference on Structural Control and Monitoring in Barcelona in July.

researchers with the George E. Brown Jr. Network for Earthquake Engineering Simulation (NEES).

During a four-year project, says Jim Ricles, professor of structural engineering, the Lehigh NEES team developed and validated Real-Time Hybrid Simulation (RTHS) as an “efficient and economic” method for testing a structure’s ability to

## Unlocking data for easier multitasking

When one of the processing cores in a computer reserves more data than it needs, says Michael Spear, there’s a cost: another core cannot access that data, and has to wait.

Spear, assistant professor of computer science and engineering, seeks to eliminate these delays in massive computing systems with an inherently speculative technique, based on transactions. NSF has recognized his work in transactional memory with a five-year CAREER Award.

Transactional memory allows a system to perform distinct operations—or transactions—simultaneously, while avoiding the conflicts that can arise when two or more transactions are using the same underlying data.

“You need to protect the data in your memory to ensure that one section of the system doesn’t interfere with another,” says Spear. “Traditionally, you would just lock huge chunks of data. But that can hurt performance, as cores have to wait for access. In most cases, though, two cores won’t need to access the same data, so there is no conflict. Transactional memory allows you to avoid

locking so multiple cores can operate at the same time.”

It does this, says Spear, by allowing the core, when it detects a conflict, to reset the system to a point that precedes the conflict. “When things don’t go the way you planned, however, you can’t always analyze the transactions to discover what’s wrong. So we have also invented a mechanism that will allow you to see inside if you aren’t getting the results you expect.”

Spear is working with Intel and Oracle to make transactions easier to use. “Transactional memory requires changes at the lowest levels of a computer system. It takes new compilers, new programming languages and, in some cases, new hardware.

“Once a system gets big enough, you can’t tell how the parts are going to interact. It’s true in individual programs, and that’s why we need transactions. But it’s true in computer systems too, which makes for great research opportunities. You get to work across the entire stack, from applications all the way down to the hardware itself.” **1**



## Helping Mexico go green

Scientists seek to use recycled CO<sub>2</sub> to boost geothermal power production.

Lehigh's Energy Research Center is leading an effort to recycle the carbon dioxide emitted by fossil fuel power plants while helping Mexico boost its use of renewable energy sources and cut CO<sub>2</sub> emissions.

The ERC has signed a contract with the University of Michoacan San Nicolas de Hidalgo (UMSNH) to study and test methods of using CO<sub>2</sub> to enhance the extraction of geothermal energy from underground aquifers and rock formations. The three-year project is receiving \$1.67 million from Mexico's National Council for Science and Technology (CONACYT).

The project will deliver several benefits, says ERC director Carlos Romero, who is co-principal investigator with former ERC director Edward K. Levy.

Because CO<sub>2</sub> is a greenhouse gas, scientists are trying to develop ways of sequestering it, or storing it permanently, in underground mines and rock formations and at the bottom of the ocean. Combining sequestration and the reuse of CO<sub>2</sub> would be a cheaper way of preventing it from entering the atmosphere after it is emitted from coal- or oil-fired power plants.

In addition, says Romero, the physical properties of CO<sub>2</sub> promise to enable it to harvest geothermal energy more efficiently than water, the conventional geothermal heat extraction medium.

Geothermal power, Romero notes, does not attract as much media attention as wind, solar and other renewable energy sources. But it generates electricity continuously—not just when the wind blows or the sun shines. And unlike fossil fuel-fired power plants, geothermal power plants produce electricity cleanly, emitting significantly less CO<sub>2</sub> and no sulfur dioxide or other toxic pollutants, such as mercury.

Mexico, with 8,000 megawatts (MWe) of electrical output, has the world's second-highest proven reserves of geothermal power after Indonesia. It is also the globe's 12th-leading emitter of CO<sub>2</sub>. The country has set targets to cut national CO<sub>2</sub> emissions 30 percent by 2020 and 50 percent by 2050.

Mexico is also hoping to double its reliance on renewables—from 17 percent of national consumption this year to 33 percent by 2018. In its drive to go green, the country is placing big hopes on geothermal power. The country has built, or is in the process of building, eight conventional geothermal power plants.

The typical sources of geothermal energy are

volcanic rock formations, deep saline aquifers and hot dry rock formations, which lie farther beneath the earth's surface. If the temperature in a water-dominated reservoir is high enough, engineers can harvest geothermal energy by drilling a production well to the reservoir. The pressure from the heat of the water, combined with the difference in pressures on the aquifer and on the surface, causes the water in the reservoir to rise to the geothermal plant, where it turns the turbines that power the generators to make electricity.


In its project in Michoacan, the ERC will perform simulations and experiments using supercritical CO<sub>2</sub> (which has been heated and pressurized) as a medium to extract heat from all three types of geothermal energy sources.

Because of its lower viscosity and larger density differences at different temperatures, says Levy, supercritical CO<sub>2</sub> is more mobile than water and should therefore percolate more readily into a geothermal reservoir. Heated CO<sub>2</sub> will rise through the production well, creating several options for generating power. The hot gas can turn the turbines to power the generator or it can be diverted into a heat exchanger working with an organic fluid or other medium. The heat would convert this fluid to steam to turn the turbines and power the generator. The heat can also be used in the process to capture CO<sub>2</sub> at a fossil fuel-fired power plant, or for district heating.

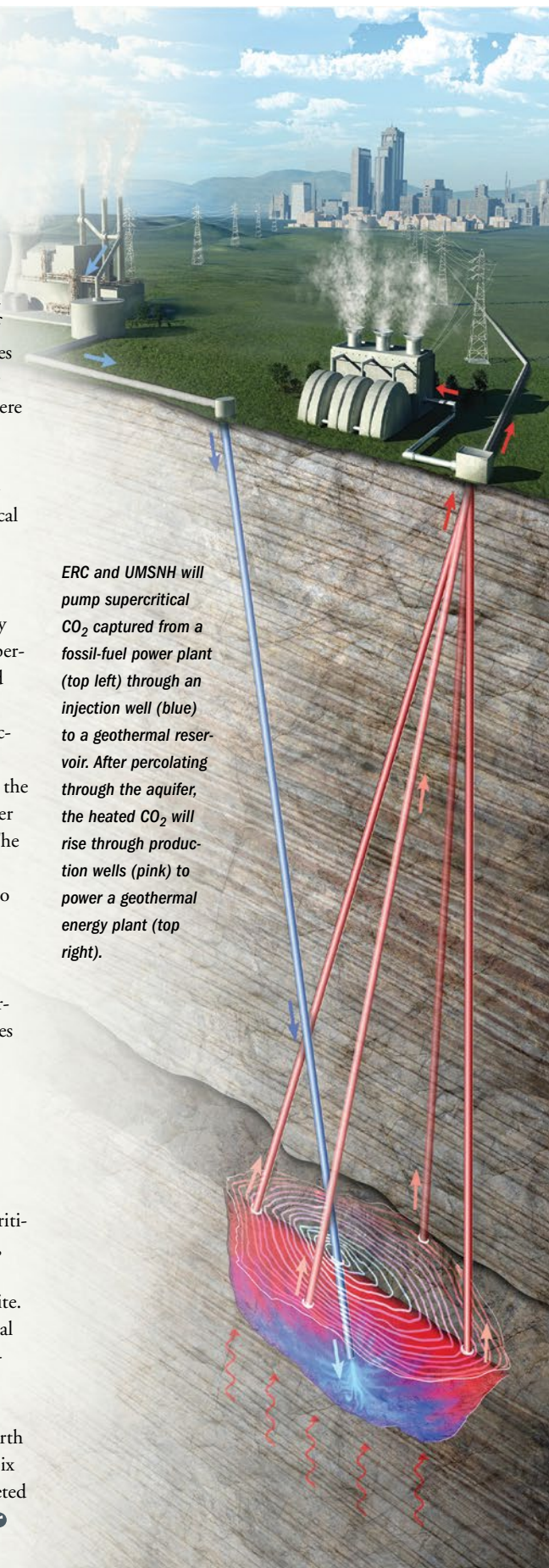
The superior properties of supercritical CO<sub>2</sub>, says Levy, also give it the potential to mine geothermal energy more efficiently from a reservoir that lies closer to the earth's surface. Water temperature is typically lower in these aquifers but their easier access reduces drilling costs.

UMSNH, says Romero, has two experimental geothermal units capable of generating 300 megawatts of electricity. The ERC and UMSNH will convert one unit into a pilot plant utilizing supercritical CO<sub>2</sub> and an organic heat-exchange fluid. Later, the researchers will install and test a pilot plant at UMSNH and deploy the system at a geothermal site.

The long-term goal is to construct a geothermal plant in Mexico near or adjacent to an oil- or coal-fired power plant providing a readily accessible supply of CO<sub>2</sub>.

The collaboration with CONACYT is the fourth major project the ERC has conducted in the past six years in Mexico. ERC researchers have also completed projects in the U.S., Canada, China and Europe. 

*ERC and UMSNH will pump supercritical CO<sub>2</sub> captured from a fossil-fuel power plant (top left) through an injection well (blue) to a geothermal reservoir. After percolating through the aquifer, the heated CO<sub>2</sub> will rise through production wells (pink) to power a geothermal energy plant (top right).*





# WHEN A MOLECULE TAKES A SELFIE

## A PHYSICIST EXAMINES ELECTRONS IN THEIR OWN TIME SCALE

Paul Corkum '67G '72Ph.D., a pioneer in ultrafast laser spectroscopy, uses lasers to generate attosecond pulses that take photographs of electrons orbiting inside atoms. In the 1980s and 1990s, he developed and confirmed models of atomic ionization and recolliding electrons. In 2001, he and his colleagues demonstrated the first laser pulses lasting less than a femtosecond. Corkum holds a joint chair in attosecond photonics at the National Research Council of Canada and the University of Ottawa. In 2009, he was elected a member of the U.S. Academy of Science and also received the Gerhard Herzberg Canada Gold Medal for Science and Engineering, the most prestigious science prize given in Canada. Corkum holds a B.S. from Acadia University in Nova Scotia and an M.S. and Ph.D. from Lehigh.

**Q: *Beyond scientific and mathematical intelligence, what are the qualities necessary to be a good researcher?***

**A:** Just as in the arts, in science you need the basic skills and creative ideas. But art is a solitary profession; physics, a very social one. Experiments are almost always done in teams. Discussion and debate are integral parts, as are presenting and defending results to others. Teamwork is essential. I can't think of a more social profession than physics.

**Q: *What motivates you?***

**A:** I love physics. You get to think about how nature works at its most fundamental. I love the ideas. What is most exciting is when you have a new idea that no one in the whole of history has ever thought about before. And when it proves to be important, that is really fun. I was lucky. The big idea I came up with was recollision and how it affects a wide range of

physical phenomena. That led to attosecond pulses (10-18 seconds) and how to take the image of the orbital. Nobody thought you could do such a thing. It has had a big impact.

**Q: *What is the secret of maturing as a scientist?***

**A:** One gets so deeply involved in a subject, and so interested that you naturally think about it every time you relax. New ideas are constantly bubbling up to the surface of your mind. Most of these ideas are wrong. The trick is to select the right ideas and critically reject the wrong ones as quickly as possible.

**Q: *When did your interest in attosecond science begin?***

**A:** At Canada's National Research Council we used lasers to measure the properties of plasmas. Soon, I began working to make shorter light flashes to measure faster phenomena and I began thinking of the unique experiments that could be done with



UNIVERSITY OF OTTAWA / B. FINGLEY

of an attosecond pulse as a camera flash ideally suited to measuring electrons. The shorter the flash of light, the faster the speed you can measure.

**Q: How did you model the ionization of atoms in the 1980s?**

**A:** I took ideas that were well-developed in one area of physics and applied them to a new area. I applied the ideas from plasma physics that describe how intense light interacts with free electrons and ions. I asked, "What if we were to start from an atom? What would the resulting plasma look like? And if there were too few atoms to actually make a plasma, what characteristics would the electrons and ions have?" [My] findings led to Optical Field Ionization (OFI), a new approach to X-ray lasers, recollision and attosecond science.

**Q: How significant are the OFI lasers you helped develop?**

**A:** OFI allows the frequency range of conventional lasers to be extended toward X-rays. Scientists are still developing this approach today. But in the end, they were bypassed by recollision, which is a significant variation of Einstein's original idea.

**Q: Tell us about recollision.**

**A:** Let me draw an analogy. If a big wave of water hits a boat moored to a dock, the rope might break, just as an electron can snap free from the atom using optical field ionization. Once free, the boat might smash back into the wharf on the next swell and be shattered. Similarly, the electron can smash (recollide) into its parent ion, giving out a flash of light—the X-ray light that we can use to make attosecond pulses. The X-ray light flash is the analogue to the crashing sound of the boat breaking up as it shatters.

**Q: How did the Recollision Electron Model that you developed in the 1990s lead to the generation of attosecond pulses from lasers?**

**A:** As soon as I understood recollision, I knew it would lead to the most important new theory of nonlinear optics since (1981 Nobel physics laureate) Nicolaas Bloembergen. That was already very exciting. Because it is so intuitive it was also easy to think how to apply it. We can engineer the light wave to allow only one possible collision that can last for only a fraction of a light cycle. That is how we make an attosecond pulse. The current record pulse duration is 67 attoseconds. That's faster than an electron orbiting a hydrogen atom, which makes

a revolution in 150 attoseconds. So we have a tool to look at electrons on their natural time scale.

**Q: You have said that attosecond light pulses can stimulate a molecule to "take a selfie." How does this happen?**

**A:** It comes from recollision. A laser pulls an electron from the molecule and then drives it back. When it recollides, it converts to light as the electron refills its initial place in the atom. That light contains information about the molecule's structure. We capture this light.

**Q: How do you make and measure attosecond pulses?**

**A:** The trick is to make sure that the light wave that controls the recollision electron allows only one possible crest of a wave in which the electron can be ripped from the atom and only one following crest of the wave for the electron to recollide. To measure attosecond pulses we make a photoelectron replica of the unknown pulse and measure that. By measuring what happens to many electrons, we measure the duration of the pulse.

**Q: Have the images you've obtained of atoms changed our understanding of the atomic world?**

**A:** The Harvard chemist Dudley Herschbach (1986 Nobel laureate) once told me that the nitrogen orbital that we measured will eventually change how chemistry is taught. I am not a chemist, but elementary chemistry introduces orbitals abstractly. Now that we can "take a selfie," we can say that there is an experimental way to see an orbital. So I think attosecond science is changing our understanding of the atomic world.

**Q: What role have Lehigh and the teachers and colleagues you had here played in your career?**

**A:** At Lehigh I shared an office with four or five other graduate students. We discussed the problems that Professors Bob Folk or Al MacLennan would assign us. That's where I first learned to work in teams. I did my Ph.D. thesis in theory with MacLennan. Though the rest of my career has been in experiments, I think my background at Lehigh in theory influenced all the rest of my career. It gave me a theoretical perspective on all the experiments I did. That was the heritage I got from Lehigh and from Al MacLennan more than anyone else. 📍

**DR. CORKUM'S FASCINATING AND WIDE-RANGING INTERVIEW WAS EDITED FOR PRINT; DON'T MISS THE LONGER-FORM ARTICLE AT [LEHIGH.EDU/RESOLVE](https://www.lehigh.edu/resolve).**

these lasers. One day it struck me—a "blinding idea." I knew how to make the world's shortest pulses and I could even see how to measure them and what to do with them. It was so exciting!

**Q: How do you relate an attosecond to the age of the universe?**

**A:** An attosecond is to one second as a second is to the age of the universe. Here's another way to understand an attosecond. If you could travel at the speed of light—the fastest speed possible—you would circumnavigate an atom in one attosecond!

**Q: Why would anyone ever want such a short flash of light?**

**A:** Everyone has seen that famous photo of a bullet exiting a light bulb that it has just pierced. The photographer, H.E. Edgerton, needed a very fast flash—fast enough to freeze the movement of a speeding bullet. An attosecond pulse is fast enough to freeze a speeding electron, to stop the action so you can resolve what's happening, step by step. You can think



# A REAL-TIME WINDOW INTO THE MAKING OF PLASTICS

*A collaboration with industry is helping John Coulter's group gain new insights into the effects of melt rotation techniques on polymer properties.*

**Researchers seek to improve the process of injection molding.**

From sunglass frames to high-precision optical network connections, plastics are everywhere. More than 85 billion pounds of polymer products are manufactured each year in North America, most by a process known as injection molding, says John P. Coulter, professor of mechanical engineering and mechanics.

Coulter and Ph.D. candidate Qi Li are expanding the scientific understanding of how molten



polymers flow through intricate networks of tubes, or "runners," into the molds for individual parts. Along with other Lehigh participants, such as undergraduate student Lauren Walker, they are collaborating with Beaumont Technologies Inc. (BTI), a company based in Erie, Pa.

The project, which is funded by the National Science Foundation, spans materials science,



fluid dynamics and thermodynamics. The researchers are developing techniques to manipulate polymer flows so that parts have consistent quality, which can afford U.S. companies a competitive advantage.

Injection molding forces a molten polymer into a steel mold at high temperature and pressure. The polymer winds through a series of twists and turns to fill as many as 64 product cavities simultaneously, Coulter says. The connecting runners range from 1/8 inch in diameter to 1/2 inch or larger.

Conventional wisdom in the industry says that the runners don't affect the end result as long as they are "naturally" balanced, meaning the paths to each cavity have the same geometry and maintain similar temperatures. But Coulter's research with BTI shows that assumption is incorrect.

Inside the machined steel runners, polymers experience shear forces induced by the channel walls. Higher shear strain rates in the outside regions of these flow paths cause the molecules to disentangle so "the material is thinner and flows faster," Coulter says.

"When you come to a 'T,' where the runner splits to feed two new channels, the thin material whips around the tight corners. The slower and relatively thicker central flow region comes later. If you are making 32 products in a mold you have a lot of intersections, and every time you reach one you have a different resulting flow and shear history distribution." Cavities fill at different rates depending on the mixture of thin and thick polymer flowing to them. In some cases, not all the cavities fill completely.

In 1998, John Beaumont, a professor at the Plastics Engineering Technology program at The Behrend College at Pennsylvania State University in Erie, patented a technique called melt rotation that enables engineers to design channels that manipulate the polymer flow to fill product cavities more consistently. He formed BTI, which licenses the technology to plastics producers.

Melt rotation doesn't eliminate the problem, Coulter says, but it uses an understanding of the shear imbalance

to modify runner junctions to rotate or "flip" the polymer flow by specific angles in order to achieve a desired result.

Coulter and Beaumont began collaborating a decade ago to try to achieve a better understanding of what happens inside injection molds. In their current NSF project, they are particularly interested in improving the filling of cavities with material of identical composition and properties.

Polymers are injected at temperatures of 300 to 500 degrees Fahrenheit, says Coulter. Molding machines apply as much as 200 tons of pressure to counter the force exerted by the material, which can reach tens of megapascals.

The Lehigh team has developed a technique to create molds with sturdy "windows" of polymethyl methacrylate (PMMA) that are optically transparent and can withstand real-world conditions. By placing high-speed video equipment and optically polarizing films inside the molds, researchers can observe temperature differences and molecular orientation in the molten polymer in real time. This enables them to judge the effectiveness of melt rotation techniques in specific applications.

"We have no more mysteries about what is happening inside a steel mold," Coulter says. "And if you can see what is happening, you can do something to fix it."

The Lehigh technique enables researchers to compare different melt rotation techniques. BTI has also introduced adjustable melt rotation devices that can be changed as needed.

The joint research project, says Coulter, "is exploring the effects of melt rotation on the properties of the polymer, and not just on the filling of cavities, for the first time."

Coulter believes the project will change long-held misconceptions in the industry.

"Historically the focus was on understanding what happened inside the cavities," Coulter says. The assumption that runners are straight pipes, and that intersections don't matter, he adds, is baked into the computer simulation software that is used in the field.




"If you use simulation codes based on that thinking, you can get beautiful color graphics showing the cavities all filling simultaneously. Then you build the mold and it doesn't work.

"Even today, there are those who question whether the runners really matter," Coulter says. His team is providing enhanced scientific analysis of the phenomena that occur in injection molding and evidence that the runners affect the properties of the finished products.

Both Lehigh and BTI have benefited from the collaboration, says Coulter.

"It really makes a difference for the students involved at all levels to connect with and, if possible, spend time in industry. Industry is often focused on making earnings and putting out fires, so connecting to the thorough but traditionally slower-moving university research environment is not always easy.

"This kind of partnership allows us to accomplish what often doesn't get accomplished." 

*Video equipment and optically polarizing films allow Coulter and Li to see temperature differences and molecular orientation in the molten polymer in real time.*



# THE FREEDOM TO ASK THEIR OWN QUESTIONS

AT MOUNTAINTOP, STUDENTS  
PURSUE THEIR IDEAS FOR  
CHANGING THE WORLD.

STORY BY **CHRIS QUIRK**  
PHOTOGRAPHY BY **CHRISTA NEU**

BUILDING C ON LEHIGH'S MOUNTAINTOP CAMPUS is a hulking edifice that wears with surprising grace a sleek skin of glass and gridded concrete.

The former Bethlehem Steel building has an airy, open interior that is rimmed with color-coded piping and conduits and other postmodern decorative motifs.

Lehigh was able to lay claim to and renovate Building C thanks to a \$20 million gift from Urban Outfitters founder Scott Belair '69.

During the summer of 2014, teams of students conducted open-ended venture research projects there based on their ambitions for changing the world. Implicit in this Mountaintop Initiative are questions about what a 21st century education should look like, what the world will need from university graduates, and how graduates will serve and find their place in the world.

The whiteboards in Building C's workspaces sport the jumbled and overlapping scrawls of many hands. Tables are cluttered with prototypes, debris and the detritus of hastily taken meals. The mood is freewheeling, with students milling over to nearby workstations to chat or work through problems with members of other groups. There is widespread evidence of caffeine consumption.

"This is a different idea of teaching," says William Best, professor of practice in mechanical engineering and mechanics and co-director of Lehigh's IDEAS (Integrated Degree in Engineering, Arts and Sciences) program. "The students are selected for the program based on merit but also on whether they can fully take advantage of this unique environment. It's completely unstructured; students create their own deliverables. They're not encumbered by classroom or curriculum. The faculty are here as advocates, but in a way we are kind of meaningless. I met with one group and couldn't get a word in edgewise."

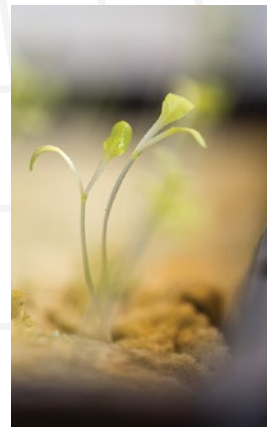
Richard Weisman, professor of civil and environmental engineering and, like Best, a faculty adviser, is working with several Mountaintop groups. "The students are great learners; they're independent learners. They have invented the projects, and they have a lot of freedom, even freedom to fail.

"When I have a course during the regular semester with a deliverable at the end, I want to make sure the students have the sense of accomplishing that goal. I may let them

go down a blind alley a bit, but then reel them back in. "At Mountaintop, we don't reel them in."

The program gives the concept of interdisciplinary study more than lip service, says Weisman.

"When we used to say 'interdisciplinary,' it meant a structural engineer and a foundation engineer working together. Here it's engineering with others from across the academic spectrum. Our social science and humanities students might question how they can contribute to an engineering problem, but they do."



### AQUAPONICS IN A DISTILLERY VAT

For example, Emily Poche '16, who majors in international relations and francophone studies, is working with Alex Derish '15 (finance), Kimberly Hetrick '15 (environmental engineering) and Jeff Schwartz '14 (civil engineering) on an aquaponics project, growing produce and raising tilapia inside an old 1,000-liter distillery vat filled with water.

On their white board, the students have jotted the words, "Give a man a box of food and he'll eat for a day. Teach a man aquaponics, and he'll eat for a lifetime."

Aquaponics—from aquaculture (raising fish in tanks) and hydroponics (cultivating plants in water)—was invented in the 1970s, says Schwartz.

"No one has taken it quite where it can go. You can get an acre of growth out of a shipping container, it's not dependent on weather and the produce we're getting is amazing."



*Mountaintop students are raising fish and produce in an aquaponics tank (above), tailoring a prosthetic hand for Cambodians (below) and designing a wind turbine (far right) to pump water from shallow wells in Africa.*

“This technology could revolutionize the way people feed themselves,” says Poche. “I could teach anyone to build and use this system, and that’s what I would like to be doing, humanitarian engineering. It’s really cool.”

Schwartz outlined how it works. “We have single-sex tilapia in a tank. Our only input is fish food. The fish excrete soluble and insoluble waste. We harness the soluble waste, essentially ammonia, and put it through a bacterial process to create nitrates, which nourish the produce. The plants have natural systems to purify the water, which is then re-circulated back into the system.”

The project’s faculty advisers are Weisman and Mark Orrs, professor of practice in political science and director of Lehigh’s sustainable development program.

Poche, who wondered at first what she had to offer the enterprise, is running the public relations effort and seeking support. Those less-versed in hard science, she says, contribute in other ways as well. She recounted draining one of the project’s draft beds.

“We had a problem with the pump. The tank is heavy and there’s 300 gallons of water running through it. Our engineers were trying to fashion a siphon, and then devise a lever system to tip the tank. Finally Alex, our finance major, looks and says, ‘Let’s just take a bucket and dip it in from the top.’ Sometimes you can get too sophisticated and over-look something simple.

“On the other hand, I’m writing the manual teaching people how to use and troubleshoot the system. Someone from a tech perspective can say: ‘Well this is good, but you totally missed what to do if there’s a fish kill.’”

## A PROSTHETIC FOR CAMBODIA

Other Mountaintop projects also require reaching across academic frontiers. The broader sociological, environmental and other concerns often aren’t obvious, and it takes inclination, research and creative thought to find them.

Zakaria Hsain ’17 (mechanical engineering), Danielle Taitt ’16 (science, technology and society/economics) and Arielle Weiner ’16 (bioengineering) are designing a prosthetic hand that is cost-efficient and can be used in developing countries. “It has to be affordable, but also preserve performance,” says Hsain. “To reduce maintenance, we’re making it body-powered with no electronics.”

The students are producing the prosthetics on a 3-D printer in their cubicle. Numerous prior efforts litter their work table.

“We’ve wired belts and attachments to the prosthetic,” says Weiner. “It’s controlled by shoulder movements to make it open or close. We’re focusing now on a power grip and pinching, so it requires two specific types of movement.”

Taitt focuses on the sociological research. “There is a need for prosthetics in Cambodia because of land mines. Some of the things we found out really influenced our design. We started out with a kind of bionic, three-finger hand. But we learned there is discrimination against the disabled there, so we went to a five-finger design with a glove to fit over it so the wearer can appear as able-bodied as possible.”



“Some things we couldn’t do,” says Hsain. “Many amputees work in agriculture, so the hand has to have high tolerances for lifting. We first put the thumb on the side, to make it realistic, but the most useful grips involve the thumb being vertically opposed to the fingers. It’s a more secure grip.”

“There are many more angles we had to look at as we got into the project, so there’s a lot of brainstorming. Something always comes up and you have to make a decision.”

Everyone has a different perspective,” says Taitt. “That puts a lot of options on the table from the start, and gives you recourse if the first attempt doesn’t work out.”

### COMBATING VITAMIN A DEFICIENCY

Vitamin A deficiency, which affects 250 million children in 88 countries, can cause blindness and other maladies. The World Health Organization estimates that as many as 500,000 children lose their sight each year due to the condition. Half of them die within a year of becoming blind.

Sebastian Boberg ’14 (finance) and Corrina Lucini ’14 (bioengineering) are taking on the problem with help from Akshaya Shankar, a Ph.D. candidate in chemical engineering.

“It’s pretty easy to fix,” says Boberg. “If you have a known population, you can introduce rice enriched with vitamin A. But resources are limited so you have to figure out where to put them.”

There is no cheap, noninvasive, effective test for the deficiency, says Boberg. “There are tests that are too expensive for broad use, or cheap tests that require feedback from the person you’re testing, which won’t work for infants and very young children.”

“Our idea is for a handheld sensor and disposable, inexpensive chips,” says Lucini. “It would use carbon nanotubes and field-effect transistors to reflect a signal.”

The students envision taking a small blood sample with a tiny lancet, placing the blood on a chip and feeding it to the sensor. The sensor would measure the conductivity in the sample, which correlates to the level of vitamin A.

“The protein that carries vitamin A in the bloodstream is conductive,” Lucini says. “Carbon nanotubes are perfect because they’re so small. Each tube is a ring one atom thick. Any change to any atoms on the tubes will make a big difference, so it’s very sensitive.”

Lucini reflects on her summer at Mountaintop. “I love having the application to look forward to. The kind of education we’re getting here is making us well-rounded and preparing us to deal with things we haven’t faced before. I think the world is moving towards people who have that kind of versatility and agility.”

### SAFE ACCESS TO WATER

Manraj Matharu ’15 (bioengineering) and Greg Jacobs ’15 (electrical engineering) are designing a wind turbine that can be built in Africa with local materials and can pump water from shallow wells. They are also producing an instruction manual using only illustrations that can be easily understood.

“We’re focusing now on Kenya and East Africa,” says Matharu. “They’re near Lake Victoria, there’s high wind and temperatures are low at night. In addition, there are few obstructions, and we have connections in Kenya who will help us get started.

“There are two kinds of wells in that area. The first are the wells that people dig themselves. That means sending someone down a hole and hauling out sand and rock to the 50-foot depth where the water is. It’s dangerous. On average, there are two fatalities for every well dug this way, not including children who may fall in after it’s built.

“The other kind of well is built by aid organizations. They go down 1,500 feet and give you perfect access to water but they are cemented in place so you can’t access the system for repair if a part breaks.

“We want to analyze the wells constructed by aid organizations to see if there’s a pattern to the failures, and if there’s a fix we can come up with. We’ve seen pictures of playing kids hanging off the handles of these wells. Maybe part of the answer is something simple, like an effective community education project.”

This project, says Best, exemplifies the multifaceted role of the 21st-century engineer.

“So much of engineering today has to do not only with the ethical and social impact of technology,” he says, “but also with learning how to ask the right questions, and having the freedom to find the significant questions.”

“All of this work we are doing is totally applicable,” says Matharu, “and we’re doing it because we want to do it. That makes all the difference.”



Scan the QR code to watch a video about a student team turning garbage into gold—and making Lehigh more sustainable.



STORY BY RICHARD LALIBERTE

# OVERLAPPING OPPORTUNITIES

## SYNERGY IS HELPING NANO-THEMED RESEARCH CENTERS INNOVATE.

WHERE DO GREAT INVENTIONS ORIGINATE? From basic science that reveals new possibilities for applications? Or from an idea for a new technology that spurs the basic discoveries that need to be made?

One possibility: The best answer isn't *either/or* but *both/and*. The most fruitful outcome incorporates both elements. Yet at many research institutions, the ingredients of innovation are separated: People in one area concentrate on fundamental science without thinking about how it might be used. People in another area imagine breakthrough applications before answering all the "how" questions.

Lehigh, however, has a long tradition of encouraging researchers to cooperate, says Richard Vinci, professor of materials science and engineering.

"We have many separate disciplines," says Vinci, who directs the Center for Advanced Materials and Nanotechnology (CAMN), "but a surprising number of people, topics and research areas overlap."

One major example of that cooperation is the collaboration between two research centers that both do much of their work at the nanoscale—CAMN and the Center for Photonics and Nanoelectronics (CPN).

If CAMN provides many of the fundamental discoveries that are developed into devices and other new technologies, CPN projects often begin with desired outcomes and work back toward the basic

science necessary to bring a vision to life.

"CAMN tends to concentrate on fundamental materials opportunities," Vinci says, "creating new materials and processes with new functionalities that can be plugged into new systems."

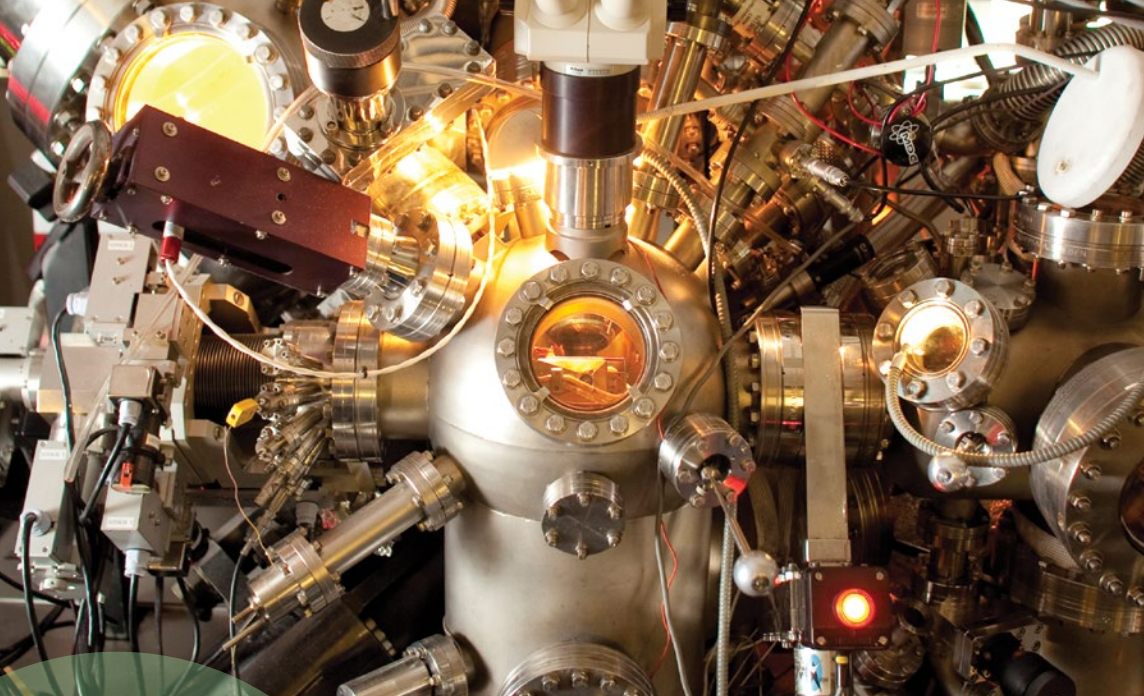
CPN merges two previous centers, the Center for Optical Technologies, which was devoted to photonics research, and the Sherman Fairchild Center for Solid State Studies, which concentrated on research in electronics and solid state devices.

"The goal of CPN," says director Nelson Tansu, the Daniel E. ('39) and Patricia M. Smith Endowed Chair Professor in Photonics and Nanoelectronics, "is to transform the science of photonics and nanoelectronics in ways that help us develop material devices and device architecture to meet the grand challenges in society.

"By combining a strong foundation in computational, materials, devices and integrated systems with core expertise in photonics and nanoelectronics, we hope to enable CPN faculty and students to work on advancing the frontiers of science and technology with ambitious and long-term visions."



*Collaboration, says Vinci (left), can help researchers identify and disregard false barriers.*



Lehigh's electron microscopy and surface analysis facilities, including the high-sensitivity, low-energy ion-scattering spectrometer (above), give researchers an unprecedented view of atoms and surfaces.



**“Being able to see things down to the nanometer or atomic scale allows you to understand materials at a level that’s really unprecedented. We have some of the best tools in the world at Lehigh for accomplishing that.”**

—Rick Vinci

## RESOURCES FOR INNOVATION

Meeting the challenges of technological innovation now more than ever requires a meeting of minds from different fields. “The really interesting problems that can make a big impact tend to be beyond the ability of any one discipline to completely sort out,” Vinci says. “They require input from people with many different backgrounds.”

Collaboration broadens the pool of available expertise and introduces fresh thinking. “People who are not yet experts tend to ignore what seem to be obvious barriers to people who are experts,”

Vinci says. “It turns out that a lot of those barriers aren’t real. If you don’t know they exist, you can accomplish things that surprise everybody.”

Cross-fertilization between CAMN and CPN has already taken place. “Even at the director level, Nelson and Rick have worked before on joint grants, so they know how that works and how everybody can benefit,” says Volkmar Dierolf, department chair and professor of physics. “There’s already quite a bit of overlap between CAMN and CPN, and a boost in the energy and resources invested in these centers will allow us to exploit their strengths even more.”

Both centers seek to leverage success in targeted areas where Lehigh has developed an international reputation—including characterizing properties at the nanoscale with electron microscopy, and analyzing and manipulating surfaces and interfaces.

“Being able to see things down to the nanometer or atomic scale allows you to understand materials at a level that’s really unprecedented,” Vinci says. “We have some of the best tools in the world at Lehigh for accomplishing that.”

Facilities available to the two centers include CPN’s Smith Family Laboratory for Optical Technologies, with material epitaxy and nanofabrication capabilities, a suite of electron microscopes in CAMN’s Nanocharacterization Laboratory, and Lehigh’s surface analysis facilities.

Among the powerful tools that these facilities house are spectroscopy instruments such as the high resolution x-ray photoelectron spectrometer (HR-XPS) and high-sensitivity, low-energy ion-scattering spectrometer (HS-LEIS), which provide extremely precise, high-resolution views of surfaces and subsurfaces that govern a material’s properties. World-class electron microscopes such as the JEM-ARM200F allow researchers to observe the chemical structure of a material at the atomic level, with specimens often prepared using a recently acquired FEI Scios DualBeam focused ion beam/scanning electron microscope. An array of instruments also allows researchers to optimize the growth of semiconductor materials on a variety of substrates.

With the help of such resources, “technology is evolving rapidly at what’s called the cyber-physical interface,” Tansu says. “In the past, the computing and physical worlds have largely been separate domains. We want to be able to transform the physical world and relate it to the cyberworld.”

To do that, says Tansu, CPN is also forming collaborations with researchers from Lehigh’s Environmental Initiative, Emulsion Polymers Institute and Integrated Networks for Electricity research cluster, and from academic departments in the sciences and engineering.

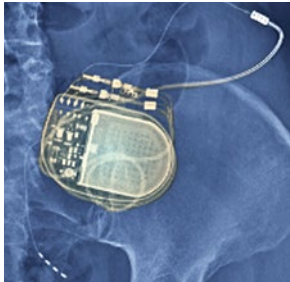


## TWO MAJOR THRUSTS

CPN's goal is to channel Lehigh's intellectual and physical resources in materials science, photonics and nanoelectronics into two key areas. The first is energy, sustainability and the environment, and the second is health, bioengineering and medicine.

In both areas, more advanced understanding of how photons, electrons and heat interact could lead to a wide variety of applications. These include making semiconductor-based lighting more efficient, enhancing energy storage in batteries, generating and storing solar energy, reducing industrial emissions, creating new materials that can be implanted in living tissue and even linking the mind to the body.

"Think of chronic pain relief," Tansu says. It's often treated with chemicals such as acetaminophen, ibuprofen or opioids, which can cause side effects, become addictive or lose effectiveness. "But if you understand electronics, photonics and biomaterials,



you may be able to implant a very tiny integrated circuit in the body that releases heat directly to the point of pain when you need it and in the right amount."

Implantable devices have already been used in microelectromechanical systems to replace joints and release glucose into the blood. Brain implants, or microchips on the surface of the skull that could detect, measure and control brain signals, represent a new frontier. "A chip implanted in the brain could control a lot of functionality," Tansu says. "Integrating photonics and nanoelectronics, along with understanding biocompatible materials, requires researchers from CPN, CAMN and bioengineering."

Similarly, developing the cyber-physical interface could not only make lights, solar panels and insulation more energy-efficient, but also lead to smart-room technology in which your mere presence in a space triggers changes in its environment. Today, lights go on when you enter a room. "In the future, a room will recognize your

## A SAFER METHOD OF DECONTAMINATING CERAMICS

*Researchers remove impurities without resorting to dopants.*



On Martin Harmer's office table sits a crystalline cube that looks like a glass coaster but is actually a piece of magnesium aluminate spinel, whose qualities make it eligible for a range of uses, from a superior optical material for lasers to a window material half the weight of bullet-proof glass that can withstand projectiles.

"It takes a great deal of effort to make it this clear and sharp," says Harmer, who has spent three decades tailoring the properties of ceramics and metals at the atomic level. "We have to heat-treat it for a long time to get rid of the impurities. As a result, the material weakens."

Harmer's latest work involves an innovative way to decontaminate ceramic material and strengthen its fundamental nanostructure. Improving the processing techniques is crucial, because ceramics are the building blocks of many products, including the powder-based polymers used in selective laser sintering (SLS), a rapid 3D printing method.

Ceramics are made by applying heat and pressure to pack together separate grains. Understanding the properties of the boundaries between the bonded crystals, which are only a few atoms wide, is the key to engineering the desired materials.

"Like bricks on a house, where the polycrystalline grains meet represents an important region that can determine the properties of the material as a whole," says Harmer, professor of materials science and engineering. Characterizing these grain boundaries can help overcome abnormal grain growth and other problems. Lehigh's uniquely powerful electron microscopes are indispensable to observing the behavior of ceramics particles at the nanoscale, Harmer says.

"There are still a lot of mysterious things going on at the nanoscale, at the grain boundaries, that we don't fully understand. An example is anti-thermal behavior. That's when the atoms move faster at cooler temperatures and slow

down at higher temperatures."

Like other physical materials, grain boundaries have their own phases and properties, for which Harmer has coined the collective term "grain complexion," and which can be fine-tuned.

Changes in the complexion can lead to abnormal grain growth and embrittlement, so the ceramics industry is striving to produce high quality ceramic powders with a uniform grain size and without contaminants.

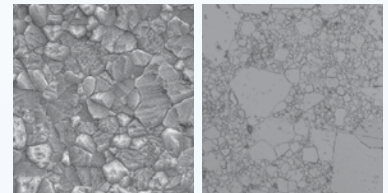
The usual way to remove impurities in ceramics involves adding a dopant, or additional

compound. However, the typical dopant used in industrial processes, lithium fluoride, weakens the overall material and degrades its optical properties over time. And removing impurities is a sensitive process. "A difference of a few tens of parts per million of common elements can have a profound impact on the properties of the material," Harmer says.

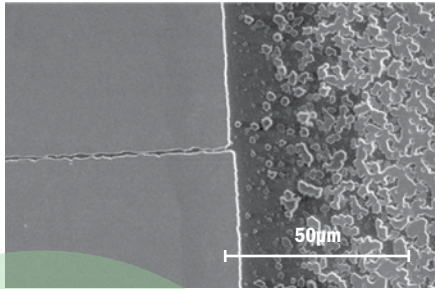
Working with Lehigh research scientist Animesh Kundu, Harmer has invented a pre-treatment process that strengthens ceramic powders and removes impurities without adding dopants. The method exposes the powder to an ultra-high vacuum and low temperature, effectively detaching and evaporating any solid impurities to a gaseous state. This part of the process has a simple beauty, similar to the way dry ice changes phase directly to vapor, Harmer says.

The innovation has the potential to improve the ceramic materials that are used in the aerospace and defense industries, and it represents the only successful effort to date to purify ceramic powders without altering their physical characteristics.

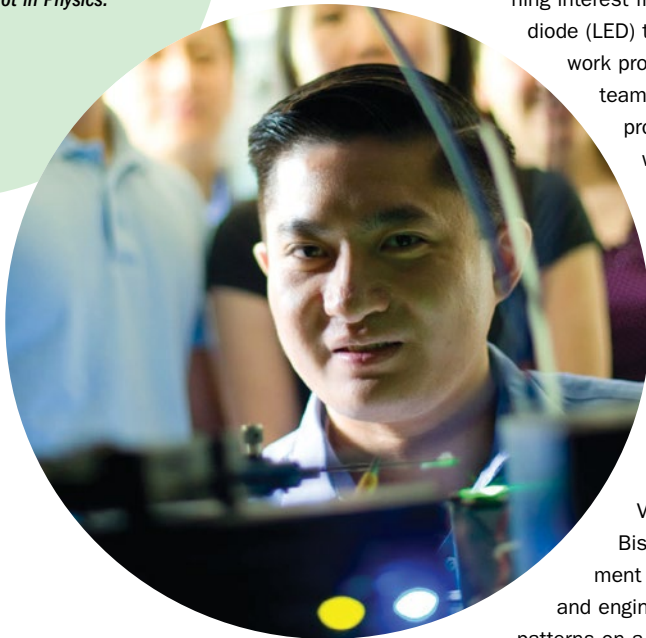
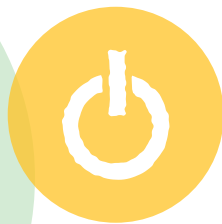
The two scientists won a National Innovation Award for their project, titled "A Novel Decontamination Process for Powders for Transparent Ceramics," at the 2014 TechConnect World Conference and Expo in Washington, D.C.



*Ceramic powders made using Kundu and Harmer's pre-treatment process (left) show greater consistency in grain sizes than powders fabricated conventionally.*



*Tansu (below) Dierolf and their students reported improvements for green wavelength emissions in nitride-based LEDs in a paper that ScienceWatch ranked fifth in a recent list of "What's Hot in Physics."*



**"With careful investment and coherent integration of the core expertise in the activities of our centers," says Tansu, "we believe our innovations can impact society for the next 15 to 20 years."**

—Nelson Tansu

preferences," Tansu says. "It will know that at 7 a.m. you want a bright white light to help you start to be productive, and that by 3 p.m. you want a warmer tone." If your spouse walks in, the room would know what to do when the two of you are present at the same time. Going a step further, if you look at curtains and imagine them closing, the curtains will close on their own.

Aside from incremental improvements in windows, structural materials and lighting, housing today is much the same as it was 50 years ago, Tansu says. "As we look to the future of sustainable living, we have to ask, 'Can we design smarter, more energy-efficient living spaces that are based on viable modern technologies and not on past technologies?'"

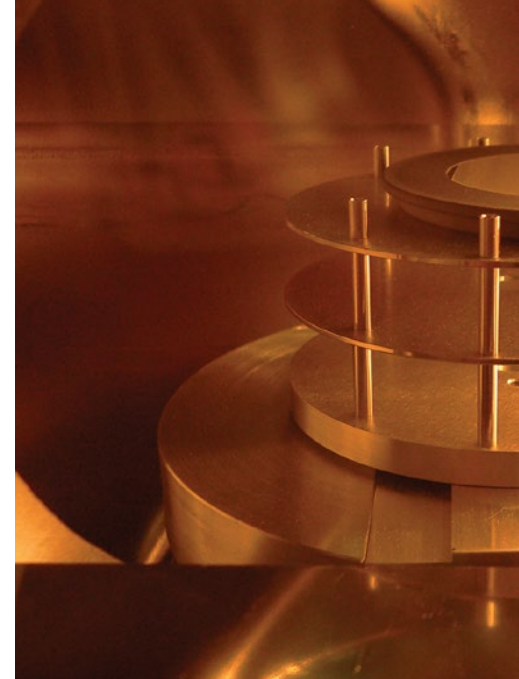
### **GREATER EFFICIENCY IN LEDS...**

One area of sustainable living in which Lehigh already has contributed significant innovations—generating patents and winning interest from industry—is light-emitting diode (LED) technology. "Lehigh's LED work provides good examples of how teams working in collaboration can produce achievements that they wouldn't have the expertise to accomplish alone," Vinci says.

In one project, researchers simplified the growing of high-quality gallium nitride (GaN) on sapphire surfaces—a key to how much light an LED can generate.

A CAMN team including Vinci, Ph.D. student Jeffrey Biser and Helen Chan, department chair of materials science and engineering, created nanoscale patterns on a sapphire substrate to give its surface a variety of tiny topographical features. Tansu and Yik-Khoon Ee '09 Ph.D. investigated the effect of the features on the growth of GaN. Together, the teams developed a growth method that took less time, cost less money, boosted quality, enhanced efficiency and resulted in a patent.

In a similar project, Tansu, Dierolf, Hongping Zhao '10 Ph.D., Guangyu Liu '14 Ph.D., Jing Zhang '14 Ph.D. and Jonathan



D. Poplawsky '10 Ph.D. described approaches for optimizing the internal quantum efficiency for green light produced with indium gallium nitride.

"Currently, the green LEDs you find in stores are really blue LEDs that convert light to the rest of the visible spectrum," says Dierolf. "It would be better to have the semiconductor itself emit green light. Our paper was significant because it showed a smart way to improve the efficiency of that color in the future of LED lighting." Published in 2011 in *Optics Express*, the group's paper ranked fifth in a ScienceWatch top 10 list of "What's Hot in Physics" in January 2014.

Dierolf also has an NSF grant to try to reduce the size of lithium niobate and other crystalline materials that are used in the optical applications and modulators that drive the Internet. "It's an advantage to confine light in smaller dimensions," he says, "so devices and applications can use less space and material."

Meanwhile, Dierolf and Prof. Himanshu Jain (materials science and engineering), have NSF funding to create a new class of material called ferroelectric crystal-in-glass architecture (FCGA).

"Making glass and doing it in bulk is fairly easy compared to making crystal, which is more delicate," Dierolf says. "But crystals have better performance and specific functionalities." Highly controlled short pulses from a femtosecond laser can reconfigure atomic structures to form crystals inside of glass. The process promises to combine the exceptional properties of crystal with the relative flexibility and low cost of glass—vital for



the next generation of health and environmental monitoring devices, optical communications networks and consumer electronics.

### ... AND ENERGY AND SEPARATIONS

Greater efficiency usually results in energy savings. Israel E. Wachs, the G. Whitney Snyder Professor of Chemical and Biomolecular Engineering, is developing new ways to convert natural gas efficiently into a liquid form that can be transported. This has major ramifications for an industry in which gas extracted at remote sites is often vented or flared, leading to environmental degradation and waste of resources. In another project, Wachs is looking to better understand the catalytic process by which biomass is converted to a renewable fuel.

Reducing emissions contributes to sustainable living as well. Research by Prof. Kai Landskron (chemistry) shows that mesoporous material punctuated with nanoscale pores can electrically separate gases such as nitrogen and carbon dioxide. As he and colleagues write in *Nature Communications*, this may offer a low-cost method of reducing greenhouse gases from power plants.

“We want to understand the parameters that influence the size of the effect, its kinetics and whether the effect extends to other gases,” Landskron says.

Making materials porous usually makes them weaker, but mesoporous diamonds retain much of their inherent strength even under high pressure. That has implications for filtration membranes, nanooptics and drug delivery. “Diamonds are known to be biocompatible,” Landskron says. “It may be possible

to load a drug into mesoporous diamond and release it in the body with less toxicity than with nanoporous silica.”

Broad applications could come from other NSF-funded efforts to better understand how material, biological and computational components interface with each other.

Research led by Profs. Filbert Bartoli (electrical and computer engineering) and Xuanhong Cheng (materials science and engineering) promises to push the frontiers of optical sensing, nanoplasmonics, biointerface design, nanofabrication, microfluidics, cell-based tissue and lab-on-a-chip technology. They’re working to develop real-time sensing capabilities that would help differentiate and control the development of precursor cells that could be used in tissue transplantation—a major challenge in biomedicine.

Prof. Slava Rotkin (physics) is exploring a new class of rare-earth-based biocompatible materials in which tiny nanoscale tubes wrapped in DNA may be able to acquire optical sensing capabilities through better understanding of near-field electromagnetic physics between nanotubes, rare earth material and bio-molecules.

On the computational front, Prof. Heather Jaeger (chemistry) applies quantum mechanics equations to computer models that illuminate the sometimes-unexpected behavior of phenomena at

the nanoscale. “Part of our job is helping to explain or provide a rationale for what happens in the lab by actually computing the properties that people are observing,” Jaeger says.

Computation can also pave the way for discovery. By developing simulations of electron density in real time, Jaeger explores how negatively charged electrons and positively charged electron holes separate at the nanoscale when light or energy is applied. “Solar cell efficiency is based partly on charge separation, so we’re trying to do that better and better,” Jaeger says. “To control electron and electron hole densities, you need to understand what the driving forces are, and that’s where our simulations come in.”

Throughout CAMN and CPN, there’s a push to integrate simulations and modeling into design and engineering in a movement called Integrated Computational Materials Engineering (ICME). “Materials researchers focus primarily on how to make things—the chemistry, physics, characterizing and manufacturing,” says Prof. Natasha Vermaak (mechanical engineering and mechanics). “In the past, those have largely proceeded independently of each other.”

Vermaak applies advanced optimization algorithms to materials research, manufacturing and component design to coordinate computations before fabrication begins. The goal is to realize greater efficiency by optimizing material properties, fabrication processes, decision-making and, ultimately, the performance of new technologies.

This, in a nutshell, is the overarching aim of the two research centers.

“Our hope,” says Vinci, “is to achieve even greater synergy by continuing to coordinate our activities and work together.”

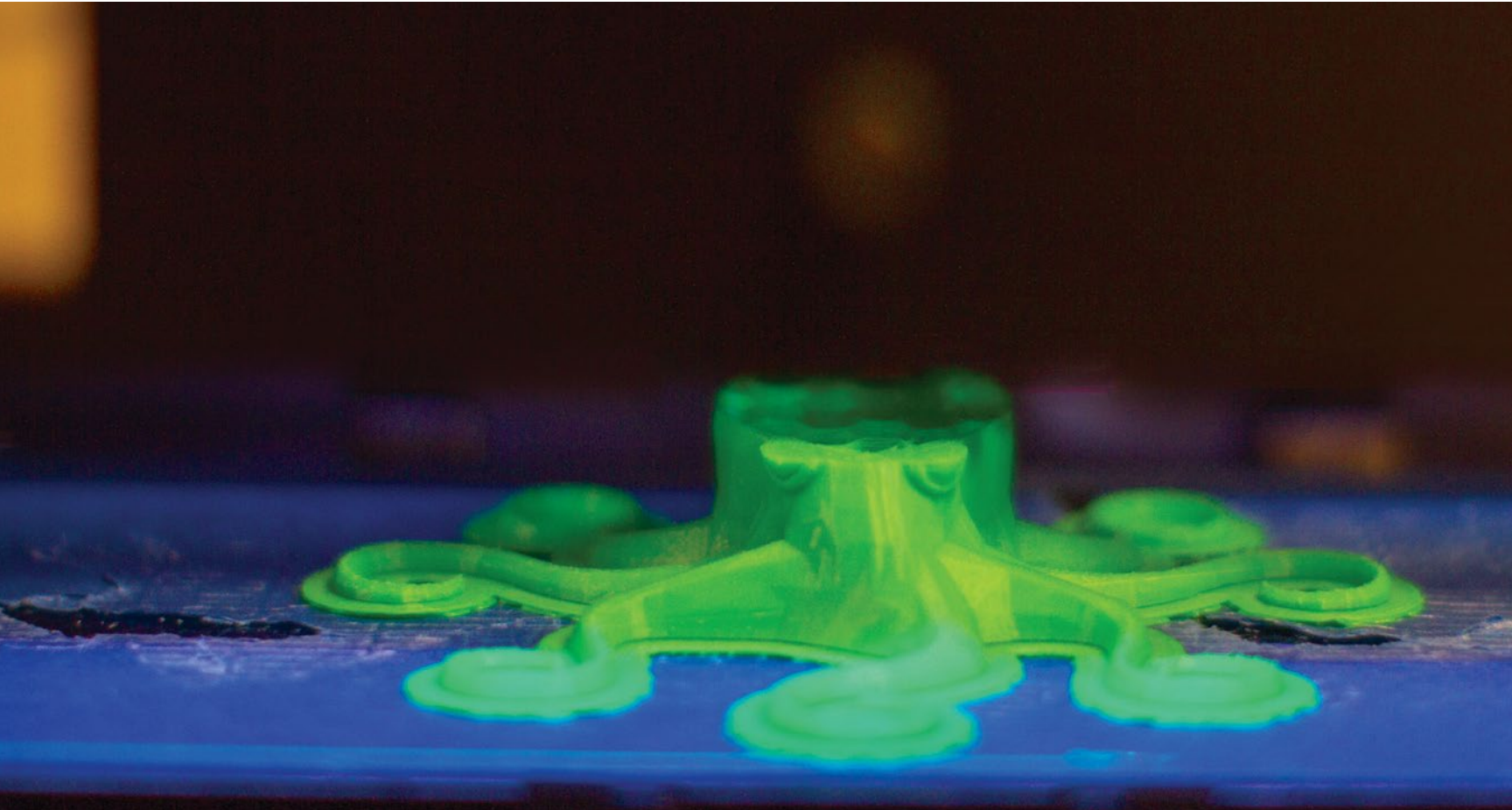
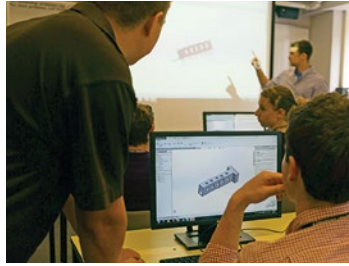
“With careful investment and coherent integration of the core expertise in the activities of our centers,” says Tansu, “we believe our innovations can impact society for the next 15 to 20 years.”



Scan the QR code to watch a video about new directions for CAMN and CPN.

## FEATURE

*Students at the first Pennsylvania Governor's School for Science, Engineering and Technology tried their hand at CAD, 3D printing and stress tests.*



# A MISSION TO THE ART OF ENGINEERING

**AT A STEM PREP SUMMER SCHOOL, THEORY TURNS INTO REALITY.**

YOU'RE ON A MULTIYEAR MISSION TO MARS, operating a robotic explorer and collecting rock samples, when a key component breaks. You don't have a full machine shop, and you are years from a spare part delivery. How can you get the explorer back in service?

That's the kind of challenge that faced 50 rising high school seniors at the Pennsylvania Governor's School for Science, Engineering and Technology, a selective two-week program held at Lehigh during the summer of 2014.

Armed with insights into computer-aided design, 3D printing and mechanical testing, students split into teams to tackle the problem. At Fritz Lab they used software to predict the strength of designs under load. At Wilbur Powerhouse they watched 3D printers work and learned how additive manufacturing could produce working parts for the explorer.

"It's like science fiction," said Amelia Trello of Mt. Lebanon. "It's a technology that can change the world as we know it."

Theory became reality in Prof. Richard Vinci's Mechanical Behavior Lab, where, on Instron testers, the students applied stress to parts of varying composition and design. Gathered around the instruments, the students dialed in stress levels to determine tensile strength and rigidity. Each audible snap drew a cheer when a group learned its part's failure point.

If the Mars mission was fiction, the students' exposure to the range of problems solved by engineers was real.

The Governor's School is an effort by the state to encourage top students to consider careers in STEM fields—Science, Technology, Engineering and Mathematics.

The goal of the school was threefold, said academic director William Best, who directs Lehigh's IDEAS (Integrated Degree in Engineering, Arts and Sciences) program.

"Our vision," said Best, "is for students to learn that engineering is a unique way of thinking, that it is an art form, and that everything engineers do has profound social implications. Engineers can never forget their ethical obligations to the society they serve."

"Young people are inundated with technology," said Laura Moyer '99, '05 Ph.D., lab manager for the materials science and engineering department, who helped plan the school. "It is so important for them to learn how things work."

The state invited Lehigh to host the school, and the engineering college and Iacocca Institute created the program. Some 180 students from around the state applied.

Drawing on faculty and on industry connections at NASA and AT&T, the program covered bioengineering, nanotechnology, energy, additive manufacturing, robotics, cybersecurity and other "big-picture themes," said Moyer.

Trello, who is not sure whether to pursue science or liberal arts, said the program may help her decide. "The engineering part is amazing!"

Evan Mehok, who is near the top of a 95-member high school class in rural Guys Mills, found it energizing to work with "other nerds. It's been a life-changing experience," he said. "You learn that you have to keep asking the 'Why?' questions."

The students attended presentations by professors, did hands-on work and teamed up to work on projects that they described at poster presentations at the end of the second week.

"It feels intense," said Kevin Monpara of Upper St. Clair. "The days are long—breakfast to 11 p.m.—and they blur together."

"They've done a really nice job showing us all aspects of engineering," said Taylor Pawlik of Huntingdon Mills. "The cool part is seeing all the things you can do as an engineer."

***"Our vision is for students to learn that engineering is a unique way of thinking, that it is an art form, and that everything engineers do has profound social implications."***

—William Best, Director of Lehigh's IDEAS program

Pawlik's team, mentored by Austin Keller '16, sought to apply nanomedicine to help close the health gap between rich and poor nations.

The topic, said Keller, a materials science and engineering major, aligns with Lehigh's philosophy of developing "citizen-engineers" aware of the social, environmental and economic impacts of their work.

The in-depth, hands-on lessons at the Governor's School are missing from many high schools, rich and poor, said Bill Bertrand, technical education adviser for Pennsylvania's Department of Education (PDE), which sponsored the

school. "That's where I see the biggest plus. This school gives students an understanding of just what it takes to go through a college engineering program."

Pawlik's eyes were opened during a visit with Lehigh student researchers. She came to the Governor's School with plans to go to medical school, but may change directions after bioengineering majors demonstrated a prosthetic hand. "They really opened up a whole new idea of what I can do," she said.

Trello learned engineering was broader than she expected. "As an engineer you can combine your skills to do so many things, like cleaning up the environment."



The need to collaborate also broadened students' horizons. "Here, in one room, you have kids who are all top-tier in their high schools," Trello said. "It's a whole new level of social interaction. We have to figure out our strengths and use them for the good of the group."

PDE funded the school so students could attend free. AT&T provided \$25,000. In July, Pennsylvania Gov. Tom Corbett announced that the school would be held for four weeks at Lehigh in 2015, funded by \$150,000 from the TEAM PA Foundation, a public-private partnership. ①



*Kumar and colleagues were the first to exploit thermal vibrations in the semiconductor lattice as a means of injecting electrons for THz laser operation.*

## A superlattice to generate the elusive terahertz wave

From radio waves, which are used for wireless communications and found at low frequencies, to gamma ray detection of cosmic rays at the highest frequencies, we take advantage of nearly the entire electromagnetic spectrum today.

Yet one region of the spectrum, sandwiched between microwave and infrared frequencies, is hardly utilized. Known as terahertz (THz) radiation, the portion of the EM spectrum between  $10^{12}$  and  $10^{13}$  Hz promises advances in areas as diverse as atmospheric science, astronomy, cancer research, drug detection, DNA sensing, cell biology and nondestructive testing of pharmaceuticals.

The reason for the “terahertz gap,” says Sushil Kumar, is that scientists have not developed reliable and convenient sources of generating high-power and coherent THz radiation.

Kumar, assistant professor of electrical and computer engineering, hopes to close this gap by developing a semiconductor laser that can generate THz waves at room temperature.

Semiconductor lasers for mid-infrared frequencies, known as quantum-cascade lasers (QCL), were developed two decades ago, work at room temperature and are used commercially. THz QCLs work with similar operating principles. But they need to be cryogenically cooled to function, and this rules out portability, low cost and easy use in labs and offices.

A miniature laser source for THz radiation that runs at or near room temperature and is low cost and high power, says Kumar, would lead to rapid commercialization of THz technology.

“My goal is to be able to do with THz what we can do with mid-infrared radiation now,” says Kumar, who recently received an NSF CAREER Award.

In Kumar’s lab, several elegant but heavy instruments sit by tanks of liquid nitrogen, which are necessary for the cooling process to operate the QCLs. Recently, smaller cooling devices known as Stirling cryocoolers, he says, have

enabled his group to achieve QCL functionality at temperatures above 150 K (about minus 123 degrees Celsius) for a range of lasers emitting at different THz frequencies.

To make progress toward operating THz lasers at room temperature, Kumar has turned to nanoscale technology. Working with researchers at Sandia National Laboratories, he is developing laser designs that involve assembly of a semiconductor superlattice of more than 1,500 alternating semiconductor layers of precise thickness and arrangement. When an electric current is applied, electrons travel within the sandwich-like structure, generating coherent light. Kumar and his colleagues were the first to exploit thermal vibrations in the semiconductor lattice as means of injecting electrons for laser operation in THz QCLs, changing the way electrons cascade in the superlattice and achieving robust optical gain even at relatively high temperatures.

Recently, Kumar’s group has significantly improved its laser’s beam quality by making the device emit radiation similar to the way a microwave antenna does.

A THz laser emission scatters and loses intensity quickly over a short distance, because its wavelength is larger than the dimensions of the laser

device itself. Kumar’s group has overcome this problem by altering the design of the periodic pattern of “distributed feedback grating” at the top of the laser cavity. The result is a much narrower beam spot than what was possible earlier, he says.

“We have early indications that our idea may be able to produce THz QCLs with some of the best beam profiles of any THz QCLs reported,” he says.

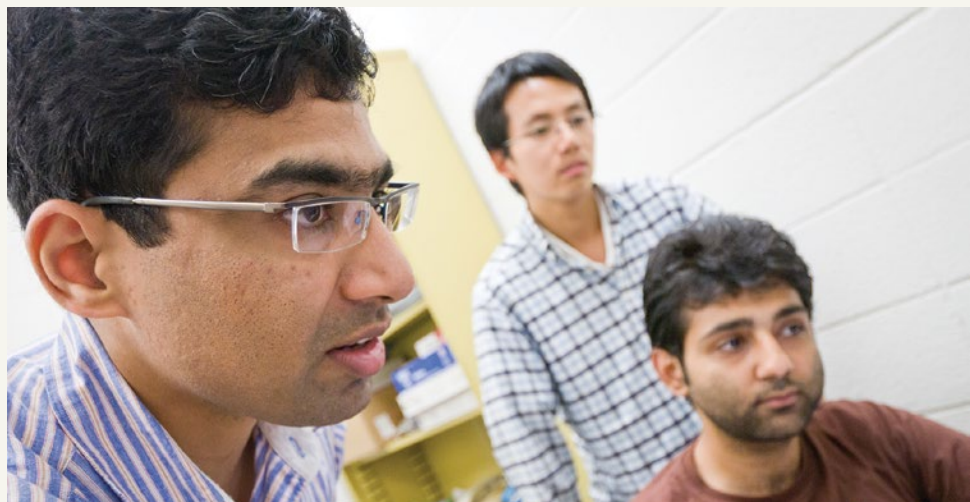
Kumar stumbled into his field by chance. Prior to doing his Ph.D. at MIT, his training had included neither photonics nor quantum mechanics. But he was invited to work with a professor whose group was the only one in the U.S. conducting research into THz QCLs. Peering into the THz gap, he says, was like catching a glimpse of a lesser-explored region of space.

Kumar envisions handheld THz devices that can sniff out hidden explosives or chemical weapons from a safe distance, or larger devices that can collect new information from space to help us understand the formation of planets, stars and galaxies.

He is among a relatively small community of scientists working with THz waves.

“It’s a very active research area,” he says, “with many questions still to be answered.”

*“My goal is to be able to do with terahertz what we can now do with mid-infrared radiation.” —Sushil Kumar*



# Lehigh NSF CAREER Awards 2009-2014

The NSF describes its CAREER Awards as the "most prestigious ... in support of junior faculty who exemplify the role of teacher-scholars."

Kudos to Lehigh Engineering's winners:



## Civil and Environmental Engineering

**Shamim Pakzad** (2014 · pictured above, gesturing)

Toward a Mobile Sensing Platform for Bridge Condition Monitoring



## Electrical and Computer Engineering

**Zhiyuan Yan** (2011)

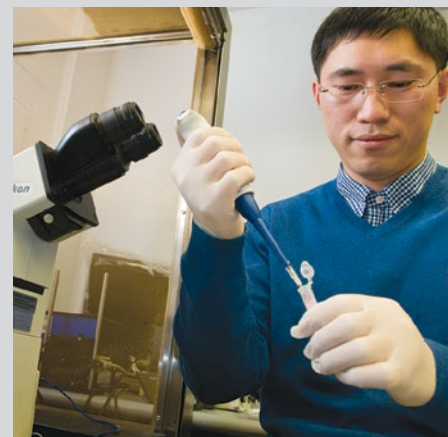
An Integrated Framework of Algebraic Universal Error Control for Network Coding: Algorithms, Complexities, and Hardware Implementations

**Parv Venkatasubramaniam** (2012 · pictured left)

Anonymous Networking with Guaranteed Quality of Service: Towards a Theoretical Foundation

**Sushil Kumar** (2014)

Development of High-performance Terahertz Intersubband Lasers



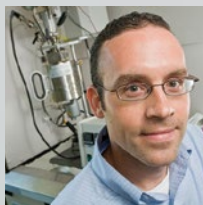
## Chemical and Biomolecular Engineering

**Mark Snyder** (2014 · pictured right)

Hierarchically Structured, Ultrathin Inorganic Membranes

**Steven McIntosh** (2010)

A Novel Approach to Catalysis for Next Generation Direct-hydrocarbon Solid Oxide Fuel Cells



## Mechanical Engineering and Mechanics

**Yaling Liu** (2013)

Predicting Nanoparticle Targeted Delivery Efficacy in Vascular Environment through Multiscale Modeling

## Computer Science and Engineering

**John Spletzer** (2009)

Towards Autonomous Wheelchair Systems in Urban Environments

**Gang Tan** (2012 · pictured left)

User-space Protection Domains for Compositional Information Security

**Michael Spear** (2013)

A Transactional Software Ecosystem



To learn more about the achievements of Lehigh engineers, visit

[lehigh.edu/engineering](http://lehigh.edu/engineering)

LEHIGH UNIVERSITY

P.C. Rossin College of  
Engineering and Applied Science  
19 Memorial Drive West  
Bethlehem, PA 18015

Non-Profit Org.  
US Postage  
PAID  
Permit 498  
Burlington, VT  
05401

## TRACKING THE ELUSIVE ELECTRON

Acclaimed physicist Paul Corkum '72 Ph.D. demonstrated the first laser pulses lasting less than a femtosecond and now uses attosecond light pulses to photograph electrons orbiting molecules and “look at electrons on their natural time scale.”

See page 12

