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A FOCUS ON LEHIGH ENGINEERING • VOLUME 1, 2009

REVEALING THE INFINITESIMAL

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LEHIGH UNIVERSITY®

P.C. ROSSIN COLLEGE OF ENGINEERING AND APPLIED SCIENCE

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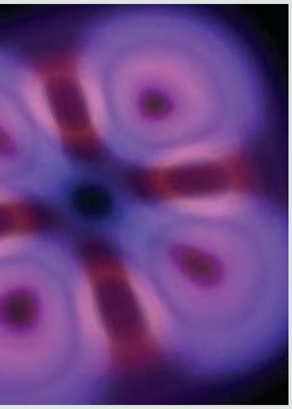

ON THE COVER

Besides quantum dots and dashes, Lehigh researchers study nanotechnology's potential for medicine, environmental remediation and a host of other applications.

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A FOCUS ON LEHIGH ENGINEERING

VOLUME 1, 2009

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LEHIGH UNIVERSITY®
CHALLENGING GREAT MINDS…INSPIRING GREAT IMAGINATIONS

Building on deep traditions

Welcome to **Resolve*****, a magazine devoted to research and educational innovation in the P.C. Rossin College of Engineering and Applied Science at Lehigh.***

Lehigh recently completed a comprehensive strategic plan that identified three areas of emphasis: the expanding needs of health care in the U.S. and abroad; the interrelated issues of energy, the environment and modern infrastructure; and the impact of globalization. Many institutions have embraced these grand challenges, so it is fitting to ask what is different about Lehigh's positioning.

Lehigh's multidisciplinary culture dates to 1865, when the university was founded with the intent of combining the scientific and classical aspects of knowledge. Lehigh also has a long tradition of bridging theory and practice. Our engineers have enriched this heritage through leadership in industry and in entrepreneurial enterprises. These traditions allow Lehigh to approach the grand challenges from a special vantage point.

For example, our emerging biotechnology initiative addresses the technology framework that is essential for researchers to develop better diagnostic and therapeutic technologies. The initiative leverages Lehigh's distinctive capabilities in systems engineering, photonics, bioelectronics and materials science and its partnerships with world-class medical facilities. Its goal is to promote research competence in the domain of affordable medicine.

Lehigh is also well-positioned to meet the challenges of energy and the environment, particularly as they relate to national infrastructure. Our researchers are seeking more efficient, clean, sustainable energy sources while addressing the problems of energy supply, delivery, consumption and environmental impact. Our successful economic development partnerships with government, industry and start-up companies are vital in making a sustained impact in this area.

The success of any research endeavor depends on the quality of the tools that researchers have at their disposal. We are aggressively enhancing our capabilities and infrastructure in high-performance computing and nanotechnology, which play a critical role in all aspects of science and engineering research.

The three emphases of Lehigh's strategic vision – health care, energy and the environment, and globalization – will draw significantly from the clusters of research expertise within Lehigh engineering:

Bio: Bio, Environmental and Molecular Engineering
Nano: Nanotechnology and Applications
Systems: Complex Engineering and Information Systems

This issue of *Resolve* highlights the activities of Lehigh researchers involved in nanotechnology-related endeavors.

"Lehigh's multidisciplinary culture and its tradition of bridging theory and practice can help society overcome pressing challenges" —S. David Wu

These investigators collaborate in three complementary research centers that represent a comprehensive set of capabilities in nanocharacterization, nanosynthesis and nanofabrication, or, put simply, in seeing, manipulating and making materials and devices at the nanoscale.

The Center for Advanced Materials and Nanotechnology is recognized as one of the premier surface science and nanocharacterization facilities in the world, on par with national labs and top-tier research centers. The Center for Optical Technologies develops new materials whose properties have enormous impact on applications ranging from illumination to biomedical imaging devices to environmental sensors. The Sherman Fairchild Center has broadened our understanding of the molecular science behind the transport of electrons, which forms the basis of computing and communications systems. Together with Lehigh's expertise in surface science, particle physics and thin-film technologies, these three centers make up a nano research portfolio that is incredibly rich and capable of supporting a wide range of applications.

I hope you enjoy this issue of *Resolve*. Please drop me a note to share your thoughts and comments.

S. David Wu, *Dean and Iacocca Professor*
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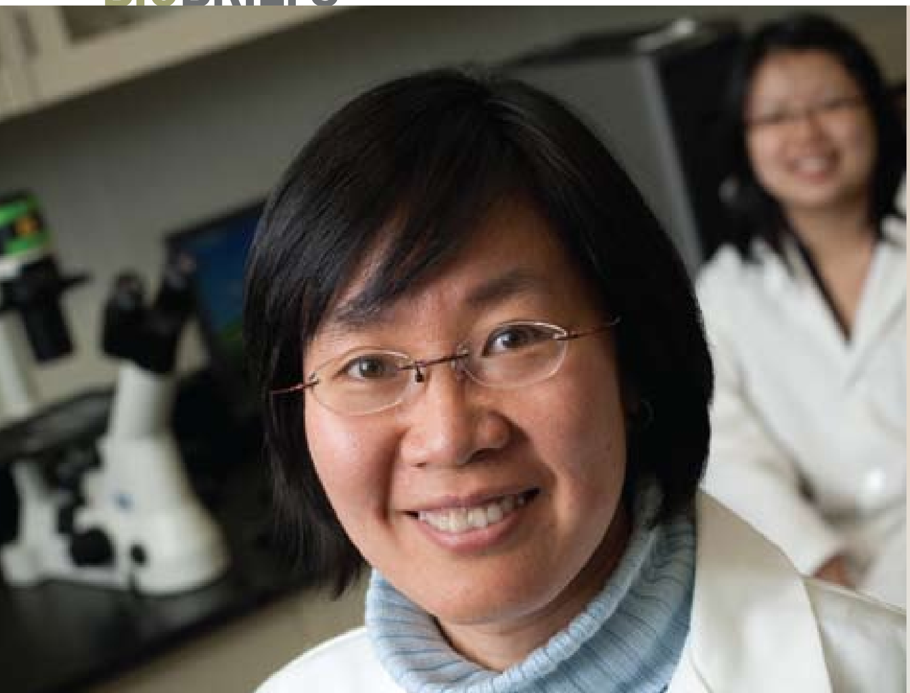


Cheng is designing a chip that separates out HIV and concentrates it for labeling.

Chipping away at HIV

More than 90 percent of Africans with HIV are unable to send blood samples to labs to determine the stage of their infection, says Xuanhong Cheng. Even more tragic, she says, is the fact that African babies with HIV-positive parents are not diagnosed.

"HIV diagnosis in adults is simple," says Cheng, an assistant professor of materials science and engineering. "You take a sample of blood or saliva and put it on a strip. If the strip changes color, you know the adult is infected with HIV and carries an antibody reactive with the strip.

"But infants get a lot of antibodies from the mother. So if a baby has the HIV antibody, the only way to confirm infection is to look for the presence of virus in the blood."

Monitoring HIV's progress in an infected adult requires two assays – a CD4 count to detect the extent of damage to the immune system and a viral load to measure the circulating viral concentration. In earlier work, Cheng designed a microchip in a handheld device that measures CD4, a type of white blood cell that defends the body from HIV and other pathogens. This cell counter is under commercial development and awaiting a field test in Africa.

Cheng is now helping to develop a portable device that measures HIV blood concentrations for infant diagnosis and adult HIV monitoring. Currently, this is done by a technician in a clean lab who separates nucleic acid from the blood. A machine then amplifies the HIV-specific sequence and an optical device measures the viral load in the amplified sample.

Cheng wants to capture and immobilize whole particles of the virus in a handheld device, tag the virus with a fluorescent dye, and count HIV particles with an optical detector. She is designing a chip that separates blood cells from the HIV virus and plasma and then concentrates the virus for labeling. Optical techniques designed in collaboration with Daniel Ou-yang, professor of physics, will count the number of labeled particles.

These diagnostic innovations are critical to determining both the stage of infection and the appropriate treatment, says Cheng, who as principal investigator works with Profs. Wojciech Misiolek and William Van Geertruyden of Lehigh's material science and engineering department, and with Dr. Timothy Friel, vice chair for research and infectious disease specialist at Lehigh Valley Hospital.

Healing technology

Lehigh's emerging biotechnology initiative will focus research efforts on diagnostic and therapeutic technologies with an emphasis on affordable medicine.

The program has three related thrusts: systems engineering approaches for medical technology, integration of devices and systems for diagnostics and monitoring, and emerging technology for novel therapies.

The initiative will build on Lehigh's capabilities in systems engineering, photonics, bioelectronics, cell and molecular science, and materials science and engineering. It will leverage Lehigh's research partnerships with world-class medical schools and clinics.

Anand Jagota, director of the new program, says it will attract entrepreneurs and start-ups to the Lehigh Valley. Its launching comes at a critical time. The U.S. faces mounting health-care costs resulting from an aging population. The threat of global pandemic is real and, increasingly, complex diseases are defying traditional treatments. Partnerships between engineering and medical science can address these challenges in a new way.

Jagota says the initiative also addresses the urgent need for education and R&D that can cut hospital stays and drug costs while improving quality of life.

"We've completed nearly three years of planning and discussion with students, faculty, alumni and representatives of the biotech industry and government agencies," says Jagota. "We've concluded that Lehigh can make a difference in health care by supporting technical innovation that targets the factors pushing up its cost. Lehigh sits at the geographical center of five of the largest biotech hubs in the U.S. Our engineering strengths align well with the needs of this rapidly growing industry."

A scientific marriage made in the skies

Himanshu Jain, director of NSF's International Materials Institute for New Functionality in Glass, was searching for a biologist to help him understand how a biocompatible glass interacts with human cells.

Matthias Falk, assistant professor of biological sciences, was looking for a materials scientist to help develop a new biocompatible material for orthopedic surgeons.

Both work at Lehigh but it was on a flight to Japan that their paths first crossed. Falk, who uses fluorescence light microscopy to study the gap junctions through which cells communicate, was traveling to Sapporo to make a presentation at the 16th International Microscopy Congress. Jain, an expert in glasses, was on his way to Kyoto University to give the keynote talk at the Second International Symposium on New Materials Science.

The transcontinental meeting initiated a partnership that combines cell biology and materials science to seek new ways of repairing bone that has been broken in accidents or ravaged by disease.

Doctors have found grafting, or implanting natural bone, preferably from the patient, to be one of the most effective ways to rebuild strong bone. But grafts sometimes require additional surgery and extensive remodeling and cannot always be used.

So researchers have started testing bioactive glass as a "scaffold" to help the body rebuild its natural bone. Recent observations show that chemicals leaching from the glass actually help grow bone on the scaffold.

With funding from NSF, Jain and his team have for several years been designing bioactive glass scaffolds that are biomechanically similar to the host tissue and encourage tissue growth.

The team, which includes dental researchers in Egypt and materials scientists in Portugal, places healthy progenitor cells on the scaffold, which is located in the injured or diseased area. To optimize bone regrowth, they use a scaffold that blends macropores (100 microns or wider to allow bone cells to grow inside the glass) with nanopores (up to 20 nanometers in diameter to promote cell adhesion). The team has developed two novel techniques for fabricating the dually porous scaffolds.

To verify that the scaffolds are biocompatible and that they promote bone cell adhesion, Jain's team has used scanning electron microscopy (SEM) and fluorescence light microscopy.

The latter technique enables Falk and his students to quickly detect and quantify the number of cells that adhere to the scaffold and to observe their shape, viability and skeletal organization. Falk says a large body of literature supports the conclusion that bone-precursor cells require direct, gap-junction-mediated, cell-cell communication during development and for differentiation.

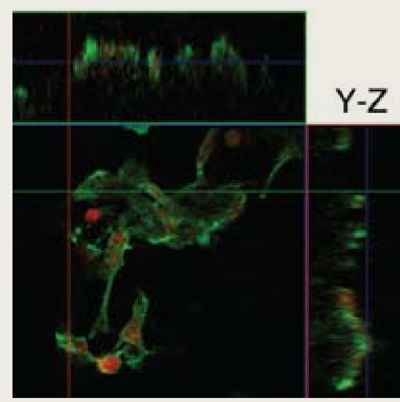
The samples made so far have been mechanically weak, and questions remain about how fast and fully the scaffolds will dissolve in the body. With funding from the Howard Hughes Medical Institute, Jain and Falk are exploring these and other questions *in vitro*. Their goal is to create the most effective bone scaffold possible for *in vivo* testing by Jain's partners in Egypt.

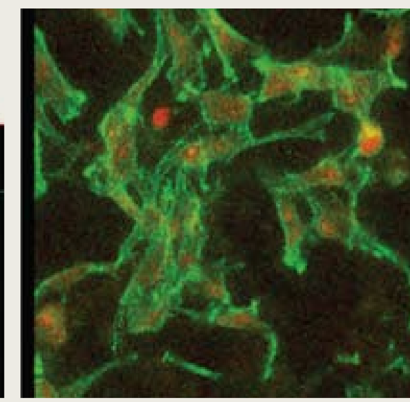
Falk is a welcome addition to the project, says Jain, because he is investigating how to make biocompatible glass that is not only not toxic to the body but actually helps prevent infection, and because he is studying how the glass can facilitate the development of precursor cells into mature bone cells.

Falk is also observing the chemicals that leach from the glass and induce the differentiation of precursor bone cells. Working with Jutta Marzillier of Lehigh's Genomics Facility, he is using Quantitative Real-Time Polymerase Chain Reaction to determine how certain genes are switched on so that the precursor cell becomes the final bone cell.

"Thousands of people have benefited from bone implants," says Jain, "and we expect the demand to grow as our population ages. Many of today's implants, made with metal, do not last long enough, often cause pain and sometimes require subsequent operations.

"What Matthias and I are hoping to do is identify those glass scaffolds that are the most biocompatible and bioactive, so that the bone regenerates and the glass poses no threat to the body and eventually fully dissolves. The idea is to help the body grow its own parts. So far, the nano-plus-macroporous scaffolds are the most promising."

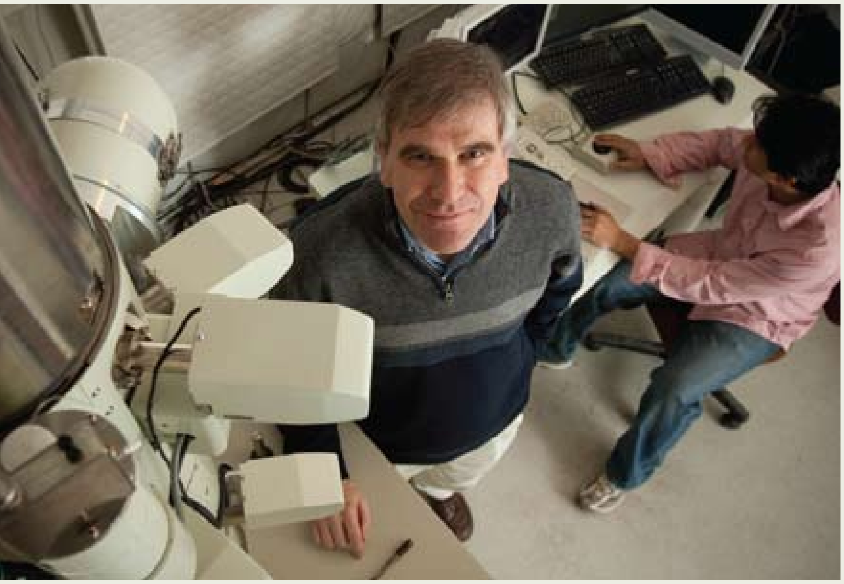




Jain and Falk use SEM and fluorescence light microscopy to observe the shape, viability and organization of the cells adhering to their glass-bone scaffold.

Scientists peel away the mystery behind gold's catalytic prowess

Few materials have had more impact on human history than gold. But it was not until the 1980s that two chemists, Masatake Haruta and Graham Hutchings, discovered that the Noble element, long considered inactive, could be an extraordinarily good catalyst.



Haruta learned that gold particles measuring less than 5 nm across possess a high level of catalytic activity when deposited on metal-oxide supports and that the particles effectively catalyze the conversion of CO into CO_2 at room temperature.

Scientists have sought since then to determine exactly how gold nanoparticles function as catalysts.

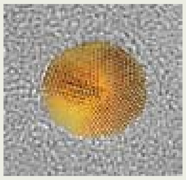
Now, researchers from Lehigh and the UK believe they have pinpointed the active species at which the oxidation reaction occurs when gold is supported on iron oxide.

Writing in 2008 in *Science*, the team said bilayer clusters measuring about 0.5 nm in diameter and containing about 10 gold atoms were responsible for triggering the CO oxidation reaction. The researchers also reported that a simple change in preparation – drying the catalyst in flowing rather than static air – helps impart to the gold its catalytic capability.

Gold catalysts could find an application in the protective masks capable of converting CO to CO_2 that are worn by persons exposed to high levels of CO. Another application is to fuel cells, which are vulnerable to damage by CO present in the hydrogen fuel stream.

The *Science* article was coauthored by Christopher Kiely, director of the Nanocharacterization Laboratory in Lehigh's Center for Advanced Materials and Nanotechnology; Hutchings and two colleagues at the UK's Cardiff Catalysis Institute; and Andrew Herzing of the U.S. National Institute of Standards and Technology. Herzing earned a Ph.D. from Lehigh in 2006.

Hutchings' group carried out the fabrication and catalytic testing of the gold nanoparticles, and characterized the catalyst using x-ray photoelectron spectroscopy. Kiely's group then used Lehigh's aberration-corrected 2200 JEOL scanning transmission electron microscope to examine the gold's nanostructure.



A cluster of eight to 12 gold atoms arranged in a bilayer just 0.5 nm thick, says Kiely, correlates with the catalyst's ability to oxidize CO.

The researchers compared two groups of gold nanoparticles. One, dried in static air, was a "dead" catalyst with little or no catalytic activity. The other, dried with flowing air, was a 100-percent-active catalyst for CO oxidation.

On the inactive catalyst, Herzing saw two types of gold species – particles larger than 1 nm in size and individual atoms scattered about on the iron-oxide support. On the 100-percent-active catalyst, he found a third species – clusters of eight to 12 gold atoms arranged in two layers measuring about 0.5 nm in dimension.

"This was the clue that enabled us to identify the tiny bilayer clusters as the important species in the catalytic reaction," says Kiely. "We deactivated the catalyst and found we could correlate the loss of the clusters with the loss of activity.

"We believe we have obtained the first conclusive evidence that bilayer clusters are occurring in a real gold catalyst, that they are the key species on that catalyst, and that their presence or absence correlates with the ability or failure of the catalyst to perform CO oxidation."

Lehigh's two aberration-corrected electron microscopes, acquired in 2004, enabled the researchers to see the individual atoms and bilayer clusters of atoms. They also made it possible to use high-angle annular dark-field imaging, a technique that requires a 1-angstrom-wide beam of electrons to obtain a scanned image of a specimen.

Hutchings and Kiely have studied the catalytic potential of gold nanoparticles for 15 years, publishing four papers in the past four years on the topic for *Science* and *Nature*.

In 2005, they reported that the selective oxidation processes used to make compounds contained in agrochemicals, pharmaceuticals and other chemical products could be accomplished more cleanly and efficiently with gold. In 2006, they reported the potential of gold-palladium nanoparticles to oxidize primary alcohols to aldehydes in a more environmentally friendly manner. That reaction is important to the production of spices and perfumes.

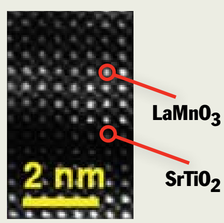
In February 2009, they wrote in *Science* that gold-palladium nanoparticles, properly tailored, could lead to a cleaner, safer method of producing hydrogen peroxide (H_2O_2). The method, which requires the pretreatment of a carbon support with nitric acid, could also enable the direct production of H_2O_2 from hydrogen and oxygen in smaller quantities and more desirable concentrations than is possible with current processing techniques.

A new TEAM player for microscopy

As a scientist with the National Center for Electron Microscopy at Lawrence Berkeley National Laboratory, Masashi Watanabe played a major role in taking electron microscopy to a historic threshold – the imaging of features less than 1 angstrom in size.

Watanabe was a natural fit for the so-called TEAM (Transmission Electron Aberration-corrected Microscope) project. In previous work in Japan and at Lehigh, the only university in the world with two aberration-corrected transmission electron microscopes, he had become one of a handful of scientists capable of drawing maximum benefit from the specially equipped TEMs.

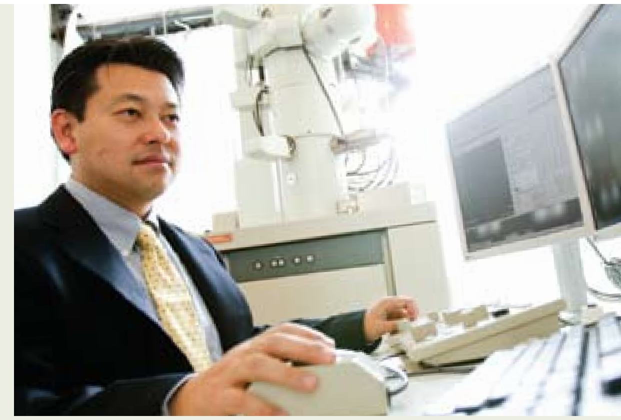
In January 2009, Watanabe returned to Lehigh as associate professor of materials science and engineering and a key player in the university's Nanocharacterization Laboratory.



With their ability to resolve images of individual atoms, and to identify those atoms' chemical composition, says Watanabe, Lehigh's aberration-corrected TEMs will lead to an improved knowledge of the way in which engineering materials and functional nanomaterials behave at the nanoscale.

One of Watanabe's aims at Lehigh will be to analyze impurities at grain boundaries, a phenomenon critical to material failures. For example, he says, minute amounts of phosphorus or sulfur at grain boundaries can cause steel to become more brittle.

"We will identify where and how much impurity is present, then determine the threshold at which the materials become brittle. The amount may be as low as a single impurity atom. We need atomic-level resolution to analyze such low amounts of impurities. These instruments make this kind of analysis possible."



Watanabe's software analyzes large-scale datasets from microscopes.

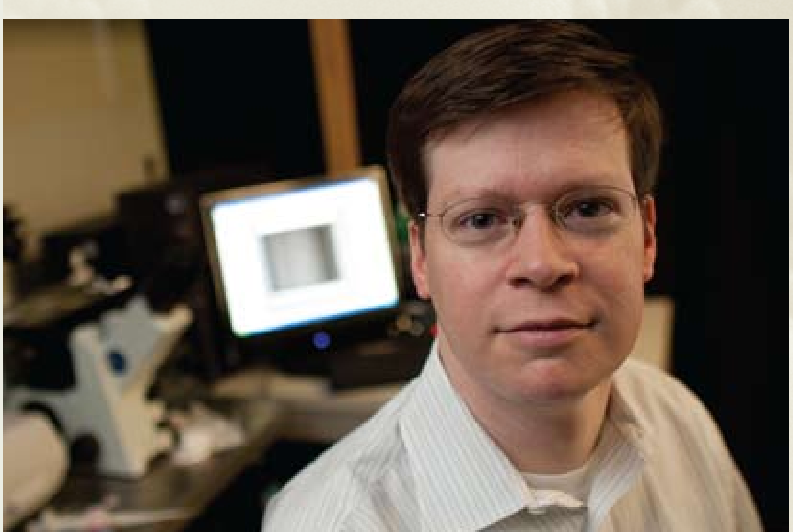
Watanabe has pioneered several analytical techniques that enable more efficient data gathering. Working with HREM Research Inc. of Japan, he helped develop and commercialize Lehigh software that analyzes large-scale datasets from microscopes.

"I look forward to expanding our research capabilities at Lehigh," he says. "We have state-of-the-art microscopes. And I have so many friends that I think we can assemble a strong team to attack some important challenges."

The minutest choreography

Imagine this task: You must cover a football field with millions of tiny tiles, placing each in an assigned position. Would you rather install each tile by hand, or throw all the tiles in the air and hope each lands in its proper spot?

James Gilchrist ponders this scenario as he studies particles that self-organize in materials and devices. He and his group explore the surface dynamics of the "coffee ring effect," in which particles from a drop of coffee spilled on a white table travel to the edge of the spill and form a ring.



Gilchrist, the P.C. Rossin Assistant Professor of chemical engineering, says if you can control the fluid, surface and particle properties of a drop of liquid, and if you can control the process by which the liquid is pulled across a particle, you can cause particles to self-organize as they dry.

This kind of knowledge is critical in monitoring diseases, improving computer efficiency and other applications.

For example, Gilchrist works with Prof. Xuanhong Cheng of materials science and engineering on a portable device that monitors HIV infection. His goal is to change the properties of tiny particles of polystyrene-coated iron oxide so they stick to infected cells in a blood sample, thus helping doctors assess the level of infection.

Gilchrist also collaborates with Prof. Nelson Tansu of electrical and computer engineering to maximize LED efficiency. Light-emitting diodes, used in computers and eventually in ultra-efficient lightbulbs, can be improved by allowing more photons to escape from the surface of an LED and thereby create light. Gilchrist's team is self-assembling microlenses on the surface of the LED, which widens the escape cone and lets more photons out.

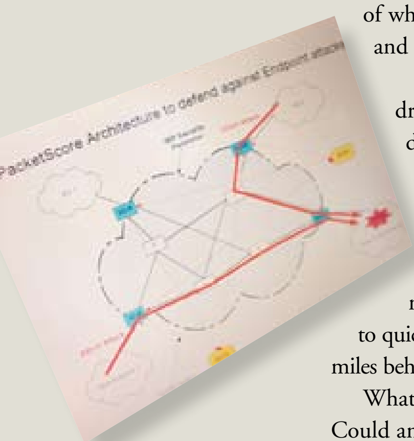
"My research focuses on the fundamental processes by which particles are deposited on surfaces," says Gilchrist. "Right now it's leading to better LEDs or BioMEMS devices. Tomorrow we hope it will enable a generation of materials and devices we haven't even envisioned."

An article by Gilchrist's team on the deposition of microsphere monolayers was recently featured on the cover of Langmuir.

Constantly alert to the growing need for wireless

Driving from Lehigh's campus to her home in Allentown, Pa., Mooi Choo Chuah, an expert in wireless network security and routing, finds it difficult to leave her work behind.

Chuah's daily commute requires her to take either U.S. Route 22 or I-78, both of which are notorious for accidents and delays.



In one project, Chuah is seeking to ensure wireless message delivery in environments with intermittently connected modes.

The congestion may vex other drivers, but it brings out the dreamer in Chuah.

If a traffic jam does occur, she wonders, could a voice-activated wireless system, using laptops or PDAs in cars as nodes, or connecting points, allow some drivers to quickly warn those following several miles behind to take a different route?

What if there is an AMBER Alert? Could an image of the kidnapped child be promptly flashed on LED billboards near the area where the child disappeared? The image could be uploaded to the billboards via wireless links.

Chuah, an associate professor of computer science and engineering, has completed two of three phases in a 4½-year project titled "Enhanced Disruption/Fault Tolerant Bundle Delivery System," or EDIFY. The project is funded by DARPA through its DTN (Disruption Tolerant Network) program. DTNs represent one of the key technologies for next-generation networks. Chuah and her students, working with researchers from the Georgia Institute of Technology, the University of Massachusetts at Amherst and BBN Technologies, are developing networking and security technologies for DTNs.

One of the goals of EDIFY, says Chuah, is to design new network protocol software systems. One of these systems will ensure wireless message delivery in environments whose nodes are only intermittently connected. Another will enable messages that are transmitted through these environments, or through several wireless domains, to remain encrypted until they are received by a person with authority to open them.

Another new feature being developed, called "late binding," will allow Internet users to send messages to a specified group of recipients without identifying them by Internet protocol (IP) address. For example, notification of a bank robbery in progress could be sent to all police cars that happen to be within 1 or 2 kilometers of the crime.

"The beauty of this feature," says Chuah, "is that the sender does not have to know the names or IP addresses of the people to whom the message is being transmitted. The late binding feature supported in DTN will allow recipients to be identified later as the message moves closer to the destination region."

A greener, more sensitive radar

Radar has helped us forecast the weather and make highways and airports safer, but radar, says Rick Blum, is due for a 21st-century facelift.

Traditional radar systems, says Blum, the Robert W. Wieseman Chair in electrical engineering, locate a target by measuring the time it takes for a radio signal to hit the target and return to its point of origin.

But radar is not infallible. The outgoing signal might hit several objects and diminish, or it might miss the object it is tracking. The angle of the target might shift, weakening the returning signal.

Blum has played a leading role in efforts to improve radar with multiple-input and multiple-output (MIMO) communications systems.

"With regular radar," he says, "you often have to 'see' the target from just the right direction to get an accurate picture of it. This is because the magnitude of the return signal can change drastically if there's a small change in the angle of the target."

MIMO overcomes this by transmitting signals from several locations.

"If you see from multiple viewpoints," says Blum, "you are going to get a much better picture. One or two illuminations might come back weak, but not all of them. And the antennas in a MIMO radar system don't need to be far apart to get a usable return signal."

Recently, Blum received grants from the Office of Naval Research and the Air Force Office of Scientific Research to study MIMO radar systems. Among other things, he will investigate how sensor networks can achieve energy savings in MIMO radar systems.

Blum creates formulas that allow "smart" sensor networks to cut energy use without losing performance. The sensors save energy by identifying and "censoring" (not transmitting) data that is unnecessary.

Two other recent grants, from NSF and the Army Research Office, will support Blum's work with smart sensor networks.

Blum taught a tutorial on MIMO radar at the 2008 IEEE International Conference on Acoustics, Speech, and Signal Processing in Las Vegas. He also coauthored an article titled "MIMO Radar with Widely Separated Antennas" in *IEEE Signal Processing Magazine* in 2008.

Optimizing coal combustion in China

China now leads the world in consumption of coal, says Edward Levy, director of Lehigh's Energy Research Center (ERC), and is seeking outside expertise to enable its power plants to run more efficiently and cleanly.

The ERC last summer joined forces with a Chinese company to demonstrate the effectiveness of Boiler OP, a combustion optimization technology, at a large coal-fired power plant near Beijing.

"China's new power plants are very sophisticated," says Levy. "They combine the best of the West and the East. But although several hundred power plants in the U.S. use various forms of combustion optimization, the concept is only now starting to catch on in China.

"Boiler OP is one of the first combustion optimization approaches to be tried out in China."

Developed by Lehigh researchers in the mid-1990s, Boiler OP has been implemented at more than two dozen U.S. power plants. The technology gathers data on the effects of boiler operating conditions on power plant efficiency and pollutant emissions. It integrates the data with artificial intelligence techniques to determine the combinations of boiler operating conditions that maximize plant efficiency while minimizing emissions of nitrogen oxide and other air pollutants.

ERC engineers have overseen the implementation of Boiler OP at a 600-megawatt unit of the five-year-old Pan Shan power plant and are training Pan Shan personnel in its use.

The ERC is working on the project with the XiAn JieHua Environmental Protection Science and Technology Company of Xian, which provides engineering services to the Chinese power generation sector.

Analysis of the data generated to date, says ERC associate director Carlos Romero, shows that Boiler OP will enable Pan Shan to reduce NO_x by more than 20 percent while improving thermal efficiency.

Boiler OP, which can be applied to gas-, coal- or oil-fired boilers, improves efficiency and reduces NO_x by systematically adjusting a dozen or more boiler control settings. ERC engineers have developed separate software programs that work in tandem with Boiler OP, says Romero. One program automates data analysis. Another integrates data with artificial intelligence techniques and enables plant operators to modify boiler settings in real time in response to data.

Better, faster and cheaper

Tamás Terlaky has earned international renown by proving repeatedly that almost any process can be made better, faster and cheaper.

Terlaky, chair of the industrial and systems engineering department and George N. and Soteria Kledaras '87 Professor of Industrial Engineering, studies optimization, mathematical programming and high-performance computing. He is a leading developer of interior point methods, a class of algorithms used since the 1980s and still regarded as a breakthrough in solving linear and nonlinear optimization problems.

Terlaky harnesses these algorithms to optimize the core refueling process of nuclear reactors, the radiation effectiveness in cancer treatment, the maintenance scheduling of oil refineries, and more.

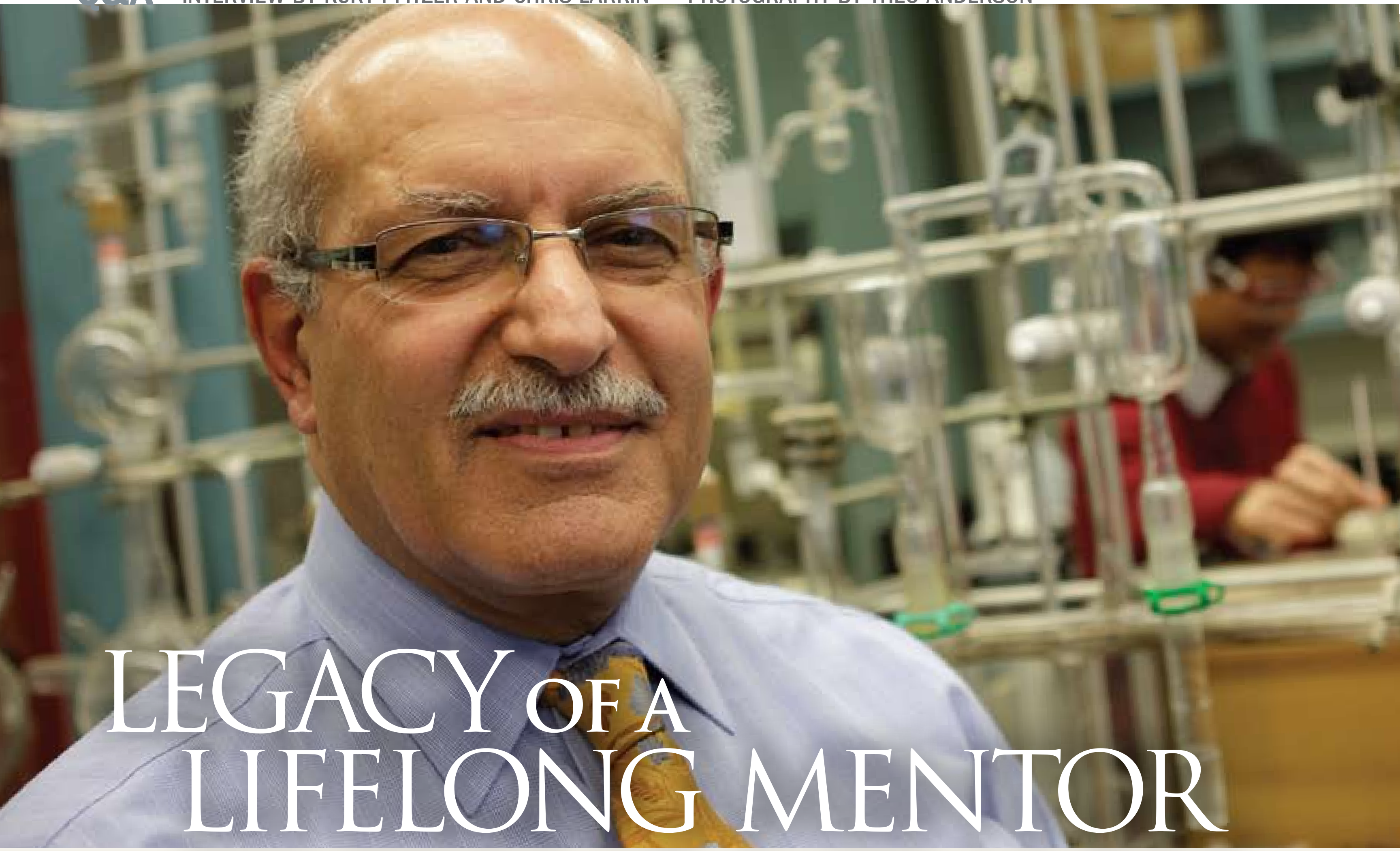
The fuel bundles in the core of a nuclear reactor cannot all be renewed at the same time, so Terlaky, then with Delft University of Technology in The Netherlands, led a research group that used partial differential equations to describe the core's physical characteristics. The group then developed algorithms that determine the right mix of the core's thousands of bundles to be replaced while maintaining optimal reactor performance.

More recently, as director of McMaster University's School of Computational Engineering and Science, and director of the Advanced Optimization Laboratory in Hamilton, Ontario, Terlaky's team created computational methods that produce sharp images of cancerous tumors and surrounding organs. These methods enable doctors and medical physicists to optimally modulate the intensity of x-rays, thus maximizing the treatment's effectiveness while sparing healthy organs from undue damage. Their robust optimization methodology takes into account the fact that everything in the body is constantly moving.

As department chair at Lehigh, Terlaky hopes to lead faculty in meeting new industrial and information systems engineering challenges. As a researcher, he wants to develop algorithms that optimize the performance of information technology systems and engineering design, while solving specific problems like the design and routing of an electric circuit layout.

"I am always working with engineers on specific applications, taking the theoretical over to the practical," he says.

 INTERVIEW BY KURT PFITZER AND CHRIS LARKIN • PHOTOGRAPHY BY THEO ANDERSON



LEGACY OF A LIFELONG MENTOR

"OTHER SCIENTISTS WILL EXPAND AND IMPROVE ON YOUR WORK"

Mohamed S. El-Aasser, a renowned expert in emulsion polymerization and polymer colloids, has served Lehigh as university provost since 2004 and was recently named vice president for international affairs. In 37 years with Lehigh, El-Aasser has earned numerous honors for his research and has advised 64 Ph.D. students, 53 M.S. students and 31 postdoctoral fellows. El-Aasser also directs Lehigh's Emulsion Polymers Institute. Under his leadership, EPI's annual short courses have attracted more than 5,000 scientists to Lehigh and to Davos, Switzerland, in the last three decades. El-Aasser and his students have published almost 400 technical articles.

Q: ***Give a general overview of emulsion polymerization and its history and impact on society.***

A: During World War II, when the West was cut off from its supply of natural rubber, the U.S. launched a national project to seek a way to synthesize rubber. Emulsion polymerization emerged as a way of doing this. The process takes a monomer derived from petroleum products and converts it to a polymer. The polymerization yields a colloidal dispersion of the polymer suspended in water.

The original intent was to synthesize tires, conveyor belts and other products previously made from natural rubber. But because you can make polymers from different types of monomers, the process has evolved into a means of making plastics, paper and textile coatings, paints, adhesives and many other products.

Meanwhile, we've learned to control the size of the colloidal particles and make different kinds of polymers. We've come up with new processes, materials and approaches to create new products.

These polymer particles, because they are monodispersed, with each particle having the same size, are useful in applications requiring uniform metrics, such as calibration of instruments and microfilters. They are also useful in medical diagnostics and drug delivery, which is where the field is moving.

Q: ***What role did you and your colleagues play in the invention of miniemulsion polymerization in the early 1970s?***

A: In classic emulsion polymerization, the first step is to make the nuclei. These nuclei, which are suspended in water, grow when the monomer, which exists in large droplets, diffuses through the water to

Throughout his career, El-Aasser has found his greatest satisfaction in working with students.

the polymerization site. In a material with little or no water solubility this diffusion will occur slowly and it will limit or inhibit the transport of water-insoluble materials to the site of polymerization.

We took the monomer, the water and the emulsifier and subjected them to the right agitation. We ended up with monomer droplets suspended in water that were 50 to 500 nm in size, much smaller than we'd seen before. This allowed us to carry out polymerization inside the monomer droplets.

Q: ***How has the field of miniemulsion polymerization evolved?***

A: We can now take tiny metal particles — gold, titanium dioxide — suspend them in the monomer phase, do miniemulsification and end up with gold or titanium dioxide particles embedded in particles 0.2 micron across. The encapsulated gold particles have found therapeutic and medical diagnostic applications. Because they are inert as well as tiny, they can be targeted to any part of the body.

The field is also giving us tools to do things with particles ranging down to 10 nm in diameter. This is helping us make small-volume, high-value-added materials in areas like biotechnology and drug-delivery systems, therapeutics and diagnostics, which require uniform-sized particles.

Q: ***In 1984, NASA named you and two colleagues Inventors of the Year for designing a device that synthesized the first products made in space. What products were fabricated, and what were the challenges of making them in zero gravity?***

A: NASA wanted to do a scientific experiment to examine the influence of lack of gravity on the rate of a chemical process. Every theoretical treatise said there should be no influence. We proposed to determine if the lack of gravity influenced the rate of emulsion polymerization.

When you do polymerization, you end up with sub-micron-sized polymer particles. At that time, we could make monodispersed particles only as large as 1 micron. But some applications require larger particles. To obtain a larger particle, we suggested taking a sub-micron particle, swelling it with monomer and restarting polymerization. To do this, you need to maintain each particle's individuality by using surfactants whose positive or negative charges create a repulsion between the particles.

As your particles increase in size and change from a monomer to a polymer, the density of the material also changes. Polystyrene is heavier than water, but the monomer from which you make polystyrene is lighter than water. At the same time, you have a faster rate of sedimentation or creaming, respectively. On earth you offset this by increasing the agitation to keep the particles in suspension. But this causes the particles to collide more frequently. When that happens they collapse and are no longer separate.

We told NASA that if we carried out polymerization in the absence of gravity, we could maintain the individuality of the particles while increasing their size with a surfactant and with the addition of more monomer. We were able to make 10-micron particles which under earth's gravitational effect would sediment in a short period of time, but which in the microgravity of space remained suspended throughout polymerization.

Our size – 10 microns – turned out to have a useful medical application. Blood cells are 7 microns across. The 10-micron polystyrene particles we made have been used in hospitals for calibrating blood counters.

We ran five experiments in the space shuttles. We ended up making 30-micron particles. Since then, using our process, engineers have succeeded in making polymer particles as large as 215 microns that are very uniform in size. You learn through the process of making.

Q: ***The last quarter-century has seen a huge increase in papers and patents resulting from advances in miniemulsion polymerization. How does it feel to be one of the founders of this field?***

A: It shows that science is not the property of any one human being. You take a good idea and develop it. Your idea becomes more mature because of the ingenuity of other scientists who expand on your work and make something even better out of it.

Q: ***You have served as department chair, dean and provost while teaching, mentoring graduate students and directing research centers. What is the secret of your organizational abilities?***

A: All of us know we have to budget our time, set priorities and be focused. Also, it's important to have a good team. I have been blessed with the students, faculty and staff whom I've worked with.

Q: ***What are the qualities a person needs to be a good researcher?***

A: You start with good ideas and an interest in exploring them. You come up with the right scientific methodologies to explain the phenomena you see. You must be open to criticism because that's what pushes you to find the answers. You should also be interested in disseminating your outcomes. It's also important to reach out to your counterparts and to develop a team whose members complement each other. This pushes your research at a faster rate and helps your ideas mature.

Q: ***How do you come up with ideas for projects?***

A: Some of them you dream up, but most come from listening to other people at conferences. You bounce an idea off your colleagues, they poke holes in it and that pushes you to refine your original idea.

Q: ***What do you consider your greatest achievement?***

A: What's most gratifying for me are the people. My graduate students and postdocs have helped me build my career and have become extremely successful. Many of them are now independent researchers. This human aspect of research is much more rewarding to me than anything else.

 ILLUSTRATIONS BY ANDY CHRISTIE • PHOTOGRAPHY BY DOUGLAS BENEDICT

Sudhakar Neti (front) and (l-r) Profs. Misiolek, Tuzla, Oztekin and Chen believe phase-change materials could optimize the storage of solar thermal energy.

REACHING FOR THE SKY

ZINC AUDITIONS FOR A ROLE IN SOLAR ENERGY STORAGE

The potential benefits of solar energy, says Sudhakar Neti, seem almost as endless as the clear Arizona sky when they are compared with the cost, the pollution and the politics of fossil fuels.

The shining sun radiates about 1,000 watts (1 kW) of energy per square meter of land, says Neti, a professor of mechanical engineering and mechanics. Every hour, the sun diffuses more energy onto the earth than the entire human population uses in a year. And sunlight is not confined by political boundaries or geography.

Harnessing energy from the sun can be cleaner than extracting energy from coal, oil or natural gas, Neti adds, and solar energy is versatile. Solar electric systems use photovoltaic cells to convert sunlight directly into electricity. Solar thermal systems employ panels of mirrors to concentrate sunlight and convert it into heat, which then is used to drive turbines or engines to generate electricity.

Neti and four other Lehigh researchers recently received a $1.5-million grant from the U.S. Department of

Energy to tackle one of the biggest obstacles to the wider use of solar thermal technology – its storage.

The three-year award will enable the group to study two materials whose phase changes (from solid to liquid and vice versa) are optimal for the storage and release of energy generated by solar thermal systems.

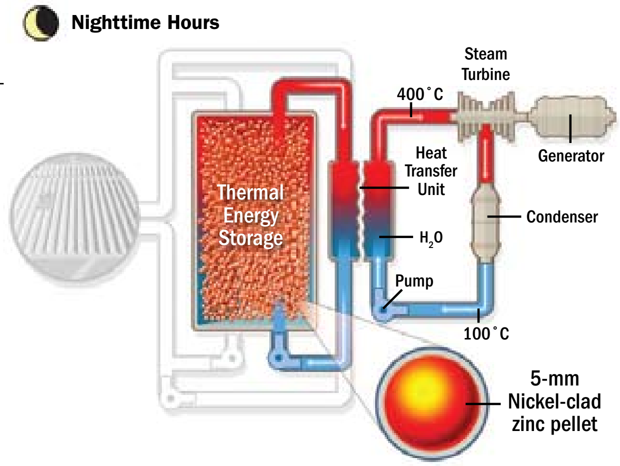
The multidisciplinary makeup of Neti's group reflects the variety of challenges posed by solar thermal storage technology.

Wojciech Misiolek, professor of materials science and engineering, is an expert in metals and metal processing. John Chen, professor emeritus of chemical engineering, is renowned for his work in heat transfer. Alparslan Oztekin, associate professor of mechanical engineering and mechanics, is a specialist in numerical calculations, and Kemal Tuzla, professor of practice in chemical engineering, is an expert in the packed heat bed transfer technology that the group will utilize in its storage system.

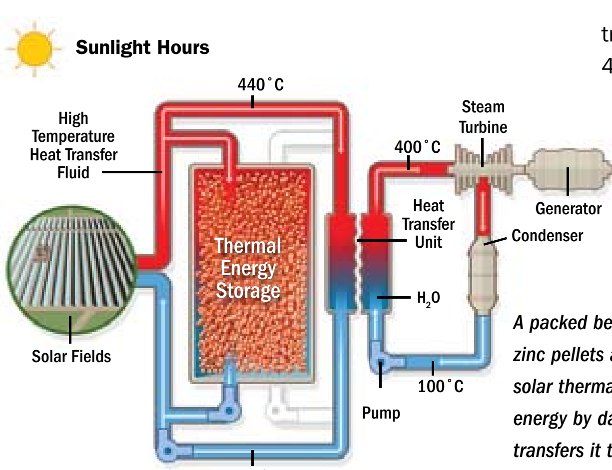
HIGH EXPECTATIONS

The proponents of solar energy hardly suffer from a lack of enthusiasm. The magazine *Scientific American* predicted a year ago that solar power could provide the U.S. with 70 percent of its electricity and more than a third of its total energy needs by 2050. Other observers predict a more modest increase in the portion of energy demand that will be met by solar and other forms of renewable energy.

In any case, the future of solar energy will depend in large part on cost and availability, says Neti. And these will require novel heat-transfer methods as well as new materials that enable solar facilities to store energy long enough so power can be generated on cloudy days and at night.



At night, the pellets stop absorbing solar energy but continue to transfer it to a heat exchanger where it is converted to steam.



A packed bed of zinc pellets absorbs solar thermal energy by day and transfers it to a heat exchanger.

"We do not yet have the means of storing energy to make solar energy viable on a large scale," says Neti. "Even in places like Arizona where sunshine is abundant, we need storage for the night."

Two storage technologies now used by solar power plants are the pumping of compressed air into underground caverns and the use of insulated tanks filled with molten salt. But these are not capable of storing solar energy for more than a day.

A HIGH DOSAGE OF ZINC

Neti's group believes encapsulated phase-change materials (EPCMs) offer a more promising alternative. EPCMs can be designed to have high melting points with constant temperature during a phase change. Materials undergoing phase changes are capable of storing and releasing large quantities of energy as they change from solid to liquid and vice versa. These materials are now used in insulation, diving suits, cooling packs and other applications.

"In a solar thermal plant," says Neti, "heat-transfer fluid is heated by solar collectors to 400–450 degrees C. This energy needs to be stored. You can store it passively in a large room filled with stones, heating the stones to store energy and reversing that process to get energy out. This has been used to date but with limits: Many good materials do not have sufficient thermal heat capacity, and this necessitates large piles of storage materials.

"We looked for a material that can change phase and thus store more energy. We settled on zinc. It is safe and nontoxic. It has a melting point of 420 degrees C., which is very good for our purposes."

Neti's group will conduct experiments on zinc pellets coated with nickel that range in diameter from 5 to 10 millimeters. The use of small spheres will expand the zinc's total surface area and heat-transfer capabilities. The nickel, with a significantly higher melting point than zinc, will maintain its integrity, acting as a shield while the zinc changes phases, thus preserving the zinc's optimum heat-transfer qualities.

"The encapsulated zinc pellets could conceivably cycle the changes of phase and store energy indefinitely," says Misiolek, but a number of questions must first be answered.

"What is the optimum size for the pellets? Which size enables the most uniform heating? What is the optimum ratio of zinc and nickel? What is the best mixing process to use?

"Also, what is the optimum thickness of the nickel? We're going to be stacking thousands of pellets in the packed bed. We need to calculate the stress imposed on the bottom layer of the pellets so we have to determine how thick the coating should be to guarantee the safety of the process."

There are other challenges: how to fabricate the zinc pellets cheaply and how best to coat the zinc with nickel.

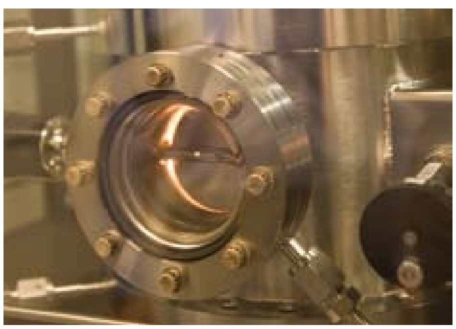
"The goal is to find the best way of storing energy as it is being generated so it will be available for nighttime use," says Misiolek, whose former graduate student Suradej Lorcharoensery successfully coated microparticles of iron with nickel several years ago as part of his doctoral dissertation.

After conducting lab experiments in a packed bed reactor, Neti's group plans to design a full-scale thermal energy storage system that can be interfaced with an existing power plant and tested.

The researchers will also conduct tests on a second phase-change material, a eutectic mixture of magnesium and sodium chlorides. A eutectic substance is an alloy or mixture whose melting point is lower than that of any other combination of the same materials. The researchers plan to house the chloride mixture inside canisters of stainless steel. They are particularly interested in the steel's ability to withstand high pressures during the heating and energy-storage process.

REVEALING THE

RESEARCHERS UNLOCK THE POTENTIAL OF THE NANO WORLD



A metalorganic chemical vapor deposition reactor deposits nanostructures one atomic layer at a time on a semiconductor wafer.

Half a century ago, the Nobel Prize-winning physicist Richard Feynman helped launch the era of nanotechnology when he told scientists to dream little, not big.

In an address to the American Physical Society, titled "There's Plenty of Room at the Bottom," Feynman told his audience they could develop tools capable of manipulating individual atoms and molecules.

Imagine putting a 24-volume encyclopedia on the head of a pin, Feynman said. Imagine 24 *million* books. Similarly scaled down, they could fit on 35 pages. What about computers? In 1959, they filled entire rooms. Why couldn't they be made of wires just tens of atoms in diameter and circuits only a few hundred nanometers across?

Feynman did not talk of **nanotechnology**. A Japanese engineer, Norio Taniguchi, coined the term in 1974, and an American engineer, Eric Drexler, popularized it in 1986 with his book *Engines of Creation: The Coming Era of Nanotechnology.*

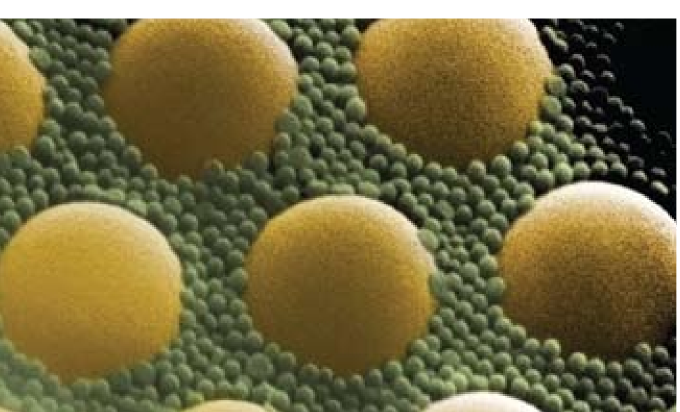
Fifty years after Feynman's presentation, much of what he predicted has come to pass. Indeed, says Marvin White, consumers now demand a steady stream of miracle products with sizes – and price tags – locked in a never-ending downward spiral.

"Nano accounts for many major electronic advances of the past 10 years – cell phones, iPods, digital cameras, laptops, you name it," says White, a member of the National Academy of Engineering and director of Lehigh's Sherman Fairchild Center for Solid-State Studies.

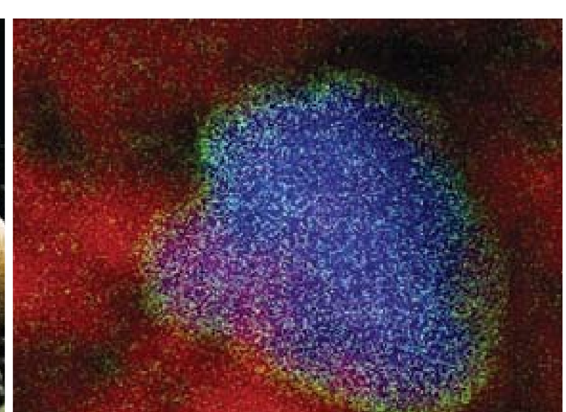
"And there are applications of nano in almost every other field. Take waterproof clothing. Water runs off it because of nanoparticles embedded in the fabric. Look at health care. The response of cells to outside stimuli can be measured, and cell properties characterized, using nano research instruments."

Nanotechnology has been defined as the engineering of systems with dimensions smaller than 100 nanometers. One nanometer (1 nm) equals one billionth of a meter or, as one wag put it, the length a man's beard grows as he lifts his razor to his face.

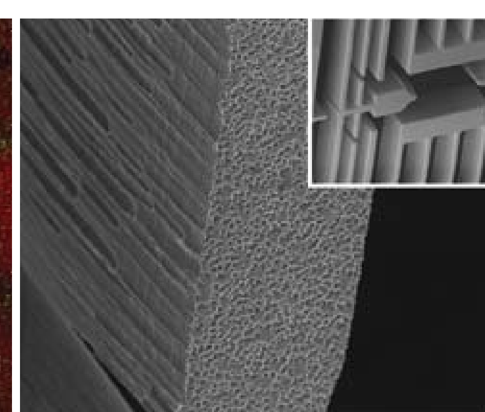
White is one of more than 50 Lehigh faculty members involved in nano research. These engineers, physicists,



Self-assembly of microspheres (SiO_2) and nanoparticles (polystyrene) for optical coatings.



AuPd nanoparticle on red TiO_2 support, with palladium (green) at surface and gold (blue) at core.



A chemically etched silicon machine for mechanical testing of nanoscale materials.

INFINITESIMAL

chemists and biologists collaborate in a variety of groups and venues, including the Center for Advanced Materials and Nanotechnology (CAMN), which is well-equipped for nanocharacterization, and the Center for Optical Technologies (COT) and Sherman Fairchild Center, which have expertise in nanosynthesis and nanofabrication.

Lehigh's nano researchers have scored successes in sensors and transducers, catalysts and sorbents, photovoltaics and light sources, nanoparticles and quantum-dot synthesis, and high-density information management. These are impacting energy, environment, infrastructure and other areas. Palladium-coated iron nanoparticles developed at Lehigh, for example, are treating contaminated groundwater in half a dozen states.

Lehigh's bioengineering researchers also work at the nano level. Electrical engineers pursue nanophotonic biosensing on a chip. Physicists model the dynamics of the cell's cytoskeleton. Materials scientists and mechanical engineers fabricate injection-molded nanostructures on which adult stem cells grow and differentiate (see p. 18).

AN EMPHASIS ON THE SUPERFICIAL

The key to nanotechnology research, says CAMN director Martin Harmer, is much what Richard Feynman envisioned – the control of molecules and atoms at the surfaces and interfaces that are a material's most reactive regions.

"Our goal," says Harmer, "is to equip surfaces and interfaces with desirable and predictable characteristics at the nanoscale. These include chemical composition and atomic structure, and structural, optical, conductive and magnetic properties."

An array of nanoholes (period: 100-300 nm) on a thin silver film with a filter function for nano plasmonic structures and potential for biosensing.

To understand the nano world, one must first observe it. Here, Lehigh offers an advantage: Its surface analysis and microscopy tools are among the world's best.

"Each apparatus we have integrates a number of analytical methods," says Bruce Koel, vice president and associate provost for research and graduate studies. "This gives us a tremendously powerful, multitechnique approach to complicated problems."

Lehigh's scanning probe microscopes, both scanning tunneling (STM) and atomic force (AFM), characterize surface topography in every kind of medium. The university's Scienta ESCA 300, one of 11 in the world and the only one in the U.S., is one of the best x-ray photoelectron spectroscopy (XPS) instruments available for chemical analysis. The high-sensitivity, low-energy ion-scattering spectrometer (HS-LEIS), under acquisition through a 2008 NSF grant, affords unprecedented surface analysis and will be the first instrument of its kind in an academic lab.

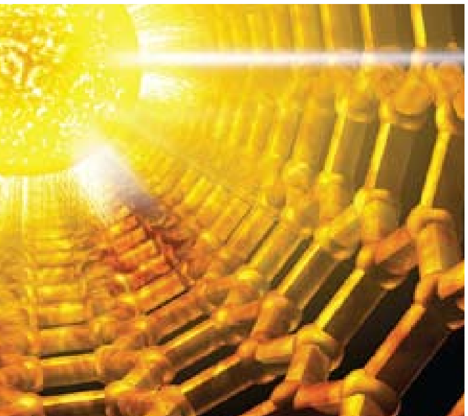
"The Scienta enables us to study surfaces with a high sensitivity and resolution for chemical analysis," says Koel, a professor of chemistry. "It gives us information about the near surface – the chemical composition of the top 10 atomic layers of a material. If you see aluminum, HS-LEIS tells you whether it's metal or oxide. If you see carbon, HS-LEIS tells you whether it is bound to oxygen or to another carbon.

"But the very top or outer layer, which measures just 0.2 to 0.3 nm in thickness, is critical for chemical behaviors. HS-LEIS uniquely tells us what the topmost layer of atoms is."

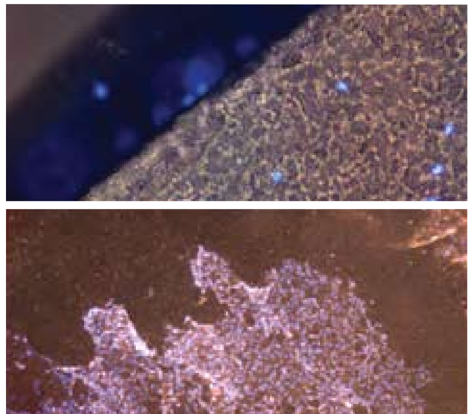
The electron microscopy facilities at Lehigh are comparable to those of a national lab. The university's annual Microscopy School draws researchers from major government, industry and academic labs around the world. Lehigh was the first university to acquire two aberration-corrected transmission electron microscopes, which determine the chemical identity of atoms in crystals with a focused beam of 0.1 nm.

Materials scientists in the CAMN have developed software (see p. 5) that more efficiently analyzes data gathered from electron microscopes, improves signal-to-noise ratio, and achieves greater resolution of small concentrations of elements. Scientists also use a technique called High-Angle Annular Dark Field imaging to enhance resolution of crystal materials.

"This technique makes it possible to see individual metal



A computer rendition shows light glowing inside a cylindrical carbon nanotube.

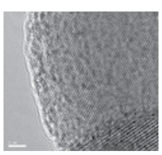


MC3T3 bone-precursor cells growing on nontransparent bioglass.

Researchers in the Sherman Fairchild Center fabricate flexible electronic displays on stainless-steel foils.

atoms or atom clusters dispersed over oxides," says Christopher Kiely, director of the CAMN's Nanocharacterization Laboratory. "It turns out that these clusters or atoms often play a critical role in material behaviors." (See p. 4.)

"The enhanced resolution of the aberration-corrected microscopes enables us to see what atoms really do," says Harmer. "Coupled with our improved computational simulation of nanostructure devices, these microscopes have shown us that the scientific assumptions on which our knowledge rests are fragmentary or even fictitious. This leads to completely new thinking about interfaces."



"The enhanced resolution of the aberration-corrected microscopes enables us to see what atoms really do. This leads to completely new thinking about interfaces." —Martin Harmer

NONVOLATILE MEMORY

To design and fabricate electronic equipment, says Marvin White, one must first understand how electrons and holes move through nanostructures. The control of these charge-carriers and their transport phenomena is vital to the non-volatile storage of data, in which information is preserved without the use of an active power supply.

White has spent 40 years investigating nonvolatile semi-conductor memory – the memory inside a thumb drive or an iPod, for example, which relies on the storage of electro-static charge in the form of negative charge (electrons) and positive charge (holes).

"We model and study the transport phenomena of charge carriers both along the surface, covered by nanolayers of thin films, and perpendicular to this surface," says White. "The carriers move along the surface in devices that switch and amplify information. In devices that store information, they move perpendicular to the surfaces by a process called 'tunneling' and are trapped in these thin films.

"We make our own devices, and we model the transport phenomena observed or created by other researchers. Our partners include Intel, Micron Semiconductor, IBM, AMD and Northrop Grumman."

The phenomena that White and his students study often occur at what he calls the realm of the sub-nano, with features a few nm or smaller.

"The structures that switch, amplify and store information have dimensions on the order of 10 or 20 angstroms or less. One structure, a silicon-dioxide film grown with atomic layer deposition, is just 4 angstroms thick." An angstrom is 0.1 nm.

Advanced tools, says White, are critical to his research. Electron beam lithography enables his group to create and investigate the properties of nonvolatile memory and scaled semiconductor devices. Angle-resolved photoelectron spectroscopy (ARXPS) helps determine a structure's thickness by locating and identifying atoms at or near its surface.

A graded grate that traps and releases light waves

Light waves guided with nanoscale precision inside the circuits of an electronic chip can bring about applications in spectroscopy, sensing and bioimaging, and hasten the advent of faster all-optical telecommunication networks.

To enable light to store and transmit data with optimal efficiency, engineers must first learn to slow or stop light waves across the various regions of the spectrum.

Qiaoqiang Gan, a Ph.D. candidate, and Filbert J. Bartoli, department chair of electrical and computer engineering, have developed a graded metal grating structure that arrests light waves in the terahertz (THz) and telecommunications portions of the spectrum.

Fabricating these nanostructures requires integrating more than 100 process steps in the lab.

CONCEPTUAL CHANGES

Nanotechnology research, says Martin Harmer, can reorder the familiar landscape of scientific knowledge. "We have recently discovered that interfaces are not accurately described as two-dimensional," says Harmer, a professor of materials science and engineering. "The traditional idea was that an interface was a region of misfit between two well-defined crystals. The new idea is that an interface is a third region with its own identity and criteria for stability. It is in fact a new state of matter, neither amorphous nor crystalline, at the interface between crystalline grains.

"We did not appreciate that internal interfaces would behave in this fashion until we acquired the tools to examine them, namely, aberration-corrected microscopy."

Harmer has coined the term "complexions" to describe these interfaces. He received the Robert B. Sosman Award from the American Ceramic Society in 2008 in part due to this fundamental discovery.

In another project, Harmer and Kiely have been synthesizing nanoparticles of iron oxide that enhance contrasts in an MRI, and characterizing the particles with TEM. Harmer and Kiely and their collaborators, who include physicists, chemists, mechanical engineers and biomedical researchers, hope to use the particles to improve the diagnosis and targeted treatment of breast cancer. The team, led by Winston Soboyejo of Princeton, includes researchers from Duke and Louisiana State Universities, as well as Makerere University in Uganda and Cheikh Anta Diop University in Senegal.

WHEN KNOWLEDGE PRECEDES UNDERSTANDING

The nano world has always been with us, says Bruce Koel. What is new is our attempt to understand and control it to make new materials and devices.

"For example, people who work in catalysis pass crude oil over catalysts to get gasoline," says Koel. "These catalysts have always been nanoparticles. What we are now trying to do is control their size, shape and features. To us, 2 nm is very different from 4 nm and a cube is very different from a sphere. This level of control is unprecedented."

Koel's point is illustrated by Israel Wachs, a professor of chemical engineering and noted catalysis expert. Wachs has learned that tungsten oxide, an acid used to boost octane in gasoline, is 100 times more reactive when attached to titania nanoparticles measuring 1 nm than when attached to titania measuring roughly 5 nm.

Himanshu Jain, professor of materials science and engineering, says "ruby glass" is another example of knowledge preceding understanding. Two millennia ago, without understanding why it happened, the Romans knew that gold dispersed in glass could cause the glass to take on a reddish hue. Not until the 1920s did scientists learn that colloidal nanoparticles of gold were responsible for imparting the red hue.

Jain has assembled an international team of researchers to explore the electrical properties of gold and silver nanoparticles distributed homogeneously in glass.

"The optical properties of gold nanoparticles distributed in glass are reasonably well-understood," says Jain, who directs Lehigh's NSF-supported International Materials Institute for New Functionalities in Glass, "but there is no literature on the electrical behavior of the nanocomposite

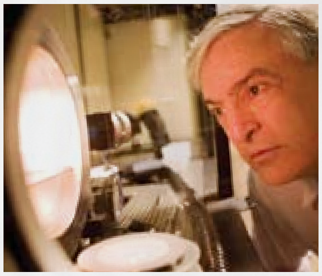
The achievement, says Bartoli, "opens a door to the control of light waves on a chip." It could reduce the size of optical structures, enabling them to be integrated at the nanoscale with electronic devices.

Bartoli and Gan reported their achievement in June 2008 and February 2009 in *Physical Review Letters*. The articles were coauthored with two other researchers in Lehigh's Center for Optical Technologies.

THz waves measure several hundred microns in length and are suitable for security applications. Telecom wavelengths measure 1330 to 1550 nm and are suitable for optical communications.

The researchers describe their structure as a "metallic grating structure with graded depths, whose dispersion curves and cutoff frequencies are different at different locations." The grating looks like a pipe organ whose pipes decrease gradually in length from one end of the assembly to the other. The degree of grade in the grating can be tuned by altering the temperature and modifying the physical features on the surface of the structure.

The structure arrests the progress of light waves at multiple locations on the surface and at different frequencies. Previous researchers, Gan says, had been able "to slow down one single wavelength within a narrow bandwidth, but not many wavelengths over a wide spectrum."



To release trapped light waves from the grating structure, and enable their use in telecommunications, the group covers the structure with a dielectric material. "By tuning the temperature of the dielectric," says Gan, "we can change the optical properties of the metal grating structure. This in turn enables the trapped light waves to be released."

Most of the group's initial work has involved mathematical equations and computer simulation. The group plans next to use focused ion beam milling to fabricate structures and near-field scanning optical microscopy to characterize them.

"Our goal," says Gan, "is to achieve a grade of grating depths that range from very shallow to as much as 50 nm on a 200-nm substrate."

The group's results, says *New Scientist*, "suggest that one day we might be able to slow down light long enough to store it as a 'rainbow' of colors - an advance that would revolutionize computing and telecom networks."

material. Our theory is that we might see nonlinear electric properties and switching."

Jain and his team hope that particles of silver measuring 8 to 10 nm might facilitate the development of antibacterial glass. They are using the Scienta ESCA 300 to examine the chemical structure of the nanoparticles as they disperse in phosphate glass.

SILICON PHOTONICS

The silicon chip, says Tom Koch, an NAE member and director of Lehigh's COT, combines economy of scale, precision and sophistication like no other technology. Its 1 billion

Koch wants to overcome silicon's optical deficiency by exploiting its superior electronic properties and the precision with which it can be fabricated.

transistors contain features as small as 45 nm, a size engineers hope to cut in half.

"As a manufacturing enterprise," says Koch, a professor of both electrical engineering and physics, "nothing in history comes even remotely close to the chip."

But silicon does not emit or detect lightwaves usable in most telecommunication applications, a shortcoming that would seem to rule out a central role in meeting the escalating demands for speed, size and power in next-generation networks.

Koch, working in an area called silicon photonics, wants to overcome silicon's optical deficiency by exploiting its superior electronic properties. Researchers at Intel and at COT partner Lightwire Inc. have shown that silicon chips can be used to encode data on a light beam at speeds of 10 billion bits per second and more. It turns out that silicon's weak interaction with light, if highly concentrated, can support practical optical device structures.

"Silicon is not the greatest material for optics," Koch says. "But you can deposit layers and pattern structures on silicon chips whose features are extremely well-developed and precise. This could enable us to design and fabricate things we cannot do with any other technology. If it works, this could be very cheaply manufactured as well."

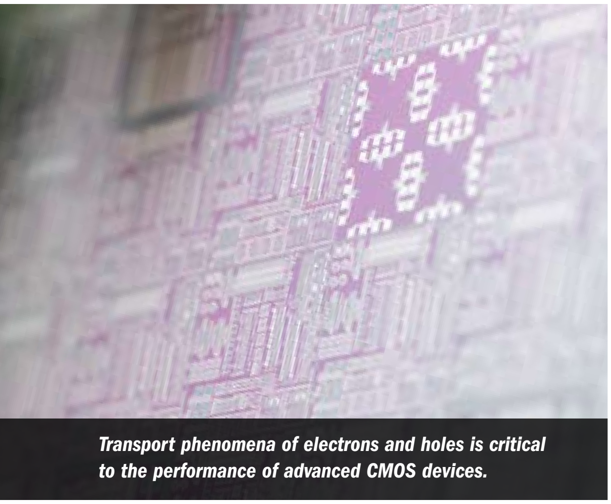
In one project, Koch is improving the ability to guide lightwaves in silicon nanostructures without losing significant quantities of the light signal. He and his group have succeeded in squeezing a remarkable fraction of the light into a sideways slot waveguide only 8 nm thick.

Koch's partners in this endeavor include MIT, Cal Tech, Stanford, Cornell, Boston University, and the Universities of Rochester and Delaware. Koch, who also collaborates with researchers in Belgium and Singapore, has given 18 invited talks and short courses on silicon photonics around the world.

One of the goals of Koch's group is to make a laser out of silicon. Into the silicon nanolayer, the team inserts erbium ions that emit light at 1550 nm, in the telecommunications region of the spectrum. By keeping light losses low in the silicon nanostructure and providing nanoscale electrical access to the ions, the group hopes to be able to excite the erbium to emit light.

"A device with this kind of waveguide also offers very good promise for chemical and biosensing applications," says Koch. "With so much energy concentrated at the nanoscale on the surface, we can functionalize the surface to sense molecules, proteins or bio species. We think we can measure down to the point of a single molecule."

Koch receives significant funding from NSF, DARPA, and the Defense Department's Multidisciplinary University Research Initiative Program.



Transport phenomena of electrons and holes is critical to the performance of advanced CMOS devices.

Researchers in the Sherman Fairchild Center use lasers to create and detect nonlinear optical effects and other excitations in materials.

Palladium-coated iron nanoparticles in solution.

A NANO-ENSEMBLE FOR H_2

In the search for clean, renewable energy sources, hydrogen has attracted much attention. Before it can be useful, though, scientists must learn how to produce hydrogen cheaply, cleanly and in large quantities. Dmitri Vezenov is developing a “multinetwork” nano-catalyst that self-assembles and uses solar energy to obtain hydrogen from water.

Photocatalytic water splitting typically uses titania as the catalyst, says Vezenov, an assistant professor of chemistry. Titania is used widely as a pigment and also in sunscreens because it absorbs ultraviolet light. It is also used in photovoltaic cells.

Titania has a limitation, however – its bandgap is too large to absorb visible light, which contains the largest amount of solar energy.

Vezenov has enlisted an ensemble of materials to overcome this shortcoming. He uses an organic linker to assemble a shell of cadmium-selenide nanoparticles (4 nm) and gold nanoparticles (20 nm) around a core formed by titania nanoparticles (20 to 40 nm).

“This is a porous catalyst with three networks,” says Vezenov. “The gold nanoparticles conduct electrons, while the titania nanoparticles do the electrochemistry to split water into hydrogen and oxygen. The CdSe nanoparticles, which are quantum dots, absorb the visible light.”

Sunlight plays a critical role in the reaction, Vezenov says, by exciting the titania electrons. As these electrons are “promoted” out of the filled valence band, they are replaced by electrons coaxed from the water, thus enabling the oxygen and hydrogen to split.

“We have generated some self-assembled catalyst films,” says Vezenov. “Because each of the materials linked has its own spectroscopic signature, we observed that they do indeed interact electronically after self-assembly. We are now checking for catalytic activity by looking for changes in the electrochemistry.”

COT researchers (p. 21) use an ensemble of quantum dashes to generate a new type of broadband semiconductor laser.

A key role for hydrogen in the solar revolution

With the silicon solar-cell industry growing by more than 40 percent a year, says Michael Stavola, scientists need better ways to neutralize defects in semiconductors.

Silicon is used in more than 90 percent of all solar cells for power modules, says Stavola, who chairs Lehigh’s physics department. Thin films composed of compounds of other semiconducting materials make up most of the rest.

Manufacturers of solar cells typically use a wafer made of multicrystalline silicon that is cheaper than the single-crystal silicon used in microchips. Multicrystalline silicon, however, has more defects, and greater amounts of carbon and other impurities, than does single-crystal silicon. These defects, which include grain boundaries and dangling bonds, reduce the ability of the solar cell to generate electricity.

Stavola has spent 25 years investigating defects in semiconductors and the ability of hydrogen to passivate those defects. His goal is to answer basic questions about the behavior of hydrogen in semiconductors, particularly in silicon solar-cell materials.

Ultimately, Stavola also hopes to neutralize one of the major obstacles to the wider use of solar energy – its price tag.

“It’s easy to make solar cells; the technology dates back to the 1950s,” he says. “But we have to be able to make solar cells as cheap to use as coal is.”

A CRITICAL COATING

When a silicon solar cell is fabricated, a thin antireflection coating is added to facilitate the penetration and absorption of light into the silicon. This coating, which contains 20 percent hydrogen, is annealed when the solar cell is processed to make its metal contacts. During this process, the hydrogen diffuses from the coating into the silicon.

Inside the solar cell, defects in the silicon undermine the generation of electricity by causing electron-hole pairs that have been generated by exposure to sunlight to recombine. The hydrogen mitigates these defects, prolonging the lifetimes of the electron-hole pairs and restoring their contribution to the electric current.

“The manufacturers of solar cells are able to make hydrogen passivate the defects in the multicrystalline silicon, but without understanding what exactly is happening,” says Stavola.

Stavola, an experimental physicist, conducts vibrational spectroscopy experiments with a Fourier Transform Infrared Spectrometer. The vibrations of atoms offer clues to the atomic structure and chemistry of materials.

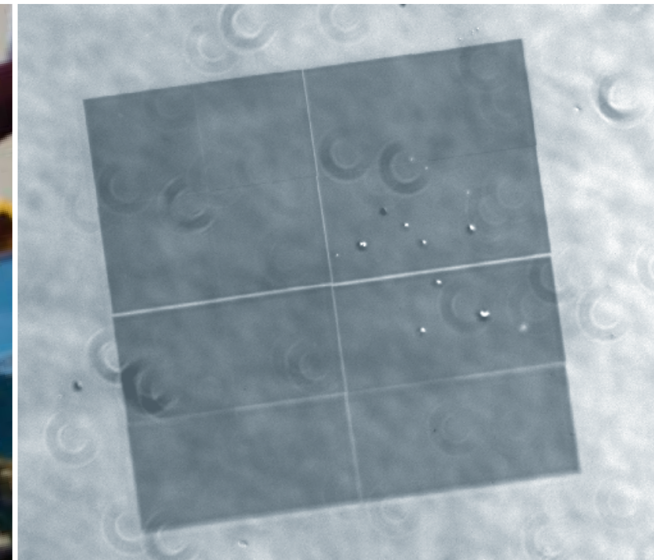
Stavola’s team is the first to observe and characterize the hydrogen that is introduced into silicon solar cells during fabrication. The group has also determined the concentration and penetration depth of the hydrogen and compared these criteria for various solar-cell processing methods.

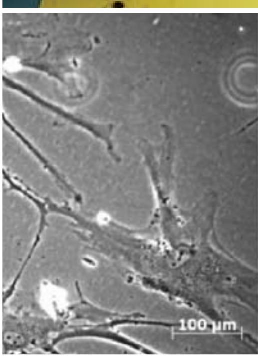
Other questions remain. Which defects are passivated by the hydrogen? What effect do the defect reactions have on the silicon? How can these reactions be modeled to enable fabricators to optimize all the steps in the hydrogenation process?

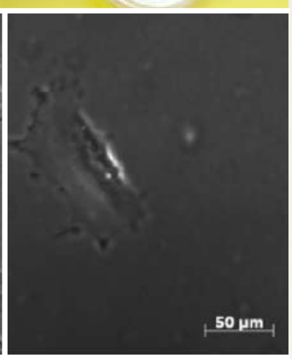
“There are a lot of ways to get hydrogen to enter solar-cell materials,” says Stavola. “What we need is a low-cost strategy that works in conjunction with the processing of the cell.”

Stavola collaborates with Beall Fowler, professor emeritus of physics and a theoretician who calculates the atomic structures and vibrational properties of material defects. He also works with Ajeet Rohatgi, founder of the University Center for Excellence in Photovoltaics at Georgia Tech. And he has ties with the Technical University of Dresden, Texas Tech University, the University of Rome, the University of Pittsburgh and American Capital Energy.

Stavola has received funding from NSF, DOE and a consortium of solar-cell companies.







Adult stem cells mature in "smart" petri dishes

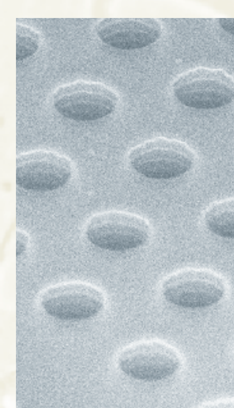
RESEARCHERS ARE FABRICATING NANOSTRUCTURED SURFACES with injection molding, modifying them biochemically and tailoring them to guide cells along the path to differentiation.

Adult stem cells – undifferentiated cells that maintain and repair tissue in living organisms – have been studied for years. Scientists hope to coax the cells to differentiate, or form specific cell types, so they can be used in medical applications.

Controlling differentiation is a challenge, so scientists are seeking to grow and study adult stem cells in the laboratory. This endeavor stands to benefit from a fortuitous collaboration between Sabrina Jedlicka and John Coulter, who have grant proposals pending to develop the biochemically modified nanostructured surfaces required for stem cells to differentiate.

Jedlicka, an assistant professor of materials science and engineering, is working on biochemical ways to push adult stem cells to differentiate into mature tissues such as bone, muscle and brain. Coulter, a professor of mechanical engineering and mechanics, is internationally renowned for his work in nanoscale injection molding, which has been used in optical, biomedical, data storage and fluid mechanics applications.

Neither researcher knew of the other's expertise until Coulter paid a visit to Jedlicka's office in 2008, soon after she joined the Lehigh faculty. A few days later, they submitted their first proposal to NSF.



John Coulter and Sabrina Jedlicka hope to develop a variety of surfaces whose "nanopillar" geometry and biochemistry can be tuned to desired cell applications.

Coulter's research group is one of only two in the world that has produced nano-injection molded products with features as small as 50 nm in size.

Their project holds great promise if they can solve a complex problem – the design of nanostructured substrates and media conditions to facilitate the consistent growth and differentiation of various types of stem cells.

To date, scientists have isolated stem cells or precursor cells and implanted them directly at the site of disease. The premise is that the body will direct these cells into new, mature, healthy tissue. But the human body does not always stimulate these cells appropriately, which can lead to failure of the therapy, implant rejection or even tumor formation.

"We need to be able to differentiate cells consistently by growing them under standardized conditions and on standardized surfaces." —Sabrina Jedlicka

"Scientists have reached a bottleneck," Jedlicka says. "To move cell-based therapy forward as a widely available, safe treatment option, we need to be able to differentiate cells consistently by growing them under standardized conditions and on standardized surfaces." This will not only lead to tissue regeneration *in vitro* for therapeutic purposes, but will also help scientists understand the complex biomolecular signaling that occurs during cell and tissue development.

NANO-TUNED INJECTION MOLDING

Jedlicka and Coulter have developed what one might term "smart" petri dishes, or biochemically modified nanostructured surfaces, on which they grow a variety of stem cells. One type, human mesenchymal stem cells, is derived from bone marrow and is believed to be able to differentiate into many types of connective tissues in the body under appropriate activation conditions.

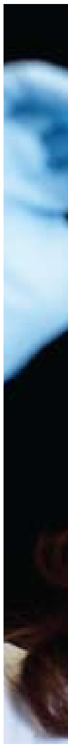
Coulter's group, one of only two in the world that has produced nanomolded features as small as 50 nm in size, fabricates experimental substrates on which the cells grow. The nanoinjection molding process requires great precision and control. A silicon mold is first fabricated at Lehigh's Sherman Fairchild Center for Solid-State Studies. Using electron-beam lithography, an electron beam controlled by a computer file exposes spots on the coating of the silicon, causing them to weaken. Plasma created by an ion-etching machine then eats away the weak regions of the coating and digs deeper into the silicon mold, creating the cavities that will form the pillars of the eventual polymer substrate.

There are more technical hurdles. The mold must be treated so the polymer injected into it doesn't stick, and the silicon mold must be protected from breaking under the high pressure exerted during injection molding. Coulter's group has solved these challenges by applying anti-stiction coatings to silicon mold inserts that are then incorporated into a larger brass mold base prior to injection molding.

Finally, the polymer must fill the mold entirely. In typical injection molding, molten polymer is deposited into a cold mold and freezes instantly. If this is done with extremely small features, however, not all the channels in the mold would fill completely. To fabricate nanoscale features, Coulter's group dynamically controls the local mold temperature and temporarily heats the mold hotter than the polymer. The polymer then flows unimpeded and is cooled immediately after it is poured.

After the nanostructured substrate is fabricated, Jedlicka prepares it for cell culture studies and places cells on it to grow. She is working on a chemical technique to modify the structures with critical protein-derived peptides to support cell adhesion and trigger differentiation signaling.

As the cells differentiate, Jedlicka examines them microscopically for morphology changes. At various points during the cycle, she does biochemical testing. This typically involves immunocytochemistry, in which researchers use antibodies to "tag" a protein of interest and view it with fluorescence microscopy. Each cell type has a different protein signature that varies throughout development. For example, neurons are known to uniquely express a cytoskeletal protein known as ß-tubulin III.



The nanostructures that Jedlicka and Coulter make have a material stiffness that approaches the physiological stiffness of the desired tissue *in vivo*. When the structures are modified with biochemicals similar to those with which the cells interact in the body, they develop into an environment with the appropriate mechanical, topographical and chemical cues. Modifying the nanoscale feature size and biochemistry makes these surfaces "tunable" to any desired cell application.

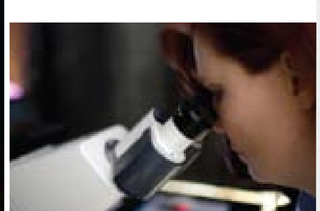
Imagine a bed of nails, says Jedlicka, and you can envision what these minute surfaces look like. Thousands of tiny plastic pillars make up the surface, and they are made stiff to produce bone tissue, less stiff for muscle and soft for neurons.

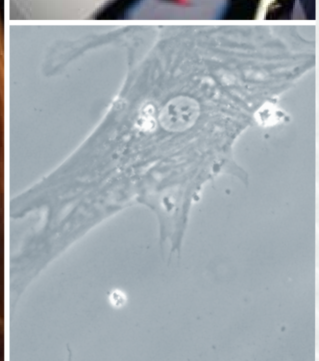
"We hope to develop a selection of these smart petri dishes, each variety with a different nanopillar geometry and biochemistry," she says, "so that a scientist who wants to make neurons can choose the dish with the longest, softest pillars modified with the laminin peptides critical for neuronal growth. Lehigh is one of the few places that can actually develop the technology to make these surfaces in large volume and at relatively low cost."

After biochemical testing demonstrates that a cell has become a cell of interest, functional testing ensures that it is becoming more mature than it would on a traditional petri dish. For neurons, this will include electrophysiological testing, neurotransmitter release characterization and synapse examination.

"Our goal is to consistently push the cells into a more mature, defined state than can be currently achieved," Jedlicka says.

Jedlicka modifies the nanostructures with protein-derived peptides to support cell adhesion and differentiation.





A QUANTUM LEAP FOR THE QUANTUM DASH

Along the spectrum of visible and invisible lightwaves, scientists seeking to develop optical technologies are often guided by a critical factor that also animates real-estate agents – location.

This is especially true with lasers, which can gain or lose the ability to perform optical telecommunications and other functions if the wavelength at which they are emitted shifts by a few tens of nanometers.

Conventional lasers emit light along a single wavelength. Broadband semiconductor lasers achieve greater spectral range by emitting light along multiple wavelengths at the same time.

Boon S. Ooi and his students in Lehigh's Center for Optical Technologies (COT) have developed a new type of broadband semiconductor laser that emits light over an 85-nm span of the infrared region of the spectrum.

Ooi, an associate professor of electrical and computer engineering, says his group's broadband laser can be generated at a cost of a few hundred dollars from a device measuring just a few hundred micrometers in size.

By contrast, conventional broadband lasers, which are generated with a short-pulse crystal laser technique, require equipment that costs several hundreds of thousands of dollars and must be housed on a large table.

The small size and low cost of Ooi's laser, coupled with an exceptional power of more than 500 milliwatts, give the laser potential applications not only in optical telecommunications but also in biosensing and biomedical imaging and diagnosis, Ooi says. One potential application will be to improve optical coherence tomography, a noninvasive imaging technique that obtains high-resolution images of subsurface tissue. The new laser will be able to achieve superior resolution at deeper penetrations, says Ooi, enhancing the accuracy of diagnostic techniques.

Ooi and his group reported the results of their research in 2008 in an invited paper in the *IEEE Journal of Selected Topics in Quantum Electronics*.

Members of the group include James Hwang, professor of electrical and computer engineering at Lehigh, and several Lehigh alumni, as well as the U.S. Army Research Laboratory (ARL) and IQE Inc., an international supplier of advanced semiconductor wafers based in Bethlehem. The group's work is supported by ARL, NSF and the state of Pennsylvania.

Beyond dots to dashes

The success of Ooi's laser requires an understanding of the behavior of lightwaves and of the physical, mechanical and optical properties of semiconducting materials at the nanoscale.

Ooi's laser device contains an ensemble of light-emitting quantum dashes arrayed on an indium-phosphide substrate at a density of 1 billion per square centimeter. A quantum dash is an elongated version of a quantum dot, a nanosized semiconductor that spatially confines electrons and hole pairs.

Ooi's team uses quantum dashes made of two semiconducting materials and assembled into a laser structure measuring half a millimeter long and 300 microns wide. The structure's diode contains four sheets, each with five quantum-dash monolayers, including embedding quantum-well and barrier layers. The dimensions of all these features measure in the tens of nanometers or smaller.

The laser's inhomogeneous structure, says Chee-Loon Tan, a Ph.D. student, enables it to emit light along a relatively wide range of the spectrum.

"Each of the dashes emits light," says Tan. "Because the dashes have different sizes, heights, compositions and geometries, they generate different wavelengths."

After the laser structure has been assembled, Ooi's team uses an intermixing technique called impurity-free vacancy disordering (IFVD) to enhance bandwidth and achieve the desired wavelength for the laser.

The researchers hope to increase the bandwidth emission of their laser to 160 nm.

THE ARTS-ENGINEERING EDGE

The arts-engineering program confers two bachelor's degrees. Students pursuing architecture and civil engineering gain unique insights into the design and construction of buildings.

VENERABLE PROGRAM IS A CAREER ENHANCER

Kim Gagnon's ideal house of worship elicits reverence through natural light, using a high ceiling made of crisscrossing beams and glass to cast sunlight and shadows in geometric patterns.

Gagnon, a junior majoring in civil engineering and architecture, built her model "sanctuary of light" as an assignment for her architecture studio. Besides its visual appeal, the building has a novel structural feature: Its ceiling rests not on walls but on concrete columns.

"I think it's really important in architecture to show structure," says Gagnon, whose father and grandfather worked in construction and taught her to appreciate well-made buildings.

In high school, Gagnon's aptitude for math and science seemed well-suited for an engineering career, but her interest in design pointed toward architecture. She applied to several technical schools and chose Lehigh because it alone offered an in-depth study of both engineering and architecture through the Arts and Engineering (AE) Program.

Established more than 60 years ago, AE requires students to complete two bachelor's degree programs in five years. Students may select any combination of majors from the College of Arts and Sciences and the P.C. Rossin College of Engineering and Applied Science. Although they may combine any two majors, such as mechanical engineering and music or electrical engineering and philosophy, almost half of AE majors select civil engineering and architecture.

"IT'S REALLY IMPORTANT IN ARCHITECTURE TO SHOW STRUCTURE."

—Kim Gagnon

"It makes sense. There's an affinity between the two disciplines," says Bruce Thomas, associate professor of art and architecture and faculty adviser to AE students.

Architects and civil engineers work together to design bridges, buildings and other structures, Thomas says, but they approach their problems from different points of view. Architects manipulate a structure's form and function to suit an owner's needs, while civil engineers tend to the building's infrastructure.

"Students who obtain the dual degree have a unique insight into the design and construction of buildings," says Stephen Pessiki, chair of the department of civil and environmental engineering and the academic adviser for AE students from that department.

"Not coincidentally," Thomas adds, "it's a very nice credential to have in the job market, whichever direction you want to go."

Students gain a greater sense of structure through the dual degree program than they would in the architecture program alone, which emphasizes history and design. Many AE alumni enroll in graduate architecture programs or start careers as engineers.

Civil engineers who complete the dual degree acquire an architect's concerns – a trait that made Geoff Brunn '07 an attractive candidate to the international design firm of Skidmore, Owings and Merrill LLP (SOM).

Brunn, now a structural engineer with SOM, spent much of his interview with the firm discussing his Lehigh degrees and his undergraduate research project in concrete. As a student, he had helped Clay Naito, associate professor of structural engineering, determine that self-consolidating concrete was worth its high price tag because it reduced labor costs and resulted in a higher-quality product.

"My research was particularly important in helping me get this job," says Brunn, who also holds an M.S. in structural engineering from the University of California at Berkeley. "It demonstrated that I have the ability to think unconventionally and to analyze a situation."

Today, Brunn draws from both his Lehigh degrees. His engineering courses provide him with the skills his job requires, but his ability to draw and visualize in 3-D helps him communicate his designs to coworkers.

Brunn transferred from Lehigh's traditional engineering track to the AE program his sophomore year when he found himself drawn to architecture.

"To me, there's something fantastic – it's romantic – to see what you've drawn and designed actually built and lived in."

Brunn agrees with Pessiki that the AE program demands extensive time and commitment. "It is not for everyone, but for me it was a great match," he says.

His sentiments are echoed by Sean Dooley '98, a civil engineering and architecture graduate who works as a civil engineer at Keystone Consulting Engineers.

"The breadth of education from the AE program and the academic rigor imposed on me at Lehigh prepared me to become a better civil engineer," Dooley says.

One of Dooley's Lehigh professors secured an internship for him at an engineering firm in Switzerland and later recommended him for a doctoral program at the Swiss École Polytechique Fédérale de Lausanne. When Dooley returned to the Lehigh Valley, Lehigh's department of art and architecture offered him an adjunct position teaching a course on the technology of building.

Gagnon, who will take the building technology course next year, worked with her professors to fit her courses around several internships at the Pennsylvania Department of Transportation. After graduation, she hopes to use her engineering skills to restore dilapidated buildings.

"Knowing how architects think," she says, "will allow me to maintain the ideas of the architect who first designed the building."

Giving passion a place to grow

Josh Brown's favorite possessions include a trombone, a drum set and a 2008 Lehigh diploma stating that he earned a B.S. in mechanical engineering. This May, he will add another treasure: a second bachelor's degree in jazz studies.

Like many Arts and Engineering students at Lehigh, Brown has used the AE program to delve into non-engineering interests.

Music, he says, "is not a hobby – it's a passion."

In his first year, Brown formed a 10-piece student funk band called J-Wok and the Pedestrians. The band is known for its blaring horns and clashing costumes – feathered hats, overalls, Lehigh sweatshirts and flashy orange suits. They have won two first-place prizes at Battle of the Bands, several gigs on campus and a monthly performance at a local bar.

Brown came to Lehigh because he could take part in music while completing a technical degree.

"I knew I was going to be an engineer," he says. "Lehigh was the only school I looked at that had great engineering and a great music program too."

Many student-musicians could enter music conservatories but opt for other careers, says Paul Salerni, professor and chair of Lehigh's music department. Lehigh allows these non-music majors to participate in ensembles and choral groups.

"Of all the engineering schools in the world, except MIT, I think we offer engineers the broadest set of musical opportunities," Salerni says.

Brown

Engineers comprise up to 50 percent of Lehigh's active musicians. The engineering college and music department have hosted a Music-Engineering Candidates Day for students interested in music, engineering and science. Salerni says engineers and musicians share similar traits – diligence, a grasp of mathematics and the drive to create.

"Not only can you do both music and engineering, we encourage you to do both," says Rick Weisman, a professor of civil and environmental engineering who has played trumpet in Lehigh's orchestra, mariachi band, wind ensemble, symphonic band and brass ensemble.

Brown now works part-time at Air Products and Chemicals while finishing his arts degree. He plans to be an engineer by day and a musician by night.

Dynamic models have improved the defense and aerospace industries, says Eugenio Schuster, and can do the same for energy applications.

Optimizing operations across engineering

Eugenio Schuster, assistant professor of mechanical engineering and mechanics and recipient of an NSF CAREER Award, can look at any type of system and visualize how it is being controlled.

"Controls are everywhere in our lives," says Schuster. "People use them without even knowing it."

As an example, Schuster cites the everyday cruise control system, which measures and monitors an automobile's speed. If that speed dips below the rate set by the driver, a microcontroller signals a mechanical device to depress the accelerator and send more gas to the engine.

It may be tempting to call Schuster a "control freak," but "enabler" is a more accurate label. Schuster works on control systems that are far more complex than cruise control and that have applications in every engineering discipline.

"We want to control systems so they respond faster and more reliably to commands. Our goals are usually stabilization and performance." —Eugenio Schuster

The CAREER Award supports Schuster's work with the nonlinear control of plasmas in nuclear fusion, a project that has been reported in previous issues of *Resolve*. Schuster is also interested in controls for other forms of energy, control of aerospace and mechanical systems, optimal control of large experimental physics devices such as particle accelerators, and magneto-hydrodynamic (MHD) flow control.

"In my field, we try to control the dynamics of a system, or how it behaves over time," says Schuster. "Our goals are usually stabilization and performance. We want to control systems so they run and respond faster and more reliably to commands. We do most of our work mathematically, exploiting the availability of differential equation models that predict a system's behaviors. Modeling a system's dynamics and carrying out high-performance computer simulations are significant parts of our work."

Schuster's collaborative work with Carlos Romero of Lehigh's Energy Research Center aims to control emissions using catalytic converters at coal-fired power plants. Under the auspices of the New York State Energy Research and Development Authority, Schuster and Romero are designing optimal controllers to reduce emissions and improve the overall economics of the plants. The controllers, driven by mathematical models, enable the catalytic converters to adapt to changes in the system, which in turn allows emissions to be minimized while power production is maximized.

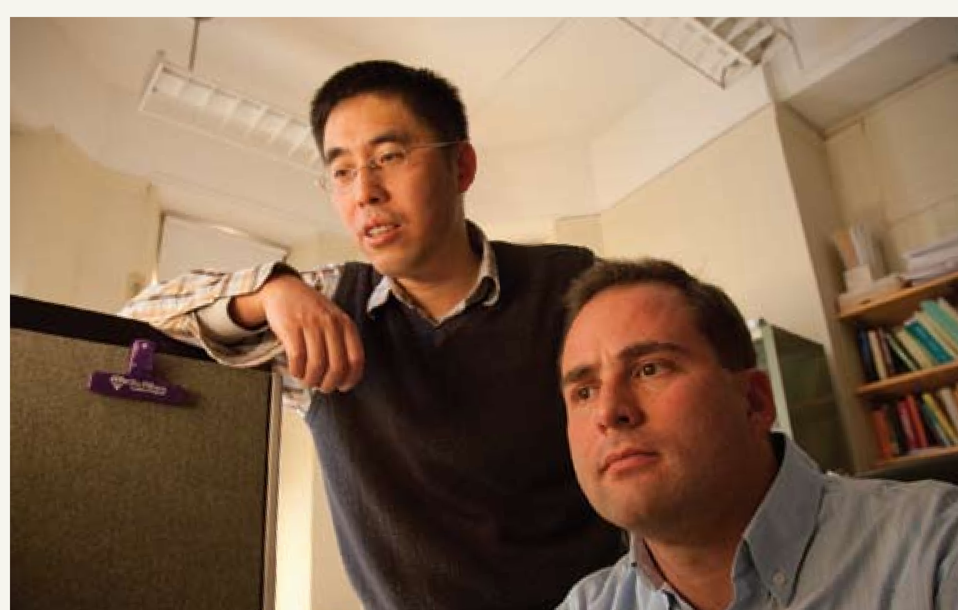
By injecting ammonia into the catalytic converters, plant operators can lower emissions. But this generates a waste product called ammonia slip, which can cause damage to the power plant. Schuster's model-based controllers allow for slightly higher but permissible emissions while lowering ammonia levels. The controllers also account for and react to real-time changes in the plant, such as coal quality, while maintaining optimal operating efficiency.

With today's overreliance on foreign oil, says Schuster, control systems have the potential to save millions of dollars for the U.S. energy sector.

"Coal-fired power plants could save significant amounts of money," he says, "but while there's a revival of interest in optimized configurations, it remains to be seen how much controls are used. Unlike the nation's defense and aerospace industries, the fossil-fuel industry is historically somewhat conservative when it comes to applying sophisticated controls.

"The use of dynamic models has been one of the reasons for the extraordinary progress of the defense and aerospace industries. We need to do the same in the energy industry. It's a pity not to exploit the models we develop."

Schuster notes that systems that depend only on time can be modeled by ordinary differential equations, but those with dynamics depending both on time and space require partial differential equation (PDE) models. Schuster is leading a group of researchers in Lehigh's Laboratory for Control of Complex Systems on PDE control. He was invited to present the results of this work at an NSF workshop at UCLA in early 2009.



Lehigh in the NAE

Many Lehigh alumni have been elected to the National Academy of Engineering. Here are a few examples:

William C. Hittinger

B.S. in metallurgy, 1944

Hittinger oversaw systems engineering for NASA's manned spaceflight program at Bellcomm. As executive vice president at RCA, he led development of the first successful demonstration of color videorecording on a disc.

George J. Tamaro

M.S. in civil engineering, 1961

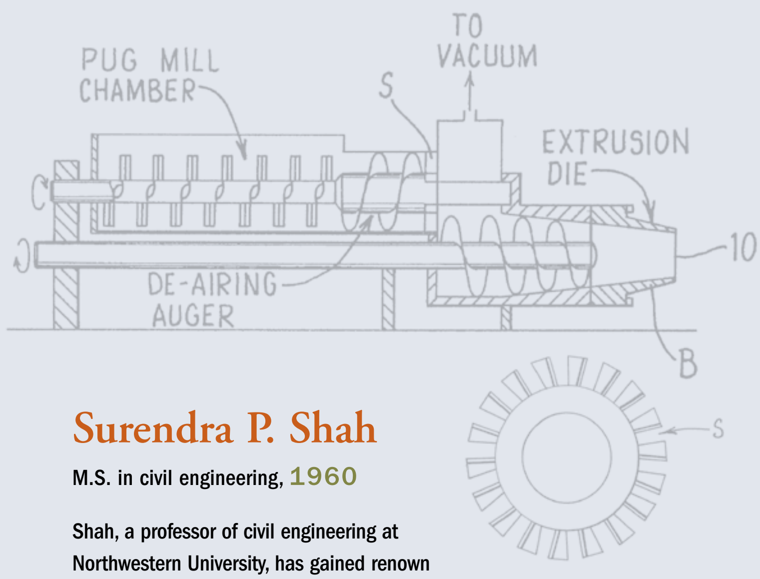
To prevent massive subway flooding in New York City after the September 11 terrorist attack, Tamaro directed the reconstruction of the subterranean perimeter wall of the World Trade Center.

Arthur Veinott

B.S. in industrial engineering, 1956

A Guggenheim Fellow and a Fellow of the Institute of Mathematical Statistics, Veinott is a founding member and 10-year chair of the department of operations research at Stanford University.

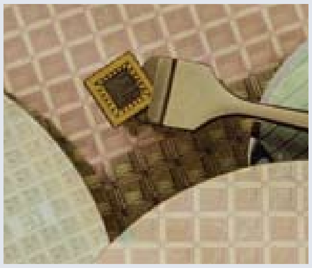
LINDA A. CICERO / STANFORD NEWS SERVICE



Surendra P. Shah

M.S. in civil engineering, 1960

Shah, a professor of civil engineering at Northwestern University, has gained renown for pioneering work in connecting the microscopic characteristics of concrete to the material's structural utility.



Gary S. Calabrese

B.S. in chemistry, 1979

Calabrese has developed advanced electronic materials and processes for semiconductor device manufacture. In 2008, he joined Corning Inc. as vice president of science and technology.

Alton D. Romig

B.S., M.S., Ph.D. in metallurgy and materials engineering, 1975-79

In three decades with Sandia National Laboratories, Romig has risen to the position of senior vice president and deputy laboratories director for Integrated Technologies and Systems.

Sandia National Laboratories

To learn more about the achievements of Lehigh engineers, visit the Lehigh Engineering Heritage Initiative at

www.lehigh.edu/heritage

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Engineering and Applied Science
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A MENTOR FIRST

Miniemulsion polymerization, says Mohamed S. El-Aasser, a pioneer in the field, is revolutionizing medicine and biotechnology as researchers learn to embed nanoparticles in polymers and deliver them to specific areas of the body.

See page 8