



TUNABILITY FOR TERAHERTZ

A laser's warmth
produces a more
robust cascade
of electrons.

See page 10



THE POWER OF IDEAS

Students bridge
not-so-different
worlds of the arts
and engineering.

See page 22

resolve

A FOCUS ON LEHIGH ENGINEERING • VOLUME 2, 2011



THE TINIEST OF DIMENSIONS, THE GREATEST OF HOPES

THREE NEW TOOLS OFFER AN UNPRECEDENTED VIEW OF THE ATOMIC WORLD. SEE PAGE 12

LEHIGH UNIVERSITY®

P. C. ROSSIN COLLEGE OF
ENGINEERING AND APPLIED SCIENCE



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Integrating engineering with the arts

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A FOCUS ON LEHIGH ENGINEERING

VOLUME 2, 2011

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RESOLVE is published biannually by the P.C. Rossin College of Engineering and Applied Science and the Office of University Communications and Public Affairs at Lehigh University.
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CHALLENGING GREAT MINDS...INSPIRING GREAT IMAGINATIONS

Reinforcing nanotech leadership

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

Few modern advances in science and technology have been as promising as the revolution in nanoscale engineering. The ability to locate, observe, manipulate and fabricate at the molecular and atomic levels has implications for cancer treatments, alternative fuels, solid-state lighting, environmental remediation, high-bandwidth communications and a host of other endeavors.

Operating at the scale of one-billionth of a meter, nanotechnology requires advanced and specialized instruments. What one can observe and quantify defines what one can do. Lehigh has long had some of the world's best electron microscopy and spectroscopy facilities. Several recent instrumentation grants from the National Science Foundation have enabled us to refine and improve upon our nanocharacterization capabilities. The new acquisitions include an aberration-corrected scanning transmission electron microscope (STEM), a high-sensitivity low energy ion scattering spectrometer (HS-LEIS), and a unique device that integrates an inverted optical microscope with an atomic force microscope (AFM).

Combined with our current facilities, the new instruments are enhancing our ability to measure the physical properties and behavior of materials and to correlate their structure and chemistry – all at the level of the nanometer and the angstrom. They are also helping us study nanomaterials in more dynamic environ-

ments while charting their reactivity. In short, they give us capabilities that rival those of any competitive research facility.

The cover feature story on page 12 offers more details.

Lehigh researchers are also developing novel nanofabrication techniques that introduce nanostructures on the surfaces of metals, ceramics, polymers and other materials for applications in optical networks, light-emitting diodes and adult stem-cell differentiation (see story on page 18) and also in microelectromechanical systems (page 4). And a new nanoinjection technique promises higher operating temperatures and greater applicability for terahertz semiconductor lasers (page 10).

This issue of *Resolve* also profiles the Integrated Degree in Engineering, Arts, and Sciences (IDEAS) program, a new B.S. degree offered jointly by the



“Our new nanocharacterization instruments enhance our ability to observe and measure materials at the level of the nanometer and the angstrom.” —S. David Wu

P.C. Rossin College of Engineering and Applied Science and the College of Arts and Sciences. The innovative honors program just graduated its first class of students. For self-starters who don't fit traditional disciplines, IDEAS offers the chance to integrate engineering with fields as varied as international relations and medicine. At the same time, IDEAS students build a framework



for successful careers in medicine, law, policy-making and other professions that increasingly benefit from the hands-on, inquiry-based mindset of engineering.

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

A handwritten signature in black ink, which appears to read 'David Wu'. The signature is fluid and cursive.

S. David Wu, *Dean and Iacocca Professor*
P.C. Rossin College of Engineering and Applied Science
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Healing the sick with nano-bio hybrids

If their interactions can be controlled, these combinations may lead to new cancer treatments and medical diagnoses

Jagota (right) and Suresh Manohar '10 Ph.D. gather quantitative data on the interaction of CNTs and DNA.

In recent years, researchers have learned how to combine biomolecules such as DNA, RNA and lipids with nanomaterials to develop medical diagnostics and treatments. One hybrid – DNA and carbon nanotubes (CNTs) – may soon be used to treat cancer tumors and deliver drug therapies to cells.

Before that happens, researchers need to learn more about how DNA molecules and CNTs interact with each

other. Dmitri Vezenov, assistant professor of chemistry in the College of Arts and Sciences, and Anand Jagota, professor of chemical engineering, work at the cutting edge of this promising area.

“The interaction fundamentals are important to understand because we need to know if the CNTs, when they’re used for treatment, will adversely affect the cells they’re binding with,” says Jagota, who directs the bioengineering program.


“Our goal is to provide quantitative data on the interaction strength and composition of these biomolecule-nanomaterial systems.”

Jagota’s CNT experience complements Vezenov’s knowledge of direct single molecule force measurements. The two have received NSF funding to examine the potential of the DNA-CNT hybrid for optical sensing and for delivering bio-

molecular agents into diseased cells.

Vezenov says DNA-CNT interactions can be difficult to predict. For example, CNTs in a stable solution might be able to carry DNA to a diseased site. “Left alone in this stable state, the hybrid has shown little toxicity,” he says. “But in the cellular environment, we know that it may be affected by other biological molecules. We’re trying to identify, quantify and predict those effects.”

Using atomic force microscopy, the research team, which also includes graduate students Sara Iliafar and Kyle Wagner, watched CNT interact with single DNA molecules. They controlled the chemical conditions in the solution, observed that DNA sticks to a flat graphite surface, and measured the force at which the DNA slowly peels off that surface like a molecular analog of adhesive tape.

The researchers hope to develop models for both the peeling and binding of the DNA-CNT hybrids. These mechanical models combine single-molecule biophysics and continuum mechanics with the goal of addressing some of the health and toxicity concerns with nanomaterials, says Jagota. 



Fighting heart disease one molecule at a time

Examining a protein’s role in atherosclerosis

Understanding how and why white blood cells attach to blood vessel walls may be critical in treating atherosclerosis, or hardening of the arteries.

Xiaohui “Frank” Zhang, assistant professor in the bioengineering program and the department of mechanical engineering and mechanics, is at the forefront of that effort, thanks to an American Heart Association-funded project that also includes medical doctors from Texas and New York.

Zhang believes the study offers hope in the fight against heart disease – the nation’s number one killer.

“To fight off invading pathogens, your white

blood cells – also called leukocytes – leave the bloodstream and migrate into infected tissues,” says Zhang. “To do this, they must attach to and permeate blood vessel walls, aided by adhesion molecules on their surface that also bind to the wall.

“The regulation of this adhesive process is tricky. Too little regulation can lead to overactive white blood cell adhesion, resulting in severe inflammatory or auto-immune diseases such as atherosclerosis, rheumatoid arthritis, and inflammatory bowel disease.”

Zhang’s team is studying the protein molecule integrin, which mediates the leukocyte-blood vessel

interactions. A key integrin-related process occurs when cholesterol is also present in the bloodstream. Left unregulated, integrin helps cholesterol harden and block arteries. But if integrin activity is overly suppressed, the leukocytes’ ability to penetrate blood vessel walls and engulf infections can be compromised.

Thus, researchers are seeking to determine integrin’s optimal level of mediation.

Using optical tweezers at the molecular level and atomic force microscopy at the cellular level, Zhang’s team is measuring integrin’s strength and stability when it combines with other proteins in the body. This will allow the group to gauge the forces required to pull the proteins apart. Once these mechanical dynamics are better understood, says Zhang, advances in the regulation of integrin’s mediating role will follow.

“From an engineering perspective,” he says,

Using metal-organic nanocages to model viral capsid proteins

Viruses lie on the border between living cells and inert matter. Their genetic material, or genome, is housed inside a protein shell, or capsid. Like living cells, viruses can reproduce but they need to hijack the biochemical machinery of a host cell to do so.

When a virus infects a cell, it releases genetic material into its host's cytoplasm and makes numerous copies of itself. Each new strand of genetic material is encapsulated by a new capsid that forms when protein molecules self-assemble.

Scientists have discovered that viral capsid proteins can form hollow shells without the presence of the viral genome. This process is not yet fully understood but is known to involve a combination of hydrophobic and electrostatic interactions.

"To gain a better understanding of the complex nature of viral capsid formation, we need to find a simple analogous model system that mimics the process," says Tianbo Liu, associate professor of chemistry in the College of Arts and Sciences (CAS). "This would allow us to determine how individual parameters such as pH, ionic strength and temperature affect shell formation.

"Viral capsid proteins are essentially charged macroions that contain both hydrophilic (water-loving) and hydrophobic (water-hating) components," says Liu, "so it is vital for our model system to contain both."

Liu had previously discovered that various hydrophilic macroions could self-assemble into single-layered vesicular superstructures controlled by counterion-mediated attractions, which distinguishes them from regular bilayer lipid vesicles.

"M₁₂L₂₄ nanocages are positively-charged macroions that contain both hydrophilic and hydrophobic components, making them good model candidates," says Liu. "The hydrophilic components are positively-charged palladium ions that are evenly distributed on the surface of the nanocage. These are held together by organic hydrophobic ligands."

In a collaboration with Makoto Fujita of the University of Tokyo and Lehigh faculty members Kai Landskron (chemistry, CAS) and Christopher Kiely (materials science and engineering), Liu studies the properties of metal-organic nanocages to determine the parameters that affect their self-assembly into hollow shells.

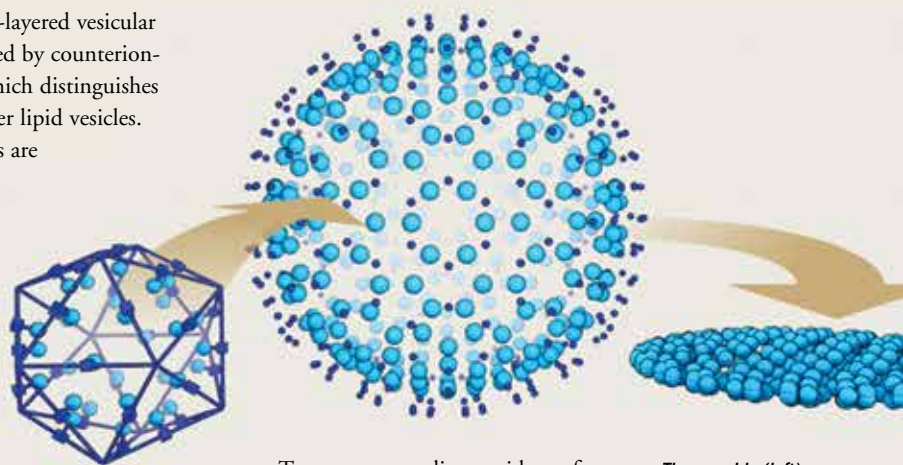
Using a combination of dynamic and static light-scattering techniques, the team has found that the vesicular superstructures formed were indeed single-layer hollow spheres with a diameter of 38nm and that the distance between the nanocages was approximately 0.7nm.

Maintaining a charge balance requires the presence of an equal number of negative ions, which in this case are small nitrate ions.

"There is plenty of space between the nanocages to accommodate these

counterions," says Liu. "The electrostatic interaction between the nanocages and the counterions help hold the nanocages together in the vesicular superstructure."

The group also found that by boosting the ionic strength of the solution with palladium nitrate, the size of the vesicles increased. The number of vesicles that started to form also increased. Conversely, a reduction in ionic strength resulted in an acceleration of the self-assembly process.




To secure more direct evidence for the formation of the hollow shell structures, Liu and Kiely obtained images of the nanocages and hollow spheres using transmission electron microscopy.

"The vacuum inside the microscope caused the solvent inside the vesicle to evaporate, and the sphere collapsed," says Kiely, director of Lehigh's Nanocharacterization Laboratory.


"But by measuring the intensity profile across the image of one of these collapsed vesicles, which was either the same or double that of a single nanocage, we were able to conclude that original vesicles were indeed single-layer hollow structures."

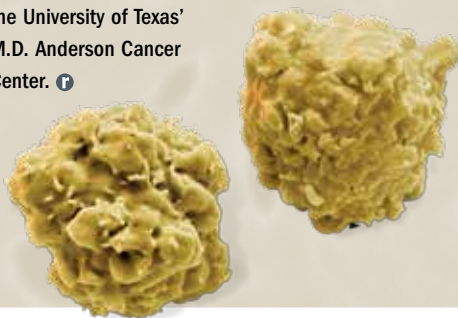
"In our current experiments, the self-assembly of single nanocages into hollow spheres requires days or even months to reach equilibrium," says Liu, "whereas the timeframe for viral capsid formation is hours or days. Experiments are underway to reduce the timeframe for nanocage self-assembly."

The project is funded by NSF and the Alfred P. Sloan Foundation. 

The capsids (left) that house a virus's genome form vesicular spheres (center) that require days or months to reach equilibrium.

"developing the ability to precisely control integrin regulation is complex and fascinating. There is also profound potential for this work to positively impact thousands of lives one day."

Zhang's team includes postdoctoral fellow Yizhen Wang, research associate Yan Guo and physics professor Daniel Ou-Yang from Lehigh; Michael Goligorsky of New York Medical College; and Qing Ma and Jeffrey Mollidrem at the University of Texas' M.D. Anderson Cancer Center. 



Solid gold research

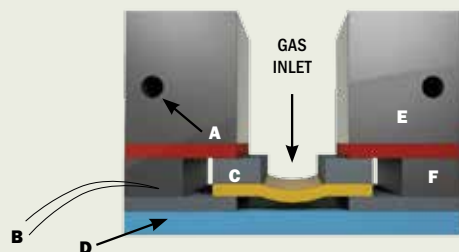
Advancing electronics technology with a pioneering study of gold alloys

Richard Vinci (center) and Ph.D. students Mark McLean (left) and Kittisun Mongkolsuttirat (right) study the behavior of thin metal films with a bulge test apparatus.

A silent revolution is occurring in electronics: Many 20th-century solid state electronic devices are being replaced by tiny microelectromechanical systems, or MEMS. They outperform their solid state counterparts in some applications, use less power and are often cheaper to make.

MEMS' commercial breakthrough came in the automotive industry where

typical MEMS device, however, its mechanical properties start to change with time. The component becomes viscoelastic, making it challenging to design stable



BULGE TESTING

- Bulge sample film
- Insulating layer
- Capacitance electrode
- 8 Embedded heaters
- Thermocouple wires
- Silicon die
- 150µm spacer
- Stainless steel blocks
- Sample alignment ring

they were used in pressure sensors and actuators in seatbelts, airbags and stability systems.

They are now found almost everywhere in the electronic world, including in inkjet printers, Wii game controllers, iPhones, digital cameras and disposable blood-pressure sensors.

As with most electronics devices, the vast majority of MEMS devices are silicon-based – mainly because of the availability of the cheap, high-quality material. Silicon is also an almost perfectly elastic material, as it exhibits no time-dependent mechanical behavior. And it resists fatigue. One switch can go through trillions of cycles without breaking.

But silicon-based MEMS have their limitations, says Rick Vinci, professor of materials science and engineering.

“There are many potential MEMS applications, for example in satellite communications, that require a much higher current-carrying capacity than silicon can provide,” says Vinci. “This is something that can only be achieved with metals.”

When the dimensions of a metal component are reduced to those of a

MEMS devices using metals.

For the past 10 years, Vinci's group has studied the time-dependent behavior of thin metal films with a novel gas pressure bulge test apparatus designed at Agere by Walter Brown, a member of the National Academy of Engineering who is now adjunct professor of materials science and engineering.

Brown's device uses gas pressure to inflate a thin metal membrane – a little like blowing up a soap bubble. The response of the membrane to the applied

“It's a fast and accurate way of measuring very small changes in displacement.”

For a 1-micron-thick film of pure gold, Vinci's team has found a 27-percent reduction in elastic modulus (deformity) over three days at room temperature under constant strain conditions.

“The restoring force available to reopen a MEMS switch based on such a membrane would become significantly reduced over time and ultimately lead to failure,” says Vinci.

By measuring the properties as a function of temperature, Vinci and his team were able to determine the activation energy for this viscoelastic behavior. It turned out to be extremely small, on the order of 0.1eV.

“This suggested that a partial or step-wise movement known as a ‘double-kink’ mechanism, a type of defect, is responsible for the time-dependent behavior,” says Vinci.

“You can test this theory by adding a small amount of an impurity such as vanadium oxide into the gold film, as impurities normally inhibit movement.”

Sure enough, when Vinci's team did this, the vanadium oxide nanoparticles significantly reduced the amount of stress relaxation in the film. This helped to confirm the “double-kink” hypothesis and also to point the way to controlling stress

“The bulge test apparatus gives us a fast and accurate way of measuring very small changes in displacement.” —Walter Brown

pressure helps determine its mechanical properties.

“The unique thing about this apparatus in comparison to other bulge test devices is that it uses the capacitance [the ability to hold an electric charge] between the bulged film and a fixed electrode, rather than optical measurements, to determine membrane displacement,” says Brown.

relaxation, which will be key if metals are to be used in MEMS applications.

Vinci remains optimistic.

“We believe these gold alloys could be the basis of the next generation of MEMS devices,” he says.

Vinci's work on gold films is funded in part by Raytheon Company, BAE Systems, DARPA and the Commonwealth of Pennsylvania.

A closer look at material complexions

Lehigh receives a MURI grant for atomic-scale interphase research

A group of universities led by Lehigh has received a \$7.5-million grant from the U.S. Department of Defense (DoD) to study grain-boundary interphases and their effects on the mechanical, electrical and thermal properties of strategic engineering materials.

The five-year project was one of 27 chosen for funding from 113 proposals submitted this year to DoD's Multidisciplinary University Research Initiative (MURI) program.

The award by DoD's Office of Naval Research is to Lehigh, Carnegie Mellon, Clemson and Kutztown Universities, and the University of Illinois at Urbana-Champaign. The principal investigator, Martin Harmer, directs Lehigh's Center for Advanced Materials and Nanotechnology.

The researchers are specifically interested in the atomic structure of grain-boundary interphases, also known as interphase complexions.

Grain-boundary interphases were studied for many years before Shen Dillon, working as a graduate student with Harmer in 2006, identified six distinct interphase structures, or complexions, in pure and doped polycrystalline alumina.

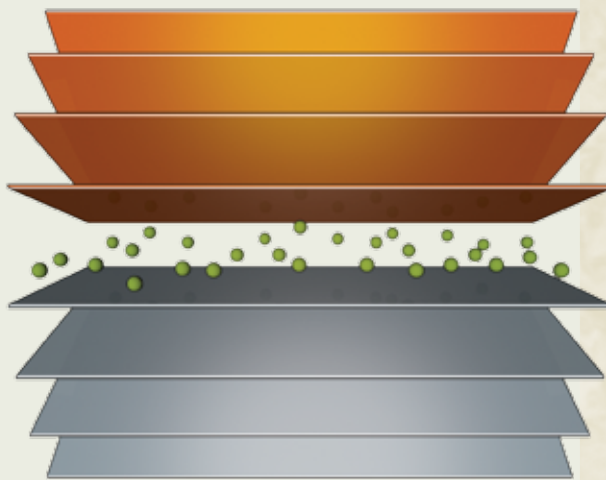
Dillon, now an assistant professor of materials science and engineering at Illinois, used Lehigh's powerful aberration-corrected transmission electron and scanning transition electron microscopes to obtain the high-resolution images needed to identify the complexions.

Since then, complexions have been identified in other ceramics and metal alloys.

"During the processing of ceramics and metals, the transition from one type of complexion to another can lead to abnormal grain growth," says Harmer. "This is a


major problem when you want to produce a high-quality material with a uniform grain size, and it must be avoided when fabricating a nano-grained material."

With help from Gregory S. Rohrer, director of Carnegie Mellon's Materials Research Science and Engineering Center, Harmer's group has combined theoretical thermodynamic models with experimental observations to show that



such detrimental transitions can be prevented by controlling two factors – the amount of a dopant and the temperature during processing.

"This new funding will allow us to extend our studies to determine the role that interphase complexions play in the properties of a wide range of materials, such as nickel alloys and tungsten carbide-cobalt composites whose properties are well known," says Harmer.

"Our goal is to create new classes of materials, such as nano-grained metal-complexionized ceramics that exhibit both the hardness of a ceramic and the superior toughness of a metal. Such a combination is not yet available even with today's most advanced material systems." 

A schematic illustration of a complexion phase shows the blue and orange crystal planes of an interface with impurity atoms (green) introduced during processing.

Making the most of a good thing

For half a century, the Industrial Liaison Program (ILP) of Lehigh's Center for Advanced Materials and Nanotechnology (CAMN) has helped companies meet materials challenges.

The program offers world-class lab equipment and expertise to industry, business and government.

In 2004, CAMN established the Lehigh Nanotech Network (LNN). Its 150-plus members keep current with new applications of nanotechnology, using Lehigh instruments to image and analyze materials at the nanoscale.

Scientists at Silberline Manufacturing Co. in Tamaqua, Pa., study pigments at the surface level to predict and control their color and function.

"We're able to examine the morphology of a pigment, tune its properties and improve its performance," says Shufang Yu, global leader for colored substrates technologies.

"We use scanning electron, transmission electron and atomic force microscopy. Because we can do it ourselves, we learn more, which helps us speed up development."

Gene Lucadamo, CAMN industry liaison officer, says some ILP members send employees to work in Lehigh labs while others rely on Lehigh scientists and graduate students. CAMN also helps companies connect with other resources.

"We can't solve every problem in-house," says Lucadamo, "but we can almost always recommend someone who can get the job done."

"Our members represent government, industry, vendors, legal and consulting firms, and universities, so we can usually help people find solutions quickly."


ILP helps scientists from Carpenter Technology Corp. in Reading, Pa., study nanostructured titanium used in medical devices.

"Our goal is to learn what is happening to large pieces of conventional titanium at the nanoscale," says Graham McIntosh, director of global technology initiatives.

Arkema Inc. of King of Prussia, Pa., works with ILP to improve the mechanical properties of wind turbine blades.

"Understanding polymer nanostructures is key for us," says Chris Roger, director of corporate and external research. "We want to improve the polymers' mechanical properties by improving their impact resistance."

"When you have blades with wingspans of 60 meters traveling on trucks, or birds flying into turbine blades, you want to be sure the material will withstand that kind of impact."

"Lehigh has the equipment and expertise to strengthen our research capabilities." 



Robert Stout and John Gross (inset photo, right) have developed a new steel alloy whose superior corrosion resistance could benefit steel bridges like Pittsburgh's Fort Duquesne Bridge (above).

An ageless collaboration

Two researchers trace their ties back seven decades

Robert Stout and John Gross have set a longevity record for collaboration that may not soon be equaled.

Now 96 and 88 years of age, the two metallurgists recently developed and tested a new steel alloy that promises significant savings in bridge construction and repair costs.

Their accomplishment concludes a five-year project funded by the Federal Highway Administration (FHWA).

It caps 20 years of research supported by FHWA, the U.S. Navy, the Welding Research Council and the American Iron and Steel Institute.

And it comes 70 years after the two men began a lifelong association in Lehigh's department of metallurgical sciences (now the department of materials science and engineering).

In 1941, Gross enrolled in a metallurgy class taught by Stout, then a Lehigh instructor.

Stout went on to earn a Ph.D. from Lehigh and serve more than four decades as professor and department chair of materials science and engineering, and also as dean of Lehigh's graduate school.

Gross earned his B.S., M.S. and Ph.D. from Lehigh, served with Stout 14 years on Lehigh's faculty and then took a position with U.S. Steel, where he once hired Stout as a consultant.

A more corrosion-resistant steel

In 1991, the Navy awarded Lehigh's ATLSS (Advanced Technology for Large Structural Systems) Center \$5.5 million to study the feasibility of using high-performance steels in submarine hulls. Stout

took charge of metallurgical testing to determine the steels' usefulness in bridges, and asked Gross to be his consultant.

A decade and a half later, working for FHWA, the two researchers developed a copper-nickel-blend plate steel with greater yield and tensile strength, more durability and fewer maintenance requirements than conventional steels. The new steel, HPS-100W, was used in the construction of a bridge in Nebraska.

In their latest project, Gross and Stout improved the durability of corrosion-resistant steel for highway bridge construction. They developed and tested 23 different steel compositions before confirming the superiority of an alloy with 2 percent copper and 2 percent nickel.

Besides superior corrosion resistance, the researchers say the alloy outperforms most conventional steels in ductility, toughness, lifecycle costs, weldability and mechanical properties.

Stout says the alloy will make a significant dent in bridge-repair costs while reducing the traffic delays and lost productivity caused by bridge maintenance.

According to an FHWA report, corro-

sion costs all U.S. bridges, including steel as well as conventional reinforced concrete structures, an average of \$8.3 billion a year in replacement and maintenance costs.

Stout and Gross want to produce a commercial batch of the new steel and conduct large-scale prototype tests to confirm the alloy's performance. Ultimately, their goal is to build three highway bridges.

"We're optimistic we'll get funding for these final steps," says Gross. "And I'm planning to manage the follow-on tests."

Passing the torch


Gross and Stout have mentored a number of graduate students who have gone on to careers in industry and research.

Kate Arico '06, '07G, now a solutions engineer for Informetric Systems Inc., developed a multivariable regression analysis that related the composition of experimental steels to their corrosion performance. The analysis

became the subject of her M.S. thesis in industrial engineering.

"I learned a great deal about the steel industry from both Dr. Gross and Dr. Stout," says Arico, a softball player who also benefited from an athletic scholarship endowed by Gross.

"Dr. Gross is one of the most generous people I've ever met. He did everything in his power to make my Lehigh experience wonderful.

"Dr. Stout was always willing to share his knowledge with me. He taught me how important it is to listen and respect your colleagues." 



Forward thinkers

Directors named to two cutting-edge programs

HISHAM NABAA, first director of the new Healthcare Systems Engineering (HSE) program, will oversee the professional M.Eng. in HSE while building ties with industry and government. He will also serve as professor of practice in the department of industrial and systems engineering.

"In an increasingly diverse, dynamic and technologically driven healthcare environment, the HSE program will provide solutions in important areas such as resource allocation, healthcare delivery, and patient care and safety," says Nabaa.

"I believe our program — and more specifically our graduates — will have a profound impact on the quality and efficiency of healthcare."

A lightweight boost for microwave data transmission

Student helps NASA improve satellite communications, takes on Google's Lunar X Prize

Andrew Abraham spent the summer of 2009 helping scientists at NASA's Glenn Academy for Space Exploration fine-tune a new device that optimizes satellites' ability to send and receive microwave signals.

Earlier this year, he learned that the team of engineers he worked with received a U.S. patent for the device.

NASA was seeking to harness the power of lightweight data transmitters, called Solid State Power Amplifiers (SSPAs), which are used for satellite-satellite and satellite-earth communications.

Working from a design developed by his NASA engineering team, Abraham built, tested and evaluated a waveguide hybrid coupler capable of combining SSPAs to achieve clearer, longer-range satellite communications.

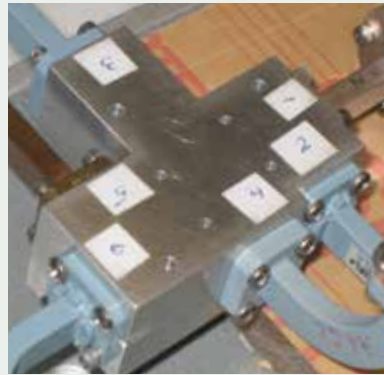
"To transmit microwave signals over a long distance requires a lot of power," says Abraham, who earned an M.S. in physics from Lehigh in 2009 and is now a Ph.D. candidate in mechanical engineering. "High-powered microwave transmission can be produced with heavy equipment, but this is expensive.

"An SSPA chip produces microwave signals more effectively than heavy equipment but it cannot achieve significant strength by itself. You can combine the output from several SSPAs into one strong signal, but how do you do this optimally?"

"We've learned how to achieve

maximum efficiency of combining three power outputs from SSPAs and turn them into one coherent signal that is much stronger than one of the three alone."

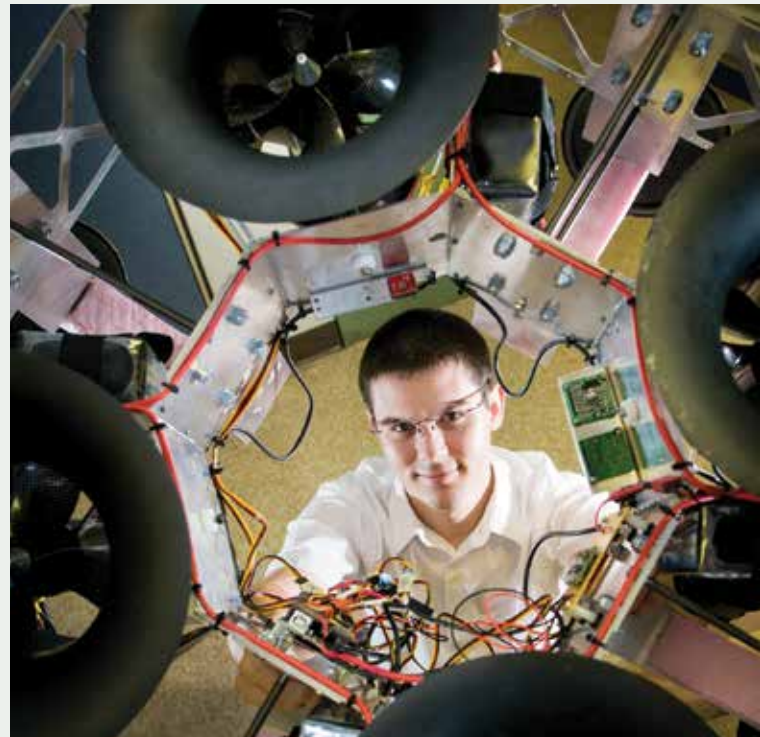
The new technology will be useful, says Abraham, regardless of the future direction of the U.S. shuttle and space flight programs.



"Our technology can be used for any application – cable TV, cell phone stations, military applications – that relies on satellite communications."

Abraham's next challenge? He's helping a Penn State-Lehigh group compete in Google's Lunar X Prize, which is challenging privately funded teams to land a robot on the surface of the moon. 

Since helping NASA improve microwave satellite communications, Andrew Abraham (with NASA mentor Ed Wintucky in lower left photo) has set his sights on Google's Lunar X Prize.



Nabaa previously was manager of design and test engineering at PRIMUS Technologies, director at Mercy Health Partners Wilkes-Barre, and director of engineering operations and strategy for Wilkes University's division of engineering and physics.


The HSE program prepares graduates for engineering and management careers in healthcare at a time when the need for professionals is growing due to the aging population and increasing medical costs.

MARTHA DODGE, new director of the Energy Systems Engineering Institute (ESEI) and professor of practice in electrical and computer engineering, has big plans for the institute's M.Eng. in energy systems engineering (ESE).

"The next steps are to broaden the involvement of industry partners and

to continue to develop relevant electives that appeal to student and industry needs while utilizing the strengths of Lehigh's faculty," says Dodge. "The core program will continue to emphasize interpersonal and leadership development, as well as career planning."

Dodge retired last year from PPL Electric Utilities, where she led electric planning and engineering and was senior director of the smart grid initiative. She holds a B.S.E.E. and MBA from Lehigh and has 28 years of energy industry experience.

The ESEI coordinates faculty, industry leaders and students who conduct research in energy and power systems. The M.Eng. in ESE prepares graduates for careers in those industries. Every member of the program's first two classes of graduates has received a job offer. 

THE THRILL OF WATCHING THE TEAM



TO LEAD WELL, ONE MUST FIRST BE ABLE TO MOTIVATE OTHERS

Alton D. Romig Jr. is vice president and general manager of Advanced Development Programs, also known as Skunk Works®, at Lockheed Martin Aeronautics. The Lehigh alumnus (B.S., M.S. and Ph.D. in materials science and engineering in 1975, 1977 and 1979) sets strategic direction for the capture of new business at Skunk Works®, which has been the preeminent seat of aerospace innovation for more than 65 years. Romig spent more than 30 years with Sandia National Laboratories, operated by Sandia Corp., a Lockheed Martin company, where he led the development and engineering activities providing science, technology and systems support for U.S. programs in military technology, nuclear deterrence and proliferation prevention, technology assessments, intelligence and counterintelligence, homeland security, and energy programs.

Q: *The world is a vastly different place than it was when Lockheed's legendary Skunk Works® group was founded to support the Allied effort in World War II. How has the organization evolved?*

A: Many people think Kelly Johnson's (the first Skunk Works® leader) legacy was the aircraft he created. I believe his legacy is the culture you find at Skunk Works®. It's a culture of innovation that understands failure as the critical element leading to a breakthrough technology. We've had our highs and lows at Lockheed but one constant is that Lockheed Martin has never failed to support this organization in all aspects ranging from financial support to embracing our passion to attempt the seemingly impossible. The customer requirements and mission goals have changed: there's a lot more bureaucracy and oversight with more focus on affordability today, but the basic ethos remains unchanged.

Q: *Both Sandia and Skunk Works® help meet needs in critical areas of national security. Why are engineers uniquely suited to contribute in these areas?*

A: As engineers we must have a spark inside of us that goes beyond our discipline. That spark to create or innovate must also extend to serving our country. That's what's most important at the end of the day, that we are passionate about providing our military and our government administrators with what is needed to make our country safe and prosperous. Engineers must also be excited about a challenge. In the national security industry we have the opportunity to solve some of the most difficult and complex challenges ever faced.

Q: *Where is Skunk Works® headed in the future?*

A: We expect to continue to meet the needs of our country and its allies. The focus on



Alton D. Romig Jr. oversees Lockheed Martin's Skunk Works®, which has produced (top to bottom) the P09-7128 Advanced Composite Cargo Aircraft, the Stalker Aerial Lookdown, the ISIS Silver 2011 radar search airship, and the F-X Next Generation Tactical Aircraft.

AEROSPACE IMAGERY COURTESY OF SKUNK WORKS®

affordability is more important than ever. I think we can address some of the cost issues by looking at the processes by which we take on incredibly complex projects. Years ago, an engineer would work on 20 different aircraft in a career. Today's projects are so complex and costly that an engineer might only work on one aircraft program in an entire career. We must find ways to shorten those project cycles while continuing to produce the most astonishing aircraft the world has ever seen.

We tackle problems that no one thinks can be solved. Years ago, you would have said it's impossible to build an aircraft that can't be seen on radar or that can fly from the West Coast to the East Coast in 67 minutes, but we have successfully produced the stealthy F-117 and the Mach 3+ SR-71.

Q: How has your engineering background prepared you for leadership roles among diverse constituents?

A: My career is technical in nature and for me a technical degree is absolutely essential to the performance of my job with Skunk Works®.

My technical degree is the foundation that makes it possible for me to manage multiple complex programs. In a high-tech corporation like Lockheed Martin, high-tech skills are vital to earn the respect you need to lead a team. Whatever your career path, a degree from Lehigh, combined with an ability to develop a broad network of professional relationships across your industry, will help prepare you to become a successful leader.

Q: What are the qualities of effective leadership?

A: Certain characteristics of leadership are internally focused; others are externally focused. From an internally focused perspective, a clear vision for the future is critical. It's also necessary to have the ability to make well-informed and well-thought-out decisions. The most important thing is the ability to motivate a team. If you can do that, you'll be amazed at what you can achieve. As a leader, I realize that the diverse knowledge and talent of my team far exceeds that of me as an individual.

From an externally focused perspective, the ability to develop meaningful relationships within and outside your industry is very impactful. A professional network composed of customers and partners from academia, industry and government is an intangible resource that helps a leader be more effective and connected to the business and the environment in which it functions.

Q: What stories from Sandia or Lockheed exemplify the learning you experienced at your alma mater?

A: At Lehigh, there's a strong sense of teamwork, just as I've found at Sandia and Lockheed Martin. If you're a student at Lehigh you're also a Mountain Hawk for life. People here have that same sense of camaraderie. I guess we'd call it institutional spirit or Skunk Works® pride. Once you spend time working here you become a "Skunk" and that pride of having been part of this team never really leaves you. You don't find that in a lot of corporations. It's reflected in how long people stay here. I recently pinned a 60-year medal on an employee. I think people like the unique technical challenges and the strong sense of "Skunk" spirit. The result is a turnover rate that is very low.

Q: Tell us about one of your greatest challenges and how Lehigh's education helped you meet it.

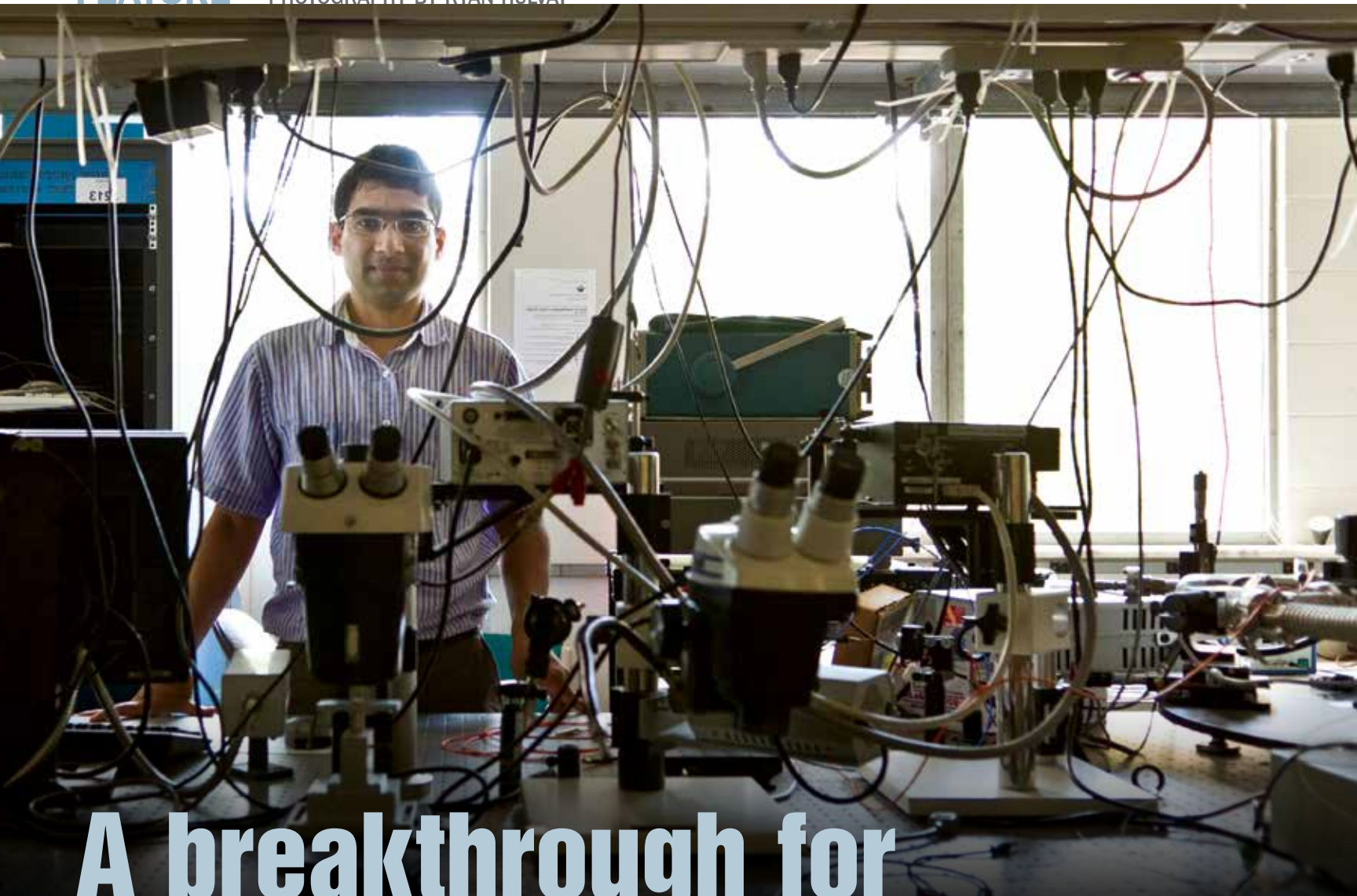
A: One of the greatest challenges for me over the last few decades has been participating in the national effort to increase the flow of science, technology, engineering and math talent. We need to produce more engineers with strong people skills and business acumen. Many engineering schools are good at training engineers, but Lehigh graduates engineers with strong business and communications skills. The skills I learned at Lehigh have served me well and set me apart from my peers.

Q: What are the qualities you look for in a researcher?

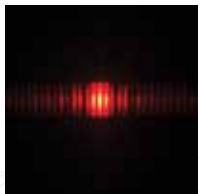
A: There are two kinds of intelligence I think you need beyond the traditional measure of I.Q. One is emotional intelligence – the ability to interact with other people. The other is cognitive intelligence – the ability to take input and information from a wide variety of sources and integrate them. The balance required between the two depends on what kind of researcher you are. For a theoretical physicist, math and science intelligence is most important. If you tend toward engineering, emotional intelligence becomes important, because engineering involves teamwork. And cognitive intelligence is important because these teams require a vast range of disciplines – engineering, business, legal and social science.

Q: In the 1960s, science enjoyed great public support. What could renew popular interest today in science and technology?

A: I think our culture tends to react to acute problems but not to chronic problems. In 1957, when the Soviets launched Sputnik, people began to fear an immediate and existential threat to the United States. That concern triggered huge investments in science and technology, including the race to the moon. Most of the leaders of technical teams today are children of Sputnik. I had hoped that energy would create that spark today. But energy is not an acute problem, it's a chronic problem. Maybe the environment or climate will hit a chord with kids the way that Sputnik did with my generation. 🌐



A breakthrough for terahertz semiconductor lasers



Sushil Kumar utilizes thermal vibrations in a semiconductor lattice to obtain the optical amplification necessary to generate a laser.

A NANOSCALE INJECTION TECHNIQUE ENABLES HIGHER OPERATING TEMPERATURES AND A VARIETY OF POTENTIAL APPLICATIONS.

Light's versatility is awesome – it inspires painters, it regulates auto traffic and it guides a moonlit stroll on the beach.

Visible light waves occupy just one portion of the electromagnetic spectrum. Radio waves, with their relatively low frequency, let the world communicate wirelessly. Higher-frequency infrared rays enable telecommunications, the Internet and consumer electronics. Farther up the spectrum, X-rays are used for medical imaging and baggage screening.

One largely unexploited region of the electromagnetic spectrum, says Sushil Kumar, is the narrow “gap” between the radio and infrared bands that is

occupied by terahertz (THz) waves.

In the presence of THz light, says Kumar, assistant professor of electrical and computer engineering, some large molecules yield specific spectral signatures, like the lines of a barcode.

This sensitivity opens up a variety of potential applications. THz technology can be used to sense trace amounts of drugs or explosives concealed in clothing or packages. It can detect hidden metal objects without harming the body, and it can decode light emanating from the outer universe to reveal clues to the formation of stars and galaxies.

Other applications include the remote sensing of the

earth's atmosphere, medical imaging and disease diagnosis, and quality control in drug manufacturing. And scientists have found that THz radiation can be used to diagnose skin cancer with advantages over X-rays.

One large hurdle stands in the way of these advances, says Kumar – the lack of a commercially viable technique to generate narrowband and high-power THz radiation.

Traditionally high-power THz radiation was produced by bulky, expensive lasers fueled by a molecular gas such as methane. In 2001, scientists in Italy invented the first THz semiconductor quantum-cascade laser (QCL). QCLs are attractive because of their size – they are as tiny as the diode in a laser pointer. But the lasers must be cooled to temperatures as low as that of liquid nitrogen (320 degrees below zero Fahrenheit) before they emit powerful THz radiation.

Kumar has collaborated with researchers at MIT and Sandia National Laboratories to make a QCL that emits THz radiation at higher operating temperatures than ever before. The group, whose work is supported by NASA and NSF, reported their achievement recently in *Nature Physics*.

Using nanoscale technology, Kumar's group assembled a super lattice of 1,500 alternating layers, placing atoms of two semiconducting materials – gallium-arsenide and aluminum gallium-arsenide – in periodic arrangements. Because each layer in the sandwich must be of an extremely precise thickness, it takes one day to “grow” a wafer. An electric current applied to the sandwich causes electrons to travel, or cascade, within its structure, according to the rules of quantum mechanics, and generate light along the way.

Previous groups had used a technique called tunneling injection to generate THz waves with a QCL. Kumar's is the first to use a scattering-assisted injection. This technique utilizes phonons, or thermal vibrations in the semiconductor lattice, to obtain the optical gain, or amplification in the sandwich of semiconductor layers, necessary to generate a laser.

“What we have done,” says Kumar, “is to change the way the electrons move through the semiconductor super lattice so that the cascade occurs in a more robust manner with increasing temperature of the semiconductor material.

“With tunneling injection, if the structure is not cryogenically cooled, the electrons fiz-

zle out and fail to generate light. With scattering-assisted injection, we obtain optical gain even at relatively high temperatures.”

A critical aspect to his group's success, says Kumar, is the ability to exploit a QCL's “tunability.”

The frequency of light generated in a material is determined by the spacing of energy levels at the molecular level. The spacing of a QCL's energy levels can be tuned by controlling the thickness of its alternating semiconductor layers so the laser emits THz radiation.

Proper tuning, says Kumar, is achieved by injecting electrons into the correct energy level of the semiconductor layers.

Electrons hop from one level to another in the layered semiconductor to generate power in the form of THz photons.

To raise QCLs' operating temperature, Kumar's group has harnessed the “relaxation process.” Electrons tend to dissipate energy in the form of lattice vibrations at higher temperatures, called “non-radiative relaxation,” which is typically detrimental to laser operation.

Kumar's group used this natural phenomenon in a controlled manner to inject electrons into the correct energy levels. This scattering-assisted injection technique is less sensitive to the thermal energy of electrons and remains efficient at high temperatures.

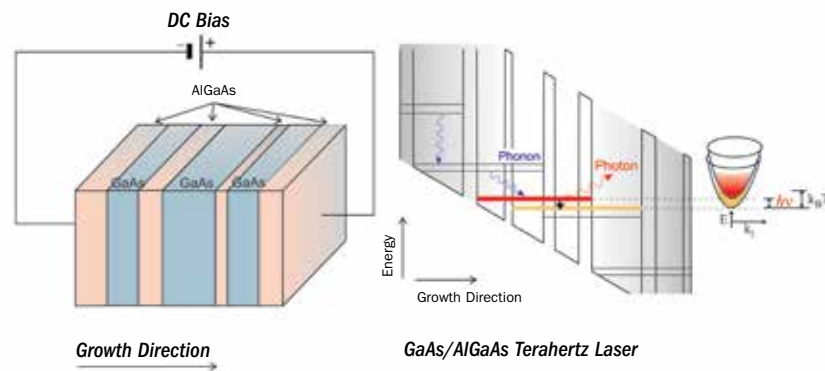
“This tremendous achievement is very promising for the future of THz laser technologies,” says Alessandro Tredicucci, research director at the National Research Council of Italy and inventor of the first THz QCL. “It shows that the power of quantum design has yet to be fully tapped and it encourages people to look for new materials and structures whose relaxation times can be slowed down.”

Kumar's group developed a 1.8-THz laser at -166 degrees Fahrenheit (163 Kelvin) compared to the previous best result, which was achieved at -260 degrees F, or 110 K, for a laser operating at similar frequencies.

More importantly, the group's solid state laser was the first whose thermal electron energy significantly exceeded the energy of its photons.

“The injection technique utilizes phonons and enables electrons to be hotter than the photon energy and still generate sufficient optical gain to generate a laser,” says Kumar.

“The energy of the photons in solid state lasers had not previously been exceeded by the thermal energy of the electrons, with the exception of a specific class of lasers that utilize very high magnetic fields for their operation.”

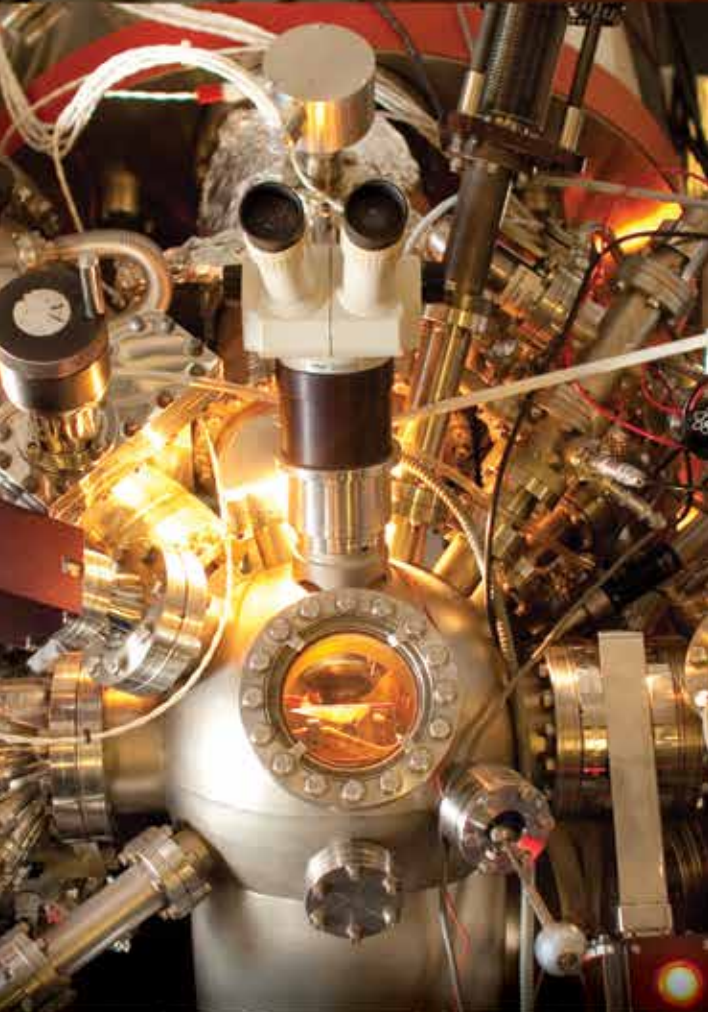


A voltage applied to alternating layers of two semiconducting materials (left), causes electrons to move inside the sandwich (center). The electrons shift to lower energy levels (horizontal lines) when impacted by a phonon (blue arrow), then move further down in an “energy level cascade,” emitting photons (light) that combine to make strong THz radiation. The buckets (right) show the extent to which each energy level is filled with electrons. Those levels increase with temperature.

The QCLs are not yet operating at room temperature, says Kumar, but further improvements could make it possible to generate THz light by cooling the lasers with a relatively inexpensive and commercially available thermoelectric cooler.

“This would go a long way toward making QCLs usable in medical imaging, quality control, and security and sensing applications among other yet unexplored applications.”

Kumar, who joined the faculty in 2010, says his work will benefit from Lehigh's world-class research facilities. These include a state-of-the-art clean room in the Center for Optical Technologies, and unmatched scanning transmission electron microscopes in the Center for Advanced Materials and Nanotechnology, which enable precise characterization of the QCL's sandwich structure. ①



THE TINIEST OF DIMENSIONS, THE GREATEST OF HOPES

A TRIO OF NEW INSTRUMENTS HELPS RESEARCHERS SHARPEN THEIR FOCUS ON THE WORLD OF ATOMS AND MOLECULES.

Few advances in modern science match the potential of nanotechnology to deliver so much from so little.

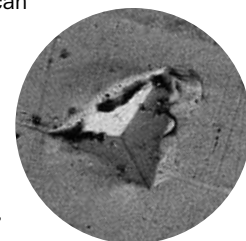
Nanotechnology involves the manipulation of materials ranging in size from single atoms to several tens of nanometers. One nanometer (nm) is equal to one-billionth of a meter, or about one hundred-thousandth the diameter of a human hair.

Out of these tiny chunks of material, researchers have created almost invisible tubes, particles, pillars, wires and a host of other shapes with special functions.

Iron nanoparticles, for example, can be designed to decontaminate groundwater, while gold nanoparticles may help chemotherapy drugs confine their damage to cancer cells. In sunscreens, nanoparticles block UV rays without leaving a white residue on the skin. In lithium-ion batteries, nanoparticle-based electrodes help power electric cars.

“Nano-whiskers” stitched into fabrics make them lightweight as well as water- and stain-repellent.

Nanocatalysts can transform bio-feedstocks into fuels, while carbon nanotubes arranged into dense “forests” are being tested for their ability to store hydrogen.



The guiding principle of nanotechnology, says Christopher Kiely, is that a material’s properties – chemical, optical, electrical, thermal and magnetic – can change when it is shrunk to the nanoscale. Normally inert gold, for example, morphs into a catalyst at the nanoscale.

To control the structure and composition of nanomaterials, and to fine-tune and optimize their properties, says Kiely, who directs Lehigh’s Nanocharacterization Lab, requires the ability to observe, measure and manipulate the nanoworld of atoms and molecules.

This, in turn, requires increasingly sophisticated instruments.

Lehigh has long possessed some of the world's best microscopy and spectroscopy tools. Its collection of electron microscopes is one of the most extensive in American academia. Lehigh was the first university to acquire two aberration-corrected electron microscopes, which can pinpoint the position and chemical identity of individual atoms.

The university's array of spectroscopy instruments is similarly impressive. Its high-resolution X-ray photoelectron spectrometer (HR-XPS) combines with a new high-sensitivity, low-energy ion-scattering spectrometer (HS-LEIS) to provide an unprecedented view of the surface and subsurface that govern a material's properties and its reactivity.

In the past two years, Lehigh has acquired funding for several new instruments that will improve researchers' ability to investigate and control the nanoworld.

- > A new JEM-ARM200F aberration-corrected scanning transmission electron microscope, with features customized by Lehigh microscopists, will image atoms with unprecedented resolution. Its low-voltage operation-range improved spectrometry will allow the study of sensitive organic materials, including carbon nanotubes, graphene, polymers and biomaterials.
- > The new HS-LEIS, the world's most sensitive spectrometer for identifying surface atoms, offers a 3,000-fold improvement in sensitivity over conventional spectrometers and also allows for elemental 2-D surface mapping.
- > A custom-made NTEGRA marries an atomic force microscope (AFM) with an inverted optical microscope, allowing a specimen to be probed from above by the AFM as it is being observed or optically stimulated by the light microscope.

The new instruments, says Kiely, have the potential to help researchers observe nanomaterials in more dynamic environments, to watch as they react with other materials, and to see how they respond to heat, light and mechanical stress.

These in turn will allow researchers to obtain a more accurate picture of the behavior of objects in the nanoworld.

"We are very adept at making and

observing nano-things," says Kiely. "We have good recipes for making nanoparticles, nanorods, nanowires and nanopillars. And we have improved our ability to examine these things with electron microscopy and spectroscopy and determine their structure and chemistry.

"However, we are much less adept at taking an individual nanoparticle or nanotube and measuring its physical properties because it is just too small to manipulate and probe.

"We need better tools for analyzing these nanomaterials, and that's what these new instruments provide."

Angstrom-level imaging and analysis

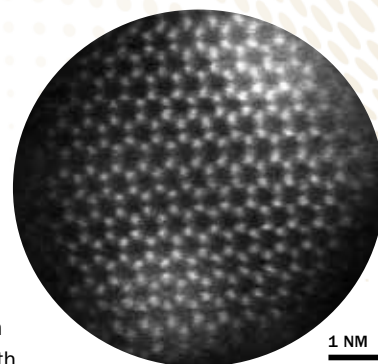
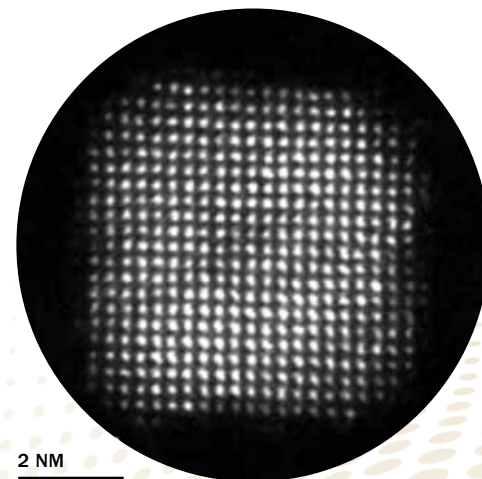
The new JEM-ARM200F aberration-corrected STEM, says Masashi Watanabe, enables researchers to correlate the structure and chemistry of materials with 3-D resolution at the angstrom (0.1nm) level.

"This capability will enable us to develop new materials and characterize their properties with unprecedented accuracy," says Watanabe, an associate professor of materials science and engineering.

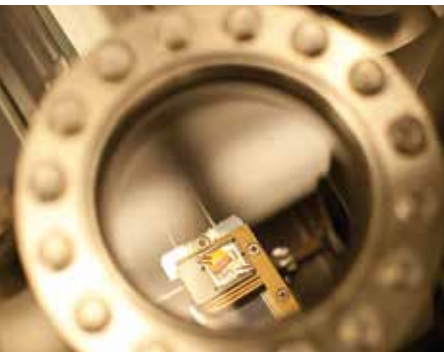
The features include the most sophisticated detectors for electron energy loss spectroscopy (EELS) and X-ray energy dispersive spectroscopy (XEDS), says Watanabe. These will allow composition analysis at atomic resolution while improving stability, data acquisition speed and image quality.

The new STEM obtains an improved signal from samples with an electron "gun," or source, that is 10 times brighter than that of any other STEM and an X-ray detector whose collection angle captures four times more signal.

Lehigh is purchasing the JEM-ARM200F from JEOL Ltd. in Japan with an NSF grant and with university matching funds. The new instrument replaces the existing JEOL 2200FS STEM, which was purchased in 2004 and was the first aberration-corrected electron microscope acquired by an American university.

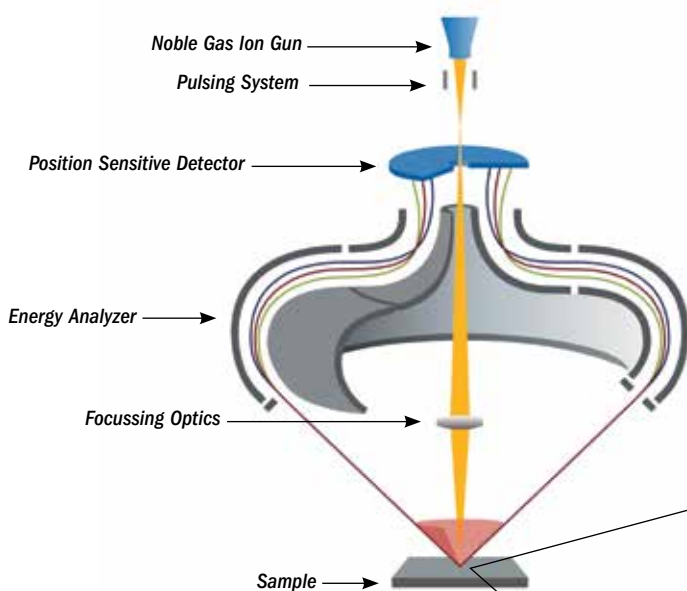


High-angle annular dark-field images taken by the aberration-corrected JEOL 2200FS STEM (facing page, top) include a cadmium sulfide nanoparticle (left) and a cerium oxide nanocube (above). New characterization tools (facing page) include the HS-LEIS spectrometer (middle) and the NTEGRA AFM/optical microscope (bottom). The new JEM-ARM200F STEM will arrive in early 2012.



Research scientist Alfred Miller (above) demonstrates the HS-LEIS (left, detail). The instrument fires noble gas ions at the surface of a sample (diagram below) and determines the identity of the surface atoms by measuring the amount of energy lost by the ions in the interaction.

HIGH SENSITIVITY LOW ENERGY ION SCATTERING (HS-LEIS)



The JEM-ARM200F operates at voltages as low as 60 kV, in contrast with the 200 kV minimum of the JEOL 2200FS. The lower voltages, says Watanabe, will enable the study of carbon-based and other “soft” materials that can be easily damaged by the bombardment of higher-energy electron beams.

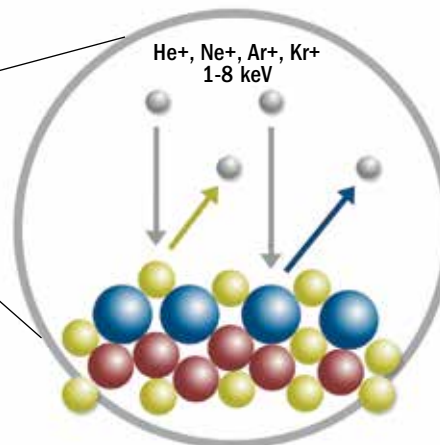
“When we first considered purchasing the new STEM, the lowest operating voltage possible was 120 kV. JEOL said this could be reduced to 80 kV. We asked for 60 kV, which would allow us to characterize many more materials. The energy threshold of 80 kV is still too high for some organic materials that require gentle imaging conditions.”

Another piece of ancillary equipment in the new STEM is an electron tomography stage that tilts in increments of one-half degree, making it possible to take as many as 720 2-D images of the same object. When combined, these images can provide a 3-D reconstruction of a nano-object.

“The ability to obtain 3-D reconstructions is critical for determining the location of individual nanoclusters on a support in a catalyst material,” says Watanabe.

The new STEM, which is expected to be delivered in early 2012, achieves greater stability with a larger column. Improved shielding isolates it more effectively from outside air movements, changes in temperature and acoustical waves, and electrical interference.

Similar JEM-ARM200F instruments are being installed at several other universities, says Watanabe, but they lack



many of the special features possessed by Lehigh’s STEM.

“I’m sure this new instrument configuration will become standard in the next couple of years. We’re proud to be the first university to have the prototype.”

Playing pool with atoms

While electron microscopy alone can achieve angstrom-level resolution, says Israel Wachs, optical spectrometers are uniquely suited to detect the random signals given off by the amorphous surfaces where material properties are determined and where catalytic activity takes place.

Two instruments give Lehigh an unparalleled ability to study surfaces, says Wachs, professor of chemical engineering and director of the Operando Molecular Spectroscopy and Catalysis Research Lab. A third records critical events that occur in nanoseconds.

The university’s Scienta ESCA 300, one of the world’s most powerful high-resolution X-ray photoelectron spectrometers (HR-XPS), complements the high sensitivity-low energy ion-scattering spectrometer (HS-LEIS), which Lehigh recently purchased with an NSF grant.

LEIS, says Wachs, “is the only technique that can identify the atoms on the outermost layer of a solid surface. XPS provides very useful chemical information from the top 10-20 atomic layers.

“These techniques combine data from the surface and near subsurface, giving a new perspective on material surfaces while establishing the basic relationships between a material’s structure and its performance. They will assist greatly in designing advanced materials.”

The physical principles behind HS-LEIS are similar to those of a game of billiards. Like a cue ball, noble gas ions are fired at the surface of a sample. An ion interacts with a sample’s surface atom the same way a cue ball strikes another pool ball – it bounces straight back or is deflected at an angle. In the process, a fraction of its energy is transferred to the surface atom.

Shedding light on metal embrittlement

A team of ceramists pinpoints a hitherto unknown internal phase transition

Why does a solid metal that is engineered for ductility become brittle in the presence of certain liquid metal impurities?

The phenomenon, known as liquid metal embrittlement, or LME, has baffled metallurgists for a century.

Now, ceramics researchers from Lehigh and Clemson University have shed light on LME by obtaining atomic-scale images of unprecedented resolution of the grain boundaries, or internal interfaces, where LME occurs.

In doing so, says Martin Harmer, professor of materials science and engineering at Lehigh, the researchers have achieved the first direct observation in a metal system of a bilayer grain boundary phase transition.

The study suggests that interior interfaces can undergo transitions similar to the solid-to-liquid and liquid-to-gas phase transitions that occur in larger, “bulk” materials.

It also paves the way for scientists to prevent LME by strengthening the chemical bonds of the materials present at grain boundaries.

“This gives us a much clearer understanding of the atomic mechanism of LME,” says Harmer, who directs Lehigh’s Center for Advanced Materials and Nanotechnology. “It promises to improve our ability to control and fine-tune the properties of metals and other materials during fabrication.”

The researchers reported their findings Sept. 23 in *Science*. Their study was funded by the U.S. Navy. The group is continuing its work, with a focus on rectifying LME-related problems in metals.

THE CRITICAL GRAIN BOUNDARY

Harmer became interested in LME after his group in 2006 identified six grain-boundary “complexions,” each with a distinct rate of grain growth, in alumina. The discovery prompted him to seek insight into the embrittlement of metals.

Using Lehigh’s JEOL 2200FS aberration-corrected scanning transmission electron microscope (STEM), which has unparalleled imaging capabilities, the group examined a nickel-bismuth alloy. They employed high-angle annular dark-field imaging (HAADF), which focuses a beam of electrons only 1 angstrom (0.1 nm) wide on a sample.

Previous studies had revealed the existence of four interfacial phases at grain boundaries (GB) in metals. Harmer’s group found two more – a bilayer and a trilayer.

“A bilayer had been seen before in a ceramic system,” says Harmer, “but no one had seen such examples of bi- and trilayers in metals.”

The aberration-corrected STEM pinpointed a bilayer of bismuth atoms at the grain boundary as the source of a weak atomic-scale bond in the nickel-bismuth alloy.

“There is a very strong bond between bismuth and nickel,” says Harmer, “so it had never been clear why the alloy is prone to embrittlement. But the bonds between bismuth atoms are weak. We are the first group to see the formation of the bismuth bilayer that weakens this material.”

A COMPREHENSIVE STUDY

Harmer’s group examined 12 independent interfaces and excluded “imaging artifacts” introduced by experimental error or by technology. To avoid distortions that result from projecting a 3-D image onto a 2-D film, they took images at different depths on the sample.

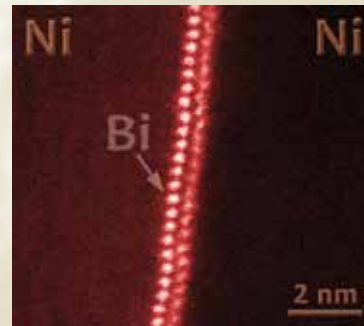
“By looking sequentially at these images and their structural thickness,” says Harmer, “we were able to rule out artifacts that give the illusion of a bilayer.”

In contrast with previous studies that looked at synthetic bi-crystals, the group examined polycrystalline nickel which resembles industrial materials.

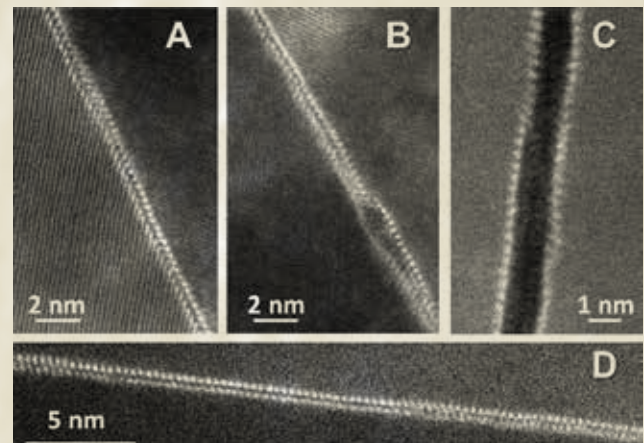
“Real grain boundaries are typically less symmetrical and have higher energy than synthetic bi-crystals,” says Harmer.

The group plans next to experiment with the chemistry of nickel-bismuth GBs to try to produce a more ductile behavior.

“Perhaps combining the bismuth with other elements that bond at the interface will prove effective,” says Harmer.

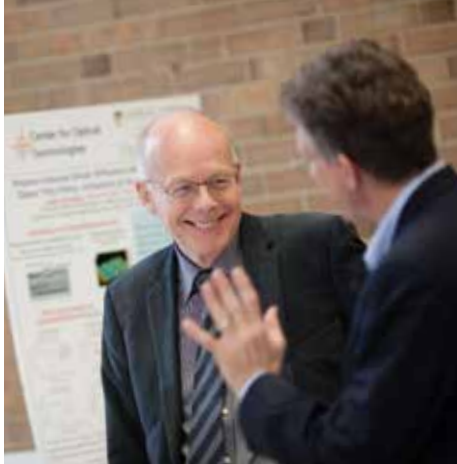


The aberration-corrected STEM revealed that weak Bi-Bi bonds at a bilayer of bismuth atoms cause grain boundaries to fracture and embrittle the nickel-bismuth alloy.





Israel Wachs (above left), principal investigator on the HS-LEIS project, and the instrument's inventor, Hidde Brongersma (above right), spoke at a recent symposium celebrating its acquisition.



The amount of energy lost is directly related to the atomic weight of the surface atom. The spectrometer measures the energy of the rebounding noble gas ions to determine the identity of the atom from which it was scattered.

A toroidal energy analyzer in Lehigh's HS-LEIS spectrometer includes a position-sensitive detector and time-of-flight mass filter that provide a 3,000-fold improvement in sensitivity over its predecessors. It also allows for elemental 2-D surface mapping that complements the elemental 2-D near-surface-region mapping capabilities of the ESCA 300.

A new Fourier Transform-Infrared (FT-IR) 8700 spectrometer enhances

Lehigh's surface analysis capabilities. Lehigh is one of the first research facilities to acquire this instrument, which collects signals in as little as 10 nanoseconds and can study liquid-solid and gas-solid interfaces.

The FT-IR 8700 provides molecular-level information critical to the photocatalytic splitting of water into oxygen and hydrogen, a clean fuel. The splitting occurs in just the nanoseconds that it takes for light-excited electrons to hop from the valence to the conduction band of a solid semiconductor mixed oxide material, and back.

"Many photocatalytic reactions and chemical processes happen in time scales on the order of nanoseconds," says Charles A.

Roberts, a Ph.D. student in chemical engineering. "FT-IR lets us monitor the rapid electron and chemical transformations that occur during these processes."

Two views are better than one

To rapidly obtain a 3-D picture of a material's surface and the location, width, height and depth of its bumps and indentations, scientists rely on atomic force microscopy (AFM).

An atomic force microscope consists of a probe, or needle, that scans a surface like an old record player stylus, measuring the height and recording the position of its topographical features. The needle can also detect surface modulations, magnetic and chemical forces, and atomic and electronic structure.

The resulting representation, says Richard Vinci, resembles a hiker's topographical map.

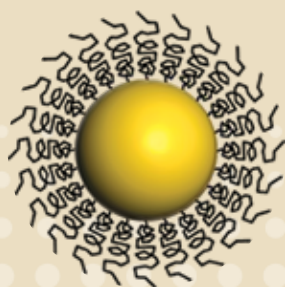
"AFM is a wonderful visualization tool to imagine what a surface looks like," says Vinci, professor of materials science and engineering. "You have to



imagine because you never really see the surface; what you see is a computer reconstruction of what the surface looks like based on the interaction between the surface and the moving probe."

A hot bath for gold nanoparticles

Researchers find a way to enhance the particles' catalytic activity



Gold nanoparticles are becoming some of chemistry's best diplomats.

They facilitate a wide range of reactions between molecules that would not normally interact or would

do so only at much higher temperatures.

And in most cases, says Christopher Kiely, professor of materials science and engineering, they effect a single favorable outcome.

Conventional methods of preparing gold nanoparticles, however, alter their morphology and catalytic activity.

Researchers from Lehigh and from Cardiff University

in Wales in the U.K. have developed a procedure that enhances the surface exposure of gold nanoparticles and their catalytic activity over a range of reactions.

They reported their results in July in *Nature Chemistry*.

"In industry," says Kiely, "the most common way of preparing gold nanocatalysts is to impregnate a nanocrystalline oxide support with chloroauric acid. A reduction reaction then converts the acid into metal nanoparticles.

"Unfortunately, this leads to a variety of gold species — isolated atoms, mono- and bilayer clusters and nanoparticles of various sizes — being dispersed on the support."

An alternative technique that allows greater control over particle size and structure, is to perform the nanoparticles in a colloidal solution before

depositing them onto the support.

The disadvantage to this method is that during fabrication the nanoparticles are coated with ligands that prevent them from clumping together. These ligands tend to impair the nanoparticles' catalytic performance by blocking the approach of molecules to active sites.

Methods for stripping away these ligands involve heat treatments of up to 400 degrees C. This alters the morphology of the nanoparticles, causing them to coalesce and their catalytic activity to decrease.

Kiely's team developed a milder way to remove ligands from polyvinyl alcohol-stabilized gold nanoparticles deposited on a titanium oxide support — a simple hot water wash.

Using aberration-corrected scanning transmission electron microscopy, the researchers compared catalysts that had been washed with those that underwent heat treatment.

Unlike an electron microscope, which operates in a vacuum, an AFM can characterize materials in liquid or air and is thus well-suited to study bio- and nano-materials.

Vinci and Slava V. Rotkin, associate professor of physics in the College of Arts and Sciences, recently acquired an NTEGRA-Spectra, which couples an AFM manufactured by the Russian company NT-MDT with an optical microscope made by Olympus.

By positioning an AFM atop an inverted optical microscope, the NTEGRA allows researchers to examine materials in multiple ways simultaneously. One option is to examine a specimen from below with the optical microscope while probing it from above with AFM. Another is to stimulate a specimen with a laser through the Olympus optics while the AFM measures its properties from above.

"This new instrument was made to our specifications by NT-MDT," says Vinci. "There is probably no other instrument in the world that is identical to our set-up. The NTEGRA actually contains no new part or component; it is exceptional because of the manner in which existing components are configured."

The NTEGRA also has fluid cell capabilities to examine biological specimens, says Vinci.

"Hot water washing had very little effect on particle size," says Kiely, "and while the particles retain their cub-octahedral morphology, their surfaces appear to become more distinctly faceted. This is presumably due to some surface reconstruction occurring after losing a significant fraction of the protective PVA ligands."

"Heating the samples to 400 degrees C also effectively removed the ligands but average particle size increased from 3.7 to 10.4nm," says Kiely. "The particles tended to restructure and develop flatter, more extended interfaces with the TiO₂ support."

For the oxidation of CO to CO₂, catalysts prepared by the hot water wash displayed more than double the activity of conventional gold/TiO₂ catalysts. This reaction is crucial for removing CO from enclosed spaces and for prolonging the lifetimes of fuel cells and firefighter masks.

"The NTEGRA is very complex. It is designed to be used for highly customized experiments that can last several weeks."

What sets Lehigh's NTEGRA apart from similar instruments, says Vinci, is its ability to simultaneously control the position of a specimen like a nanoparticle, the position of the AFM and the position of the stimulating laser.

Rotkin plans to use the NTEGRA to conduct studies of DNA-wrapped carbon nanotubes (CNTs) utilizing total internal reflection fluorescence (TIRF) in combination with AFM.

"TIRF is often used to look at live cells," says Rotkin. "We want to look at CNTs, which are smaller than cells, as they sit inside a cell. CNTs are used in medical applications, so we need to find out whether they are harmful to cells."


The NTEGRA, says Rotkin, is ideally suited to overcome one of the daunting challenges posed by CNTs – locating them on a substrate so they can be studied. It achieves this by combining TIRF and AFM.

"Our microscope can shine laser light at a large enough angle so that only nanoscale objects on top of the cover slip scatter light. If nothing is on the surface, the light is reflected and you see nothing. If there's an object on the surface, it scatters light and you see the object."

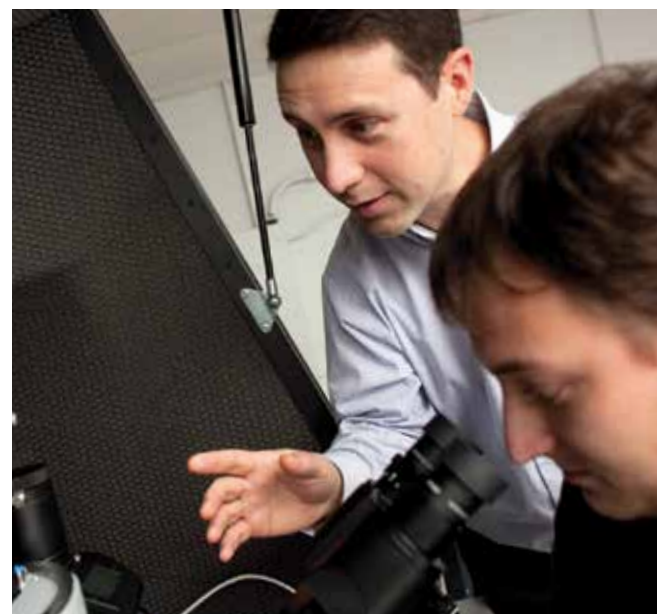
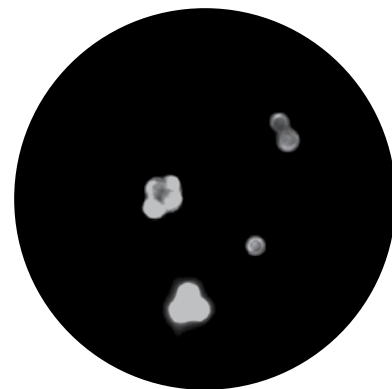
"The NTEGRA will enable us to investigate a surface with the AFM tip, find the nano-object, then examine it by focusing a light beam on the tip. Often you cannot see the object because it's too small. The tip is like a big road sign saying 'Here is your nanotube!' We can run the TIRF experiment when we know where the object is and where the AFM tip is."

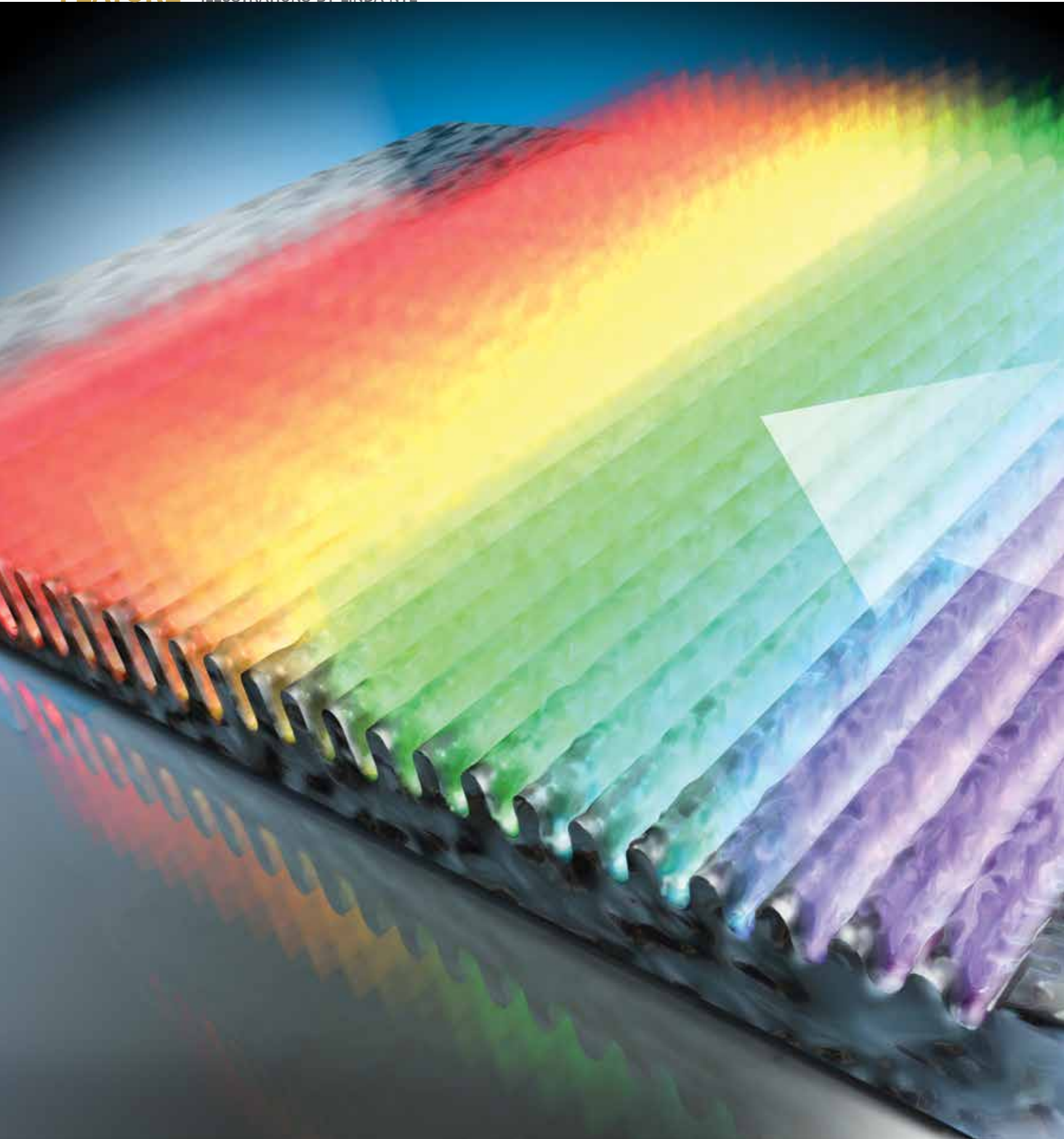
"In short, we will use AFM to locate the object and TIRF to probe the object optically."

This three-way alignment – of a specimen, and the access to that specimen by both optical microscope and AFM tip – gives Lehigh's NTEGRA its singular qualities, says Vinci.

"The simultaneous alignment of these three things is critical to the study of CNTs," he says. "No other tool can do this as well as the new NTEGRA. Other manufacturers' tools are excellent but they cannot match the NTEGRA's capabilities." 

The NTEGRA's AFM capability reveals the topographic features (below) of a single-wall nanotube field effect transistor. Vinci (bottom) with the new instrument.







Exploiting nanostructured surfaces

Researchers are using a variety of new nanofabrication techniques to introduce pillars, columns, rods and other nanostructures on polymers, ceramics and metals.

Our increasing ability to access the nanoworld is profoundly affecting the way humans communicate, utilize energy and combat disease.

One way to create a nanostructure is to 'cut it out' of a larger piece of material; this is known as the 'top-down' approach. Two techniques commonly used to do this are electron-beam and ion-beam lithography.

Scientists are also having some success in scaling down manufacturing techniques, such as injection molding, to introduce nanoscale features onto a surface.

In three NSF-funded projects, Lehigh scientists are using nanofabrication techniques to introduce nanostructures onto the surface of a metal, a ceramic and a polymer.

Their goal is to develop technologies that could one day have an impact on our everyday lives.

MOVING CLOSER TO AN ALL-OPTICAL NETWORK

As consumers demand ever-faster communications and data processing, electrical engineers are seeking to replace today's electronics with photonic (or light-based) circuitry.

Electronic devices, however, contain nanoscale components, while the optical fibers in conventional microscale photonic circuits are orders of magnitude larger.

As photonic circuitry decreases in size, the dimensions of their optical components approach the wavelength of light (450 to 700 nanometers for visible light). This causes the light waves to diffract and the signal to be lost.

One way around this problem is to exploit a type of electromagnetic wave called a surface plasmon polariton (SPP), which forms when a light wave couples (or sets up a resonance) with collective oscillations of the electrons in the surface of a metal.

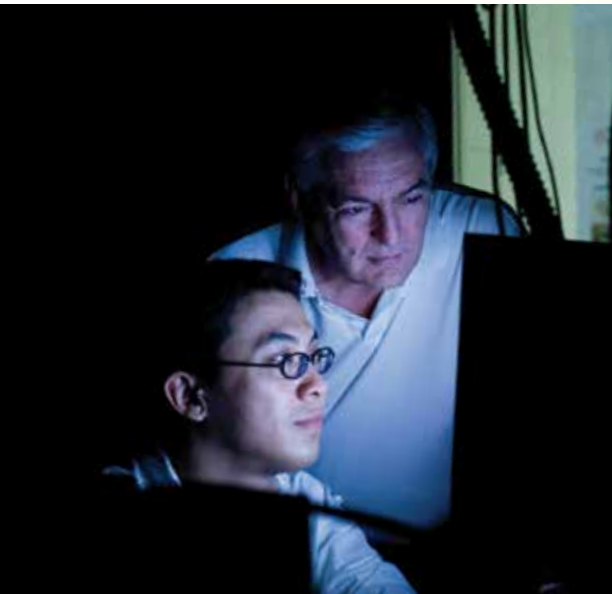
Because of the high electromagnetic fields associated with this resonance, these electromagnetic waves are confined to a very thin region along the metal surface.

"In order to build photonic devices that can store, reroute and transmit data, we must first find a way to trap these electromagnetic waves," says Filbert J. Bartoli, professor of electrical and computer engineering. "One way to do this is to slow them down to a standstill."



A graded "nanograte" traps a "rainbow" of lightwaves at varying depths, heralding the development of all-optical devices.

The gradually increasing depth of the grooves along the nanograte developed by Gan and Bartoli causes a decrease in the frequency of the collective oscillations in the surface electrons.



“We observed red and green light along the nanograte. This unambiguously demonstrates ‘rainbow trapping’ in plasmonic nanostructures.”

—Filbert Bartoli

Light can be slowed down by passing it through a material with a high refractive index. And because different colors, or wavelengths of light, travel at different speeds, a prism can split a beam of white light into its separate colors.

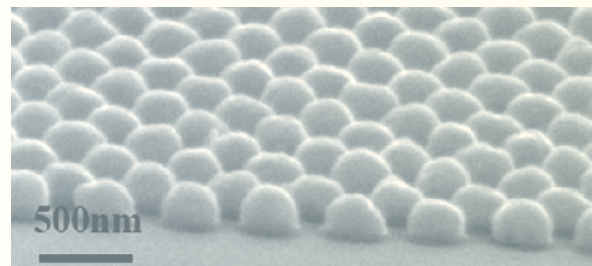
COULD THIS PRINCIPLE BE APPLIED TO PLASMONIC WAVES?

Bartoli and Qiaoqiang Gan '10 Ph.D., now assistant professor of electrical engineering at the State University of New York in Buffalo, set out to find a way to control the refractive index of the interface along which a plasmonic wave travels.

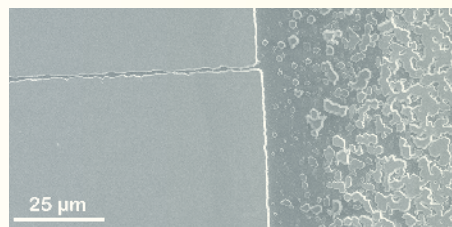
After performing theoretical simulations, Gan predicted that the lightwaves could be trapped with a nanograting – a structure consisting of a series of nanogrooves cut into a metal surface. By gradually increasing the depth of these grooves along the grating, the frequency of the collective oscillations in metal's surface electrons decreases.

“At some point along the grating, light of a certain wavelength can no longer propagate, bringing the SPP to a standstill,” says Bartoli. “SPPs of different wavelengths would be trapped at different positions along the grating, enabling white light to be separated out into its separate colors.”

Using a focused ion beam generated in the FEI 235 dual-beam microscope in Lehigh's Nanocharacterization Laboratory, Gan fabricated a series of nanogratings with grooves 150nm wide and 475nm apart.



Scanning electron micrographs of a nanopatterned sapphire surface (above) and of gallium nitride grown on a nanopatterned (right) and a planar sapphire surface (far right).



The milling time for each successive groove was increased gradually to achieve a grating with a linearly graded groove depth. A nanoslit was fabricated 13 microns from the edge of the graded nanograting to allow a beam of white light to launch surface plasmon modes on the top surface containing the nanogrooves.

Under normal circumstances, observing a beam of light that is tightly confined at the metal surface would be impossible with an optical microscope.

“Fortunately for us, imperfections in the surface of the nanograting cause some of the light to be scattered into the far-field,” says Bartoli, “and it is this scattered light that we hoped to observe with our optical microscope.”

To simplify matters, Bartoli and Gan tested the grating on incident light comprised of two colors, red and green. This was done by first passing the incident beam of white light through a filter with transmission bands centered at red and green wavelengths.

“To our delight, we observed a colorful emission of red and green light at different positions along the grating,” says Bartoli. “This is an unambiguous experimental demonstration of ‘rainbow trapping’ in plasmonic nanostructures.

“Now that we’ve managed to trap these electromagnetic waves, the next step is to find a controllable way of releasing them.”

Other collaborators in this project are Yujie Ding, professor of electrical and computer engineering, and Dmitri Vezenov, assistant professor of chemistry in the College of Arts and Sciences.

IMPROVING THE PERFORMANCE OF LEDs

According to the U.S. Department of Energy, Americans spend more than \$37 billion a year on residential and commercial lighting, accounting for almost 22 percent of total national electricity consumption. The government hopes to phase out incandescent lighting in favor of fluorescent, but the search is on for better alternatives.

The most promising contenders are gallium nitride-based light-emitting diodes (GaN-based LEDs). These small solid state devices contain several extremely thin

layers (15-500nm) of gallium nitride, aluminum-gallium nitride and indium-gallium nitride deposited onto a sapphire substrate using metal-organic chemical vapor deposition. The wavelength of light they produce can be controlled



by changing the ratio of In or Al to Ga in each layer, providing access to the whole spectrum of visible light.

Several challenges stand in the way of widespread adoption of LEDs. Improvements are needed to the internal quantum and light-extraction efficiencies of GaN-based LEDs, and manufacturing costs must come down.

Most commercial GaN-based LEDs are grown at high temperature, typically 1,000 degrees C, on a highly polished sapphire substrate.

“Direct growth of GaN on sapphire at such temperatures often results in a poor quality film containing numerous defects known as threading dislocations that grow right through the GaN layer,” says Helen Chan, professor of materials science and engineering. “This is due to stresses generated in the film which arise from the large lattice mismatch (16 percent) between the crystal structures of GaN and sapphire.”

To overcome this, manufacturers deposit a buffer layer of GaN at lower temperature prior to growing the high temperature GaN layer. This process usually adds 30 to 45 minutes to the processing time and has a significant impact on the cost of fabrication.

Chan, Richard Vinci, professor of materials science and engineering, and Nelson Tansu, associate professor of electrical and computer engineering and a faculty member in the Center for Optical Technologies, have developed a cost-effective method of fabricating GaN-based LEDs on nanopatterned sapphire substrates.

“Rather than use a GaN buffer layer, we fabricate an ordered array of single-crystal sapphire nano-islands onto the sapphire substrate,” says Chan. “These modify the nucleation and growth mech-

anism of the GaN, resulting in a defect structure that is less detrimental to the optical properties of the device.”

Producing a high-quality array of single-crystal nano-islands would be difficult using standard etching

techniques. The team adopted a novel approach, using electron beam lithography to create the nanopatterned array in a thin film of aluminum metal that had been evaporated onto the sapphire substrate. The aluminum nano-islands were oxidized at about 450 degrees C and converted into polycrystalline Al_2O_3 , and then heated to 1,200 degrees C to induce grain growth, converting the structures into single-crystal sapphire.

“While this sounds like a long drawn-out process, it must be remembered that one of the major contributions to the cost of fabricating GaN LEDs is the time spent in the growth chamber,” says Chan. “All of our surface nanopatterning is done beforehand, which could lead to significant cost benefits.”

GaN-based LEDs grown on these nanopatterned substrates show a 24-percent improvement in output power over LEDs grown on conventional GaN templates. The increase is attributed to improvements in the device’s internal quantum efficiency.

Lessons learned from fabricating GaN-based LEDs on nanopatterned sapphire substrates could contribute to the development of low-dislocation GaN material for solar cells, thermoelectric devices and smart-grid power electronics.

FINE-TUNING THE DEVELOPMENT OF ADULT STEM CELLS

Nanopatterning a polymeric surface could help scientists control the growth of adult stem cells and develop transplantation-based therapies.

Some researchers have learned that the mechanical stiffness of a flat substrate on which stem cells are placed has a profound effect on their subsequent structure and function. Nerve cells thrive on soft surfaces, while

cartilage cells prefer harder surfaces.

But stem cells growing inside tissue do not encounter flat surfaces, says Sabrina Jedlicka, assistant professor of materials science and engineering and a member of the bioengineering program.

“Instead, they are confronted by topographies that vary on the nanoscale. Mimicking the cellular environment during early stem cell differentiation may provide a way to control the process and determine the type of cells that grow.”

Jedlicka and John Coulter, professor of mechanical engineering and mechanics, are trying to develop ‘off-the-shelf’ nanostructured polymeric surfaces, comprised of an ordered array of nanopillars or nanogrooves and designed to support specific types of stem cell differentiation.

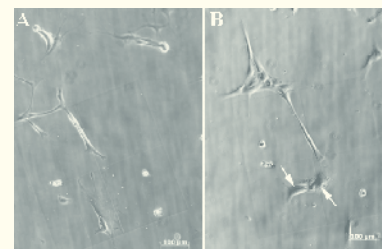
“The mechanical properties of each surface will depend on the height or depth of these features and the spacing between them,” says Coulter, who chairs the International Micro/Nano Molding Technical Group of the Society of Plastics Engineers.

Coulter’s group was one of the first in the world to develop an injection molding process to fabricate nanostructures on a thermoplastic polymer.

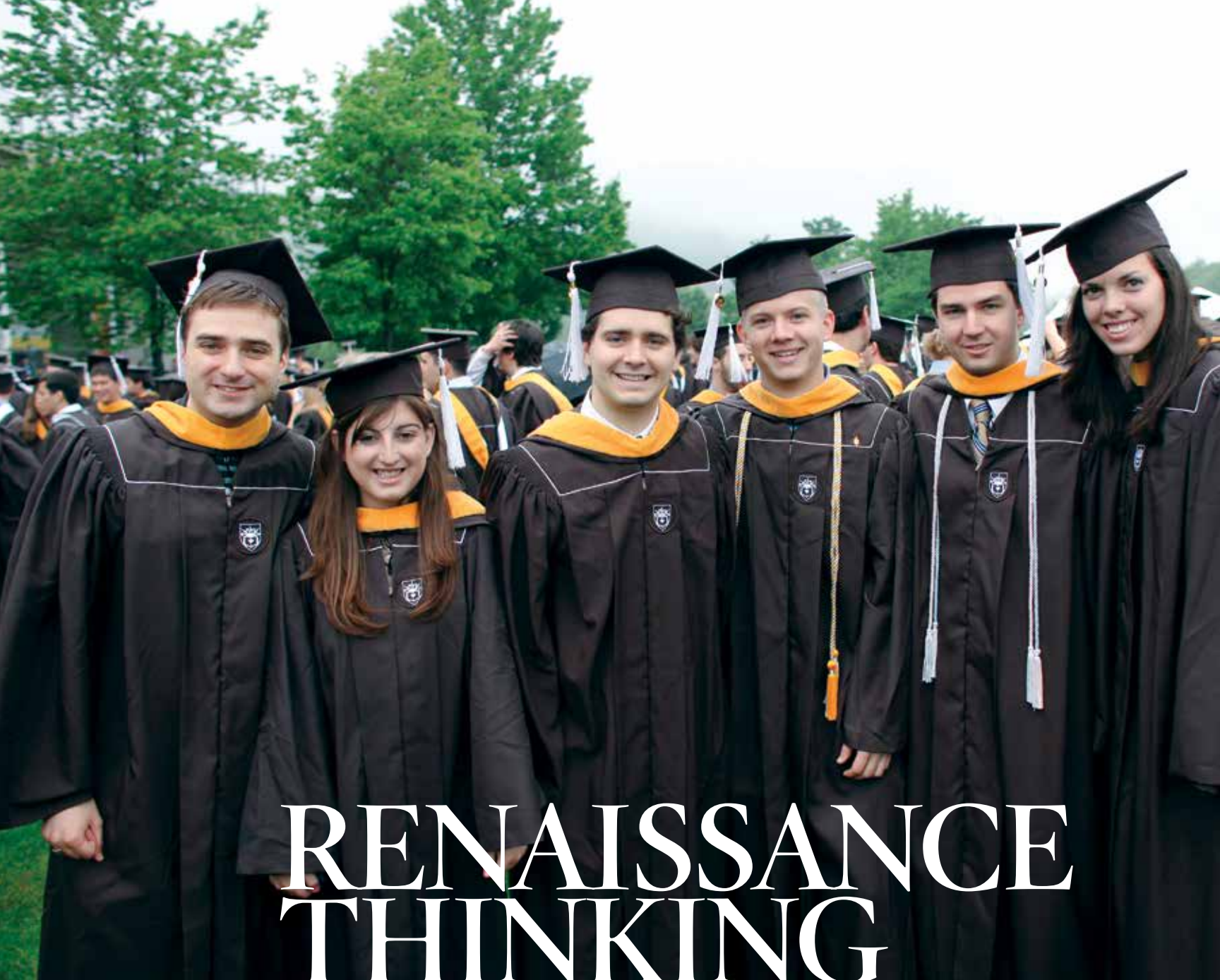
“The trick is to create a suitable mold,” says Coulter. “In this case, we introduced the desired nanofeatures into a silicon mold using a combination of electron beam lithography and ion etching.”

To ensure that none of the thermoplastic polymer remained stuck to the mold, a thin film of plasma-polymerized ‘release’ film was then deposited onto the surface of the mold. This mold was then attached onto a micro-injection molding system.

“If you want to produce ‘off-the-shelf’ nanostructured polymer surfaces at low cost, you have to produce them in large numbers,” says Coulter. “Injection molding in this respect is the only way to go, as the cycle time is around 15 seconds.”



Mimicking the nanoscale topography of a cell interior can help researchers guide the all-important differentiation of adult stem cells.



RENAISSANCE THINKING FOR THE MODERN WORLD

Students in the IDEAS program, which graduated its first class in the spring of 2011, explore the common ground between engineering and fields as varied as ethics and international relations.

Bioengineering and religion. Computer science and graphic design. Industrial engineering and international relations.

It's not easy to combine such diverse interests as these. But with the Integrated Degree in Engineering, Arts and Sciences (IDEAS), students at Lehigh are doing

just that. Jointly administered by the College of Arts and Sciences and the P.C. Rossin College of Engineering and Applied Science, IDEAS is a four-year honors program that allows students to get a bachelor's degree with heavy concentrations in both colleges.

On the one hand, the program attracts students whose first love is engineering, but who also feel passionate about the arts and sciences. Yet IDEAS is also perfect for those initially drawn to the arts and sciences, but who understand the importance and practicality of a strong technical background gained through engineering.

That said, IDEAS is not the only program at Lehigh that spans engineering and the College of Arts and Sciences. The five-year Arts and Engineering program provides students with a professional engineering education and also allows them to study a second field. But IDEAS is unique in that it allows students to integrate very different fields of endeavor into a single program of study.

"I liked the flexibility of my classes and the fact that I combined two completely different majors into one theme," says Kara Werner '11. "That's something that is really hard to find at other universities."

Werner was drawn to Lehigh because of the university's strong international relations department. But after she was invited to join the IDEAS program, she added courses in industrial engineering. In combining the two, her thesis examined how industrial engineering techniques can improve the efficiency of non-governmental agencies (NGOs) doing work in the developing world.

In a nutshell, here's how IDEAS works: In the first and second years of the program, you take seminars that draw on many different disciplines. Among other things, this helps you get used to thinking beyond the boundaries of traditional academic fields. In the final two years, you focus on a senior thesis project that combines both of your concentrations. Along the way, you work closely with advisers to develop a coursework and thesis

gameplan. What's more, you can choose from all the courses offered in both colleges.

So the program is flexible, but it's definitely not easy. Anything but. You must maintain a 3.25 grade point average, and be a self-starter with the confidence and wherewithal to quite literally create your own program of study.

"Many schools have tried programs like this, but a lot of them turn out to be degrees in introductory studies," says William Best, professor of practice in electrical and computer engineering. Best co-directs the program with Bruce Thomas, associate professor of art and architecture.

"Students in Lehigh's program are essentially building a product," says Best. "They're designing their own degree. We meet with each student every semester to develop a 'flight plan.' It is a challenging process for them, but they don't do it alone."

Developing an IDEAS major is especially challenging because students often integrate two very different disciplines to form the final project.

For example, Jim Pratt '11 combined computer science and graphic design by building a computer game to help people with disabilities make the most out of their lives.

"The program was an extremely valuable experience for me," says Pratt. "You have to deal with these types of challenges in real life all the time, where you're not given specific directions and need to figure things out by yourself. IDEAS gave me practice doing that."


Along with learning to be flexible and integrating different disciplines, students in the program benefit from

seeing the world in two very different ways: as arts and sciences majors, and as engineers.

"The main thing I'm taking from engineering is how to solve complex problems by breaking them into smaller, more manageable pieces," explains Colin Przybylowski '11, who combined bioengineering and molecular biology and is entering medical school in the fall. "As a doctor, when you're dealing with a patient and trying to figure out what's wrong with him or her, you're thinking like an engineer," says Przybylowski.

While Przybylowski's concentrations were relatively similar, Dannielle Pimental '11 combined her interest in bioengineering with religion. Her thesis focused on how Jewish beliefs affect end-of-life decisions in Israel. Pimental plans to pursue a master's degree in religion at the Hebrew University in Israel before attending medical school.



"My arts and sciences focus improved my writing ability, and my engineering classes expanded my thinking in ways I never would have expected," Pimental says. "I don't think I would have gotten as good an education anywhere else as I did in the IDEAS program." 

Colin Przybylowski '11, winner of the 2011 undergraduate research symposium, accepts his award from engineering dean S. David Wu.



Mark Snyder, below (left) with graduate students Daniel Gregory and Zheng Tian, assembles membrane sieves that can reduce the energy required to separate molecules from a gas or liquid phase.

Traffic control in the world of molecules

Tailoring membrane pores to achieve greener chemical purification and better solar cells

Mark Snyder, self-confessed traffic cop in the nano world, spends his days trying to make molecules – the right molecules – jump through hoops.

Snyder, assistant professor of chemical engineering, assembles and templates nanoporous membranes, or “sieves,” that can separate molecules of a specific type out from a mixture of many.

Just as the air filter in a home-cooling system trap particles of dust while allowing air through, Snyder’s membranes grant passage to some molecules but not others.

In the Porous and Functionalized Nanomaterials Lab, Snyder, who earned a B.S. in chemical engineering from Lehigh in 2000, works with students to create spherical particles of silica measuring 5 to tens of nanometers. They deposit them in an ordered array onto various substrates, leaving as little space as possible between particles. They cover the particles with carbon, titania or zirconia, filling the pores in between, then etch away the particles.

The result is a “fossil,” a replica of the original particle pattern, with spherical cavities interconnected with small pores whose size is dictated by the contact between the original particles.

Snyder’s goal is to fashion these fossils into membranes whose pore size, topology, connectivity and function allow him to manipulate molecules, separate them or control their reactions.

Greater control of molecular behavior, he says, could lead to applications in energy,

medicine and chemical production.

Using membranes to separate molecules, for example, could reduce the energy consumed by the distillation process used to purify chemicals.

“Distillation takes advantage of differences in the various boiling points of the components in a mixture. But it requires massive amounts of energy to achieve these boiling points and separate products.”

Membranes whose pores all contain identical molecular dimensions, says Snyder, could separate molecules of varying sizes.

“Picture a giant sieve,” says Snyder, “that separates beach balls from golf balls because the pores in the sieve are too small for the beach balls to go through.”

The pores in a membrane could also be tuned with a specific functionality that attracts only one type of molecule from a mixture.

Control over these properties gives engineers the ability to transport a molecule according to its size or its tendency to adsorb to the membrane.

“Membranes or thin porous films with tuned properties can separate molecules without the need for excessive energy input,” says Snyder. “The membrane can be organic or inorganic, and the separation can occur in a gas or liquid phase, as long as the membrane has appropriately tuned properties.”

One challenge is to create ultrathin membranes that accelerate the separation process by allowing molecules to diffuse

rapidly through the pores.

“Molecules pass through a molecular filter at a rate that is inversely proportional to the thickness of the filter,” says Snyder. “So instead of a 10-micron-thick filter, you would prefer something several orders of magnitude thinner.

“Polymeric membranes have a trade-off between separation and permeance. A highly selective membrane often has low permeance, while a highly permeable membrane has little separation. Polymeric membranes also tend to be sensitive to thermal or chemical degradation.

“Inorganic materials show promise for achieving a better balance – if we can control the thickness and create defect-free membranes.”

Snyder’s work in this area is funded by the American Chemical Society.

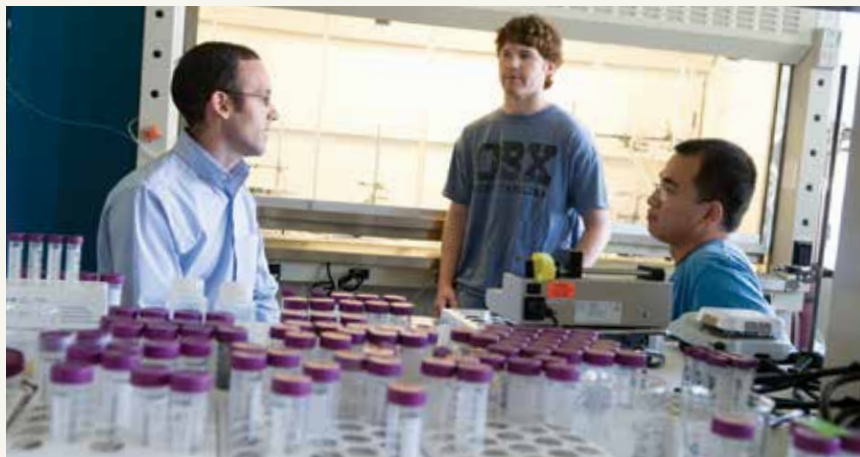
In a DOE-supported project, he is working to develop porous materials with tunable pore size and pore topology that have organic and inorganic surface functionality and can catalyze a variety of reactions. His goal is to convert biomass to high-value chemicals and liquid fuels.

“By tailoring the properties of the pores in these multifunctional catalysts, we hope to improve the selectivity with which various products are made and to limit undesired side reactions,” he says.

In another project, Snyder and Jim Gilchrist, associate professor of chemical engineering, are seeking to improve the efficiency with which dye-sensitized solar cells (DSSCs) convert sunlight into electricity. In two decades of research, he says, efficiency has improved modestly, from 8 to 12 percent.

The two researchers are tailoring the porosity of a conductive anode and integrating it with microlens technology to increase the distribution of light to the dye molecules.

“We have observed a nearly 30-percent improvement in efficiencies with some of our approaches,” says Snyder. “We have a patent pending, and we’ve launched a start-up, PAower Optics, LLC, to develop our technology.”



Lehigh Engineering Ph.D.s engage in cutting-edge research at prominent institutions all over the world. Here are a few recent examples:

Zumbal Atan '10 Ph.D. is an assistant professor of industrial engineering and innovation sciences at the Eindhoven University of Technology in The Netherlands. Her research interests include revenue management, queueing theory and multi-echelon supply chains.

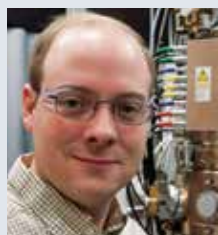
Now an assistant professor of electrical engineering at Case Western, **Hongping Zhao** '11 Ph.D. (seated) published an impressive 23 journal articles and 40 conference papers while studying at Lehigh.



As a postdoctoral fellow in robotics at the University of Pennsylvania, **Jason C. Derenick** '05 M.S., '09 Ph.D., seeks to control large-scale multi-robot systems.



Susan Daniel '99, '01 M.S., '05 Ph.D., an assistant professor of chemical and biomolecular engineering at Cornell University, makes novel devices for applications ranging from material transport in microfluidic devices to biological assays and sensors.



With three degrees from Lehigh, **Andrew Anthony Herzing** '02, '04 M.S., '07 Ph.D., joined the National Institute of Standards and Technology (NIST) in Maryland, studying chemical analysis of engineered nanostructures.

Ban Hashem Kawas '08 M.S., '10 Ph.D., a postdoctoral fellow at the IBM Research Lab in Zurich, Switzerland, studies risk and optimization in large-scale decision-making.

Faisal M. Alamgir '03 Ph.D., a former postdoc at Brookhaven National Laboratory in New York, is now an assistant professor of materials science and engineering at Georgia Tech, where he investigates materials for energy applications.

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

www.lehigh.edu/heritage

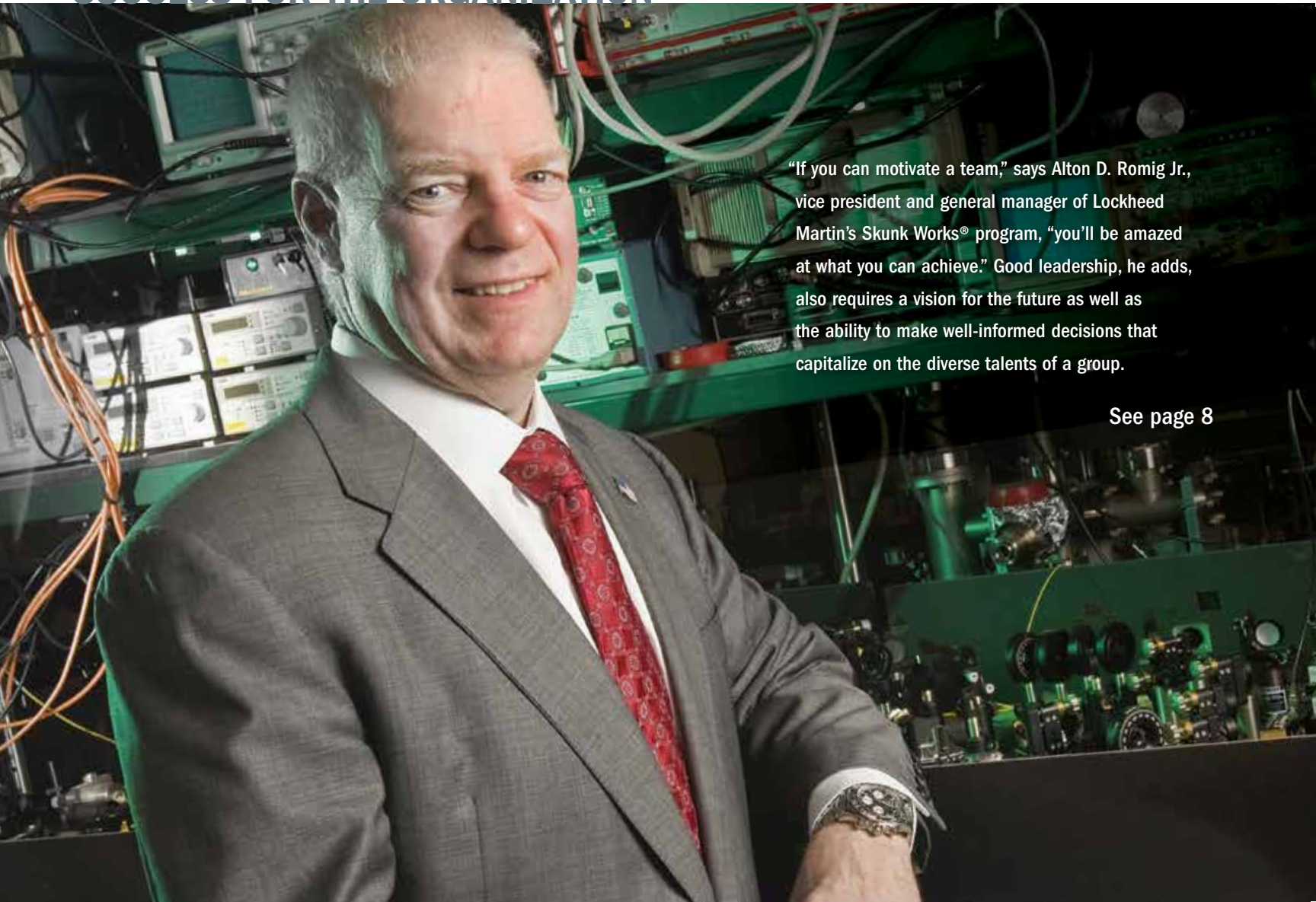


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SUCCESS FOR THE ORGANIZATION



“If you can motivate a team,” says Alton D. Romig Jr., vice president and general manager of Lockheed Martin’s Skunk Works® program, “you’ll be amazed at what you can achieve.” Good leadership, he adds, also requires a vision for the future as well as the ability to make well-informed decisions that capitalize on the diverse talents of a group.

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