A TOWER OF POWER
Honing the constancy of phase-change materials to store solar thermal energy. See page 10

SUBSTRATES MADE SMART
Stem cells chart path to differentiation on petri dishes molded with nanostructures. See page 18

REVEALING THE INFINITESIMAL
RESEARCHERS UNLOCK THE POTENTIAL OF THE NANO-WORLD. See page 12
LETTER FROM THE DEAN

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 of energy and the environment, particularly as they relate to health care, energy and the global economy.

Our researchers have at their disposal a research portfolio that is incredibly rich and diverse and have embraced these grand challenges as essential to all aspects of their work.

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

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

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 P.C. Rossin College of Engineering and Applied Science david.wu@lehigh.edu
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, materials and devices at the nanoscale. These investigators collaborate in three complementary research centers that represent a comprehensive set of capabilities in nanoscience and nanofabrication, or, put simply, in seeing, manipulating and making 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 nanotechnology-related capability and portfolio that is incredibly rich and capable of supporting a wide range of applications.

These investigators collaborate in three complementary research centers that represent a comprehensive set of capabilities in nanoscience 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 nanofabrication 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 nanotechnology-related capability and portfolio that is incredibly rich and capable of supporting a wide range of applications.

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LETTER FROM THE DEAN
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 Xianghong 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, a professor of chemical and biomolecular engineering at Lehigh. "But diagnosis in infants and young children is extremely difficult, yet crucial, to determine if a baby has 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 Wei-jie Mao and William Van Geystyn of Lehigh's material science and engineering department, and with Dr. Timothy Findlay, chair for research and infectious disease specialist at Lehigh Valley Hospital.

Lehigh’s emerging biotechnology initiative will focus research efforts on science and engineering. It will leverage Lehigh’s research partnerships in Portugal, places healthy progenitors of the lost ended cells into mature bone cells.

With funding from NSF, Jain and his team for several years been designing bioactive glass scaffolds that are biologically similar to the host tissue. "We don’t want to go for a biological reconstruction," says Jain. "The team, which also includes Jutta Marzillier of Lehigh New Materials Science.

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.

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.

Lehigh University • P.C. Rossin College of Engineering and Applied Science • 3
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 biomimetic glass scaffold which could understand how a biocompatible glass interacts with human cells.

Martha Falck, associate professor of biological sciences, was looking for a material scientist to help develop a new biocompatible material for orthopedic surgeons.

Both worked at Lehigh but it was on a flight to Japan that their paths first crossed. Falck, who uses fluorescence light microscopy to study the gap junctions in which her collaborators were 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 between Falck’s materials science and engineering department, and with Dr. Timotheos Froudakis, chair for research and infectious disease specialist at Lehigh Valley Hospital.

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, 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 virus. 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 immune system and 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, she is doing it by a technician in a clean lab who separates malaria from the blood. A machine then amplifies the viral 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 Ony-ang-fu, 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 Prof. Wojciech Misiolek and William Van Geerswynder of Lehigh’s material science and engineering department, and with Dr. Timotheos Froudakis, chair for research and infectious disease specialist at Lehigh Valley Hospital.

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 therapeutics.

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

Awarded 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. scores mounting health-care-costs reeling 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 the 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.”

Lehigh’s Genomics Facility, he is using Quantitative Real-Time Polymerase Chain Reaction to determine how a biocompatible glass interacts with human cells.
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 1890s that two chemists, Maxatake Harata and Graham Hutchings, discovered that the Noble element, long considered inactive, could be an extraordinarily good catalyst.

Hutcheson 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 CO2 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 surfaces. Writing in 2008 in Science, the team said bilayer clusters measuring about 0.5 nm in dimension and containing about 12 gold atoms are the key species on that catalyst, that their presence or absence correlates with the ability or failure of the catalyst to perform CO oxidation.

The team built 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 Kady 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 2005, they wrote in Science that gold-palladium nanoparticles, properly tailored, could lead to a cleaner, safer method of producing hydrogen peroxide (H2O2). That method, which requires the pretreatment of a carbon support with nitric acid, could also enable the direct production of H2O2 from hydrogen and oxygen in smaller quantities and more desirable products could be accomplished more cleanly and more efficiently with gold.

A cluster of eight to 12 gold atoms arranged in two layers

Hutcheson and a group of colleagues at Lehigh's Center for Advanced Materials and Nanotechnology, Hutchings and two colleagues at the UK’s Cardiff Catalysis Institute, and Andrew Herring of the U.S. National Institute of Standards and Technology, Herring earned a Ph.D. from Lehigh in 2006. Hutchings’ group carried out the fabrication and catalytic testing of the gold nanoparticles, and characterized the catalytic unit using x-ray photoelectron spectroscopy. Kady’s group then used Lehigh’s aberration-corrected 200 kV FEI scanning transmission electron microscope to examine the gold nanoclusters.

The researchers compared two groups of gold nanoparticles. One, dried in static air, was a “deaf” 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, Hutchings saw two types of gold species – particles larger than 0.5 nm in size and individual atoms scattered about on the iron-oxide support. On the 100-percent-active catalyst, he found a third species – diameters 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 Kady. “We deactivated the catalyst by increasing 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 has built a new team player for microscopy

As a scientist with the National Center for Electron Microscopy at Lawrence Berkeley National Laboratory, Masahiro 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 Microscopy) 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 Nanoscience and Nanotechnology Laboratory. With their ability to resolve images of individual atoms, and to identify those atomic chemical composition, says Watanabe, Lehigh’s aberration-corrected 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 steels to become brittle. The amount may be as low as a single impurity atom. “We need atomic-level resolution to analyze such small amounts of impurities. These instruments make this kind of analysis possible.”

Watanabe has pioneered several analytical techniques that enable more efficient data gathering. Working with FIREM 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 as many friends that I think we can assemble a strong team to attack some important challenges.”

Watanabe’s software analyzes large-scale datasets from microscopes.
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 in active, could be an extraordinarily good catalyst. Haruta learned that gold particles measuring less than 5 nm across possess the ability to oxidize CO. Another application is to fuel cells, which are vulnerable to damage by CO present in the hydrogen fuel stream.

The recent excitement has to do with gold nanoparticles, properly tailored, could be used to develop a clean, low-energy approach to oxidizing carbon monoxide. The scientists report that the nanoparticles react with carbon monoxide to form carbon dioxide (CO2) at room temperature. Scientists have sought since then to determine exactly how the 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 graphite.

In writing in Science, the team said bilayer clusters measuring about 0.5 nm in size 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 impel the gold to its catalytic capability.

Gold catalysts could find an application in the protective masks capable of converting CO to CO2, which 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.

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Driving from Lehag’s campus to her home in Allentown, Pa., Mooi Choo, an expert in wireless network security and routing, finds it difficult to leave her work behind. Choo’s daily commute requires her to take either U.S. Route 22 or I-78, both of which are notorious for accidents and delays. The congestion may vex other drivers, but it brings out the dreamer in Choo. If a traffic jam does occur, the wonder, could a voice-selected wireless system, using hyperbolic PDAs in cars as nodes, or connecting points, allow some drivers to quickly escape from 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’ wireless links.

Choo, an associate professor of computer science and engineering, has completed two of three phases in a 4-year project titled “Enhanced Dissemination Fault Tolerant Bundle Delivery System,” or EDFY. The project is funded by DARPA through a (Disruption Tolerant Networking) program. DTNs represent one of the key technologies for next-generation networks. Choo and her students, working with researchers from the Georgia Institute of Technology, the University of Massachusetts at Amherst and RBN Technologies, are developing networking and security technologies for DTNs.

One of the goals of EDFY, says Choo, is to design new network protocols 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 “call 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 Choo, “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 last binding feature supported in DTN will allow recipients to be identified later as the message moves closer to the destination region.”

China now leads the world in consumption of coal, says Edward Levy, director of Lehag’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.”

Developed by Lehag 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 Xi’an Jiaotong 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 Ramos, shows that Boiler OP will enable Pan Shan to reduce NOx 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 NOx by systematically adjusting a dozen or more boiler control settings. ERC engineers have developed separate software programs that work in tandem with Boiler OP. 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.

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Better, faster and cheaper

Tamas 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 non-linear optimization problems.

Terlaky harnesses these algorithms to optimize the core refining process of nuclear reactors, the radiation effectiveness of medical devices and 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, thus, with Delft University of Technology in The Netherlands, led a research group that used partial differential equations to develop his computerized fuel bundle optimization. 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 models that produce sharp images of cancerous tumors without harming organs. These methods enable doctors and medical physicists to optimally modulate the intensity of a beam, thus maximizing the treatment’s effectiveness while sparring healthy organs from undue damage. Their robust optimization methodologies take into account the fact that everything in the body is constantly moving.

As department chair at Lehag, 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 designs, while asking specific problems like the design and testing of an electric circuit layout.

“I am always working with engineers on specific applications, taking the theoretical to the practical,” he says.
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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 systems, while asking specific problems like the design and testing of an electric circuit layout.

“I am always working with engineers on specific applications, taking the theoretical over to the practical,” he says.
Mohamed S. El-Aasser, a renowned expert in emulsion polymerization and polymer colloids, has served Lehigh as university president since 2004 and was recently named vice president for international affairs. In 37 years with Lehigh, El-Aasser has earned numerous honors for his leadership, epi’s annual short courses have attracted more than 1,000 participants, the university has hosted more than 5,000 scientists from Lehigh and to Dawson, Switzerland, in the last three decades. El-Aasser and his students have published almost 400 technical articles. Students have published almost 400 technical articles.

Q: What are the qualities a person needs to be a great mentor?

A: Be interested in disseminating your outcomes. It’s also important to have a good team. I have been blessed with the students, faculty, and staff I’ve worked with.

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

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

Q: What do you consider the greatest achievement?

A: What’s most gratifying for me is 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.
Mohamed S. El-Aasser, a renowned expert in emulsion polymerization and polymer colloids, has served Lehigh University since 1984 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 course has 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 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.

Q: What do you consider your greatest achievement?

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 micrometer. But some applications require larger particles. To obtain a large particle, we suggested taking a sub-micron particle, swelling it with monomer and restabilizing 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.

Q: How has the field of miniemulsion polymerization evolved?

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 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.

Q: What’s most gratifying for you?

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: What’s most gratifying for you?

A: Other scientists will expand and improve on your work. 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: What do you consider your greatest achievement?

A: 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?

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Q: What role did you and your colleagues play in designing that device? Is it your idea or an idea off your colleagues?

A: We were able to carry out polymerization inside the monomer droplets. 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: What’s the greatest satisfaction in working with students.

A: 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 adjust 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 particle while increasing their size with a surfactant and with the addition of more monomer.

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

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

A: You should also be prepared to find solutions. 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: What do you consider your greatest achievement?

A: Not developing a new 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 micrometer. But some applications require larger particles. To obtain a large particle, we suggested taking a sub-micron particle, swelling it with monomer and restabilizing 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.

Q: What do you consider your greatest achievement?

A: We started with good ideas and an interest in exploring them. We came 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?

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Q: What do you consider your greatest achievement?

A: We randomly chose a 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 adjust 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 particle while increasing their size with a surfactant and with the addition of more monomer. We were able to make 10-micron particles which under normal conditions we would expect sedimentation 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 use.

Q: What do you consider your greatest achievement?

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.

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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. Harnessing energy from the sun can be clearer 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. Apuravan Oktalen, associate professor of mechanical engineering and mechanics, is a specialist in numerical calculations, and Knel Tulio, 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.

“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 powerplants 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, div- ing 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 miring process to use?

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“When the phase-change coating becomes hot enough, the zinc is stored. At night, the pellets stop absorbing solar energy but continue to store energy in a heat exchanger where it is converted to steam.

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**ZINC AUDITIONS FOR A ROLE IN SOLAR ENERGY STORAGE**

**REACHING FOR THE SKY**

Zinc for Energy Storage
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.

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“We looked for a material that can change phase and thus store more energy. We settled on zinc.”

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 formed by a eutectic mixture of magnesium and sodium chlorides. Eutectic substances are alloys.

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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. Slightly 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 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?

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.

“Are there 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, 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 Centers which have expertise in nanosynthesis and nanofabrication.

Lehigh’s nano researchers have scored successes in sensors and transducers, catalysis and semiconductors, 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.”

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 Keel, 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 Keel, 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.

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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 phenomenon 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 semiconductor memory — the memory inside a thumb drive or an iPod, for example, which relies on the storage of electrostatic 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 semiconductor materials and inside the semiconductor devices. Angle-resolved photoelectron spectroscopy helps determine a structure’s thickness by locating and identifying atoms at or near its surface.”

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. The 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 (ARPES) helps determine a structure’s thickness by locating and identifying atoms at or near its surface.

“With electron beam lithography, we can fabricate an object on a scale of 10 or 20 nm. 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.”

CONCEPTUAL CHANGES

Nanoengineering 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.”

“The carriers both along the surface, covered by nanolayers of thin semiconductor materials and inside the semiconductor devices. Angle-resolved photoelectron spectroscopy helps determine a structure’s thickness by locating and identifying atoms at or near its surface.”

“‘Our goal,’ says Gan, “is to achieve a grade of grading depths that range from very shallow to as much as 50 nm on a 200 nm sub-structure.”

The group’s research, says New Scientist, “suggested 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 telecommunication.”

When knowledge precedes understanding

Researchers in the Sherman Fairchild Center fabricate flexible electronic displays on silicon-on-flex substrates.

Lehigh University • P.C. Rossin College of Engineering and Applied Science • 15

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

When knowledge precedes understanding

Researchers in the Sherman Fairchild Center fabricate flexible electronic displays on silicon-on-flex substrates.
atoms or atom clusters dispersed over oxides,” says Christopher Kieyl, director of the CANN’s Nanocharacterization Laboratory. “It turns out that these clusters or atoms often play a critical role in material behaviors.” (See p. 4.)

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White has spent 40 years investigating nonvolatile semiconductor memory—the memory inside a hit-man drive or on an iPod, for example, which relies on the storage of electrostatic charge on capacitors to store information. Transistors then switch on and off to turn the charge on and off, generating patterns of 1’s and 0’s in the memory. 

“We model and study the transport phenomena of charge carriers both along the surface, covered by nanolayers of materials, and perpendicular to this surface,” says White. “The carriers move along the surface, covered by nanolayers of materials, and perpendicular to this surface.”

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**A graded grate that traps and releases light waves**

Light waves guided with nano-scale precision inside the circuits of an electronic chip can bring about applications in spectroscopy, sensoring and biomaging, and harness the ability to control all-optical telecommunications 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.

Qiangqian Gan, a Ph.D. candidate, and Filbert J. Bartoli, department chair of electrical and computer engineering, have developed a graded metal grating structure that allows light waves to move through the surface of the material in a controlled manner.

**The achievement, says Bartoli, “opens a door to the control of all light waves on a chip.” It could reduce the size of optical structures, enabling them to be integrated at different frequencies.**

The researchers describe their structure as a “metallic grating coupled with a dielectric slab,” Bartoli explains. “With the use of the dipole layer, we can control the transmission of light waves over a wide spectrum.”

To release trapped light waves from the grating structure, and enable their use in telecommunications, the group describes the structure as a “metallic grating structure that allows light waves to move in different directions.”

“...the current achievement allows light waves on a chip to be released.”

Most of the groups initial work involved simulating the physical equations and computer simulation. The group plans next to focus on low-temperature fabrication of the new material for use in high-speed and multi-frequency optical imaging.

“For our point,” says Bartoli, “we are able to achieve a grade of grading depths that range from very shallow to as much as 50 nm on a 200-nm sub-strate.”

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 electronic properties and switching.

Koch and his team hope that particles of silver (ranging in size from 8 to 30 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**

At the silicon chip, says Tom Koch, an AESE member and director of Lehigh’s COT, combines economy of scale, precision and sophistication like no other technology. Its 1 billion

It is a focus on Lehigh engineering and physics, “nothing in his

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

Koch, working in an area called silicon photonics, wants
to overcome silicon’s optical deficiency by exploiting its superior electronic properties and the precision with which it can be fabricated.

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

Koch has succeeded in squeezing a remarkable fraction of the light into a sideways slot waveguide only 8 nm thick.

One of the goals of Koch’s group is to make a laser out of silicon, into 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 functionize the surface to sense molecules, proteins or bio-samples. 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.

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 neu-
tralize 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 depart-
ment. These devices composed of one or more materials that make up most of the solar cells.

Manufacturers of solar cells typically use a wafer made of multicrystalline silicon. 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 Collie nanoparticles, which are quantum dots, absorb the visible light.

Silica 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 from the water, thus enabling the oxygen and hydrogen to split.

“We have generated some self-assembled catalyst films,” says Vezenov. “Because each of these materials have its own spectroscopic signature, we observed that they do indeed interact electrochemically after self-

assembly. We are now checking for catalytic activity by looking for changes in the electrochemistry.”

A NANO-ENSEMBLE FOR H₂

In the search for clean, renewable energy sources,hydro-
gen 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-assem-
bles 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 sunscreen because it absorbs ultraviolet light. It is also used in photovoltaic cells.

Titania has a limitation, however. “It is 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 sheet of cadmium-selenide nanoparticles (4 nm) and gold nanoparticles (20 nm) into 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 Collie nanoparticles, which are quantum dots, absorb the visible light.

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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. The coating, which contains 20 percent hydrogen, is ruined when the solar cell is processed to make its metal contacts.

“Manufacturers of solar cells typically use a wafer made of multicrystalline silicon that is cheaper than the single-crystal silicon used in microprocessors,” says Stavola. “There are defects to deal with. There are defects to deal with. There are defects to deal with. There are defects to deal with.

“Silicon does not contain defects, but without hydrogen the defects mitigate these defects, which are able to make solar cells 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 reduce the cost of hydrogen in the development of defects.

Ultimately, Stavola also hopes to neutral-
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Photoluminescent iron nanoparticles in solution.

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**Silicon Photonics**

At a silicon chip, says Tom Koch, an NAE member and director of Lehi's COT, combines economy of scale, precision and sophistication like no other technology. It is 1 billion times faster than electronics.

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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.
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Coulter’s research group is one of the few teams 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 failures 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 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 in-situ 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 overcome 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, motion polymer is deposited into a cold mold and freezes instantly. If this is done with extremely small features, however, the mold is cold even when the mold is filled completely. To fabricate nanoscale features, Coulter’s group dynamically controls the 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 surfaces 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 immunostaining, 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 progresses through development. For example, neurons are known to uniquely express a cytoskeletal protein known as β-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 biocompatible materials similar to those that make cells interact in the body, they develop into an environment with the appropriate mechanical, topographical and chemical cues. Modifying the nanostructure 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 nanoscale geometry and biochemistry,” she says, “so that a scientist who wants to make neurons can choose the dish with the largest, 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.

Along the spectrum of visible and invisible lightwaves, scientists are seeking to develop optical technologies that 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,” says Dore, an associate professor of electrical and computer engineering, whose 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 hundreds of thousands of dollars and must be housed on a large table.

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

Dore 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.

**A QUANTUM LEAP FOR THE QUANTUM DASH**

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 Dore’s laser requires an understanding of the behavior of lightwaves and of the physical, mechanical and optical properties of semiconductor materials at the nanoscale.

Dore’s laser contains an ensemble of light-emitting quantum dashes arrayed on an indium phosphide substrate at a density of 5 billion per square centimeter. A quantum dash is an elongated version of a quantum dot, a nanosized semiconductor that spatially confines electrons and holes pairs.

Dore’s team uses quantum dashes made of two semiconductor materials and assembled into a laser structure measuring half a millimeter long and 300 micrometers wide. The structure’s dots contain four shells, each with few quantum-dash nanoregions including embedding quantum-well and barrier layers. The dimensions of these features measure in the tens of nanometers or smaller.

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

“The dashes emit light,” says Tan, “because the dashes have different sizes, heights, compositions and geometries, they generate different wavelengths.”

After the laser structure has been assembled, Dore’s team uses an intermixing technique called impurity-free wave disordering (IFWD) to enhance bandwidth and achieve the desired wavelength for the laser.

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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 ranges 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 8 nanometer 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 manufacturing 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 minimum imaging technique that obtains high-resolution images of subcellular tissue. The new laser will also 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 2006 in an invited paper in the IEEE Journal of Selected Topics in Quantum Electronics.

A QUANTUM LEAP FOR THE QUANTUM DASH

Members of the group include James Whang, professor of electrical and computer engineering at Lehigh, and several Lehigh alumni, as well as the U.S. Army Research Laboratory (ARL) and QI& Ed Ltd., an international supplier of advanced semiconductor wafers based in Boston, whose 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 semiconductor materials at the nanoscale.

Ooi’s laser contains an ensemble of light-emitting quantum dashes arranged on an indium phosphide substrate at a density of 9 billion per square centimeter. A quantum dash is an elongated version of a quantum dot, a nanosized semiconductor that spatially confines electrons and holes together.

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

The laser’s interminous structure, say Cho-Luen 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 wave absorbing (DFW) 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.

IEEE Journal of Selected Topics in Quantum Electronics
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 define geometric patterns and volumes. Gagnon, a junior majoring in civil engineering and philosophy, almost half of AE majors select civil engineering and architecture.

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 Pesak, 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 Zaha Hadid Architects, overall Lehigh’s steady and flashy crêpe suzette. They have won two first-place prizes at Battles of the Bands, an annualлеп on campus and a monthly performance at a local bar.

Brunn 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.”

Many student-recreants could enter music conservatories but opt for other careers, says Paul Saleri, 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 engineering and music,” says Saleri. Engineers comprise up to 50 percent of Lehigh’s active musicans. The engineering college and music department have hosted a Music-Engineering Candidates Day for students interested in music, engineering and science. Saleri says engineers and musicians share similar traits—diligence, a grasp of mathematics and the drive to create. Brown also holds an M.S. in structural engineering, in helping me get this job,” says Brunn, “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 drives 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.

“Tell me, there’s something fantastic—it’s romantic—to see what you’ve drawn and designed actually built and lived in,” Brunn agrees with Pesak, that the AE program demands extensive time and commitment. “It’s not for everyone, but for me it was a great match,” he says.

His sentiments are echoed by Sean Dooley ’08, 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 Polytechnique Fédérale de Lausanne. When Dooley returned to the Lehigh Valley, Lehigh’s department of art and architecture offered him an adjacent 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 jazz studies. Saleri 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 Weinman, a professor of art at Lehigh, 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.
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 3-D shadows in geometric patterns. Architecture, built her model “sanctuary of light” as a place to grow giving passion a place to grow

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 3-D shadows in geometric patterns. Architecture, built her model “sanctuary of light” as a place to grow giving passion a place to grow
Dynamic models have improved the defense and aerospace industry, says Eugenio Schuster, and can do the same for energy applications.

The CAREER Award supports Schuster’s work on the nonlinear control of plasmas in nuclear fusion, a project that has been reported in previous issues of ResQ. 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 magnetohydrodynamic (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 respond faster and more reliably to commands. Our goals are usually stabilization and performance.”

—Eugenio Schuster

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 dip, 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.

The use of dynamic models has been traditionally 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.

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Eugenia 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

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

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 underwater portimeter wall of the World Trade Center.

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 ability.

Gary S. Calabrese
B.S. in chemistry, 1979
Calabrese has developed advanced electronic materials and processes for semiconductor device manufacture. In 2009, 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, 1976-79
In three decades with Sandia National Laboratories, Romig has risen to the position of water vice president and deputy laboratories director for integrated technologies and systems.

In 2009, he joined Corning Inc. as vice president of science and technology.
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"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, exploring the availability of differential equation models that predict a system’s behavior. Modeling a system’s dynamics and carrying out high-performance computer simulations are significant parts of our work."

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With today’s overreliance on foreign oil, says Schuster, control systems have the potential to save billions 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."

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Optimizing operations across engineering

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Gary S. Calabrese
B.S. in chemistry, 1979

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

William C. Hittinger
B.S. in metallurgy, 1944

Hittinger oversees systems engineering for NASA’s manned spacecraft program at Bulroc. As executive vice president at RCA, he led development of the first successful demonstration of color videorecording on a disc.

Arthur Veinott
B.S. in industrial engineering, 1966

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.

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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.

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