Research Horizons

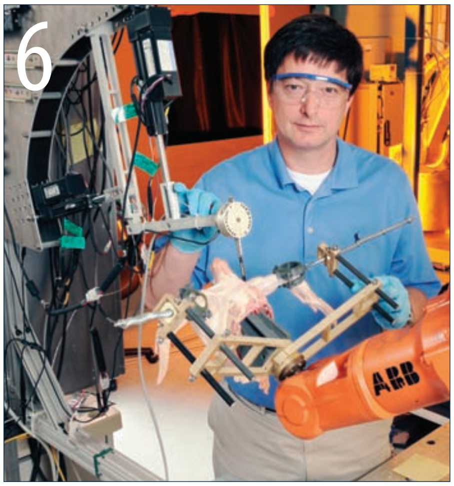
A Publication of the Georgia Institute of Technology

Winter 2012

RESEARCH BOOSTS ADVANCED MANUFACTURING

Georgia Institute of Technology

- *People Logistics*
- *Simulated Atmosphere*
- *Printed Protection*
- *Breaking Down Plastics*
- *Writing Nanostructures*



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– Stephen E. Cross, executive vice president for research

COVER STORY

"We offered Georgia Aquarium leaders accurate predictions on how the new AT&T Dolphin Tales exhibit would impact guest flow within the aquarium and how to optimize the operations logistics, efficiency and show schedules for the new exhibit."

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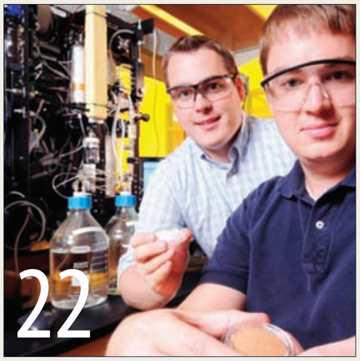


"Understanding that insoluble dust forms more droplets than we thought it could, and that those droplets form close to the sources of the particles, could change our picture of how precipitation is formed in areas like the Mediterranean, Asia and other climate-stressed regions."

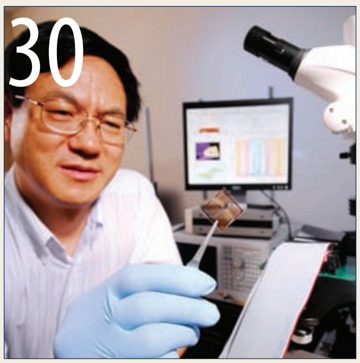
– Athanasios Nenes, professor in the School of Earth and Atmospheric Sciences

"Jupiter collected much of the original solar nebula, that sheet of material that surrounded our sun when it formed. Knowing how much water is in the atmosphere of Jupiter is going to give us real insight into how the whole solar system has evolved. Understanding Jupiter really helps us understand how we got started."

– Paul Steffes, professor in the School of Electrical and Computer Engineering

“This prototype represents a significant step toward producing an integrated wireless system for explosives detection. It incorporates a sensor and a communications device in a small, low-cost package that could operate almost anywhere.”

– Krishna Naishadham, principal research scientist in the Georgia Tech Research Institute (GTRI)



“We can provide the interface between biology and electronics. This technology, which is based on zinc oxide nanowires, allows communication between a mechanical action in the biological world and conventional devices in the electronic world.”

– Zhong Lin Wang, Regents’ professor in the School of Materials Science and Engineering

“We are working to develop a new standard specification for anaerobically biodegradable conventional plastics. This specification is intended to establish the requirements for accurate labeling of materials and products made from oil-derived plastics as anaerobically biodegradable in municipal landfill facilities.”

– Lisa Detter-Hoskin, principal research scientist in the Georgia Tech Research Institute (GTRI)

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Cover: Researchers in Georgia Tech’s College of Architecture are helping automate the process of turning CAD designs into manufactured products. Here, they are evaluating custom wall structures manufactured using a new process. (Photo: Gary Meek)

Before the new AT&T Dolphin Tales exhibit opened at the Georgia Aquarium, logistics experts carefully studied how guests would move and recommended ways to improve their experiences while minimizing congestion. As a result, more than 1,800 visitors can move smoothly through the exhibit, entering and leaving through the same set of doors.

People Logistics:

Systems Engineering Helps Improve Flow of Visitors in Georgia Aquarium's New Dolphin Exhibit

By Abby Robinson

Photo: Georgia Aquarium

Georgia Tech systems engineers offered Georgia Aquarium leaders accurate predictions on how the new AT&T Dolphin Tales exhibit would impact guest flow within the aquarium.

More than 1,800 visitors can move smoothly through the Georgia Aquarium's new AT&T Dolphin Tales exhibit, entering and leaving through the same set of doors. Their experience is not by accident. Before the exhibit opened, Georgia Tech logistics experts carefully studied how guests would move and recommended ways to improve their experiences while minimizing congestion.

"We offered Georgia Aquarium leaders accurate predictions on how the new AT&T Dolphin Tales exhibit would impact guest flow within the aquarium and how to optimize the operations logistics, efficiency and show schedules for the new exhibit," said Eva K. Lee, a professor in the H. Milton Stewart School of Industrial and Systems Engineering at Georgia Tech.

The new 84,000-square-foot AT&T Dolphin Tales attraction, which opened in April 2011, includes a theater with performances of Atlantic Bottlenose dolphins in a Broadway-style production with live actors and trainers, all set to an orchestral soundtrack.

"We knew that managing the flow of guests through the new AT&T Dolphin Tales exhibit was going to be more difficult than the other aquarium galleries because guests would be entering and exiting the exhibit through the same space," said Brian Davis, director of education and guest programs at the Georgia Aquarium. "The logistical predictions and recommendations Georgia Tech provided us were extremely accurate and enabled us to ensure an amazing guest experience while remaining fiscally responsible."

To provide recommendations to the Georgia Aquarium on how to optimize visitor flow through the new exhibit, Lee and Georgia Tech graduate student Chien-Hung Chen created RealOpt-ABM, a large-scale modeling and decision support software suite that could model guest movement through the entire aquarium.

With this software, the researchers predicted guest flow through the new exhibit and the impact of the new exhibit on surrounding areas and overall visitor flow. They were also able to determine the best strategies for show scheduling, resource allocation, space usage, and theater loading and unloading. RealOpt-ABM produced recommendations that were implemented for operations design of the new exhibit, according to Joe Handy, vice president of guest experience at the Georgia Aquarium.

According to Lee, the software's success lies in its integrated simulation and optimization approach and its inclusion of human cognitive and behavioral elements. The software's computational speed also allowed for rapid solution strategies and on-the-fly reconfigurations. Facility layout, physical design and activities at specific points of interest were captured in sub-models, which were aggregated and coupled to form the overall model.

"RealOpt-ABM incorporated advances in agent-based simulation that capture the stochastic nature of the events within the aquarium, optimization of resource allocation and show schedules, and modeling of human cognitive decisions that affect show preference and guest behavior," explained Lee.

To validate the model, Lee, research engineer Niquelle Brown and 10 Georgia Tech students analyzed guest flow and behavior patterns in the entire aquarium before the new exhibit opened. Through time-motion studies in 2010, they collected guest flow data and captured information about the decisions guests made, such as turning left or right when they arrived at an intersection and how long guests spent in each exhibit area. The data showed that guest movement changed based on the time of day and what time guests arrived at the museum.

Using RealOpt-ABM, the researchers accurately predicted the amount of time required to load and unload the AT&T Dolphin Tales theater, depending on the number of guests, which led to a recommendation that performances be separated by at least 90 minutes to minimize congestion.

RealOpt-ABM also detailed the optimal number and location of ticket scanners and traffic controllers and the best time to open the theater doors so that the waiting time and queue length were acceptable. The study also predicted that unless other provisions were made, a large percentage of the new exhibit's lobby area would be occupied by baby strollers that were not allowed in the theater. Lee's team recommended the creation of valet stroller parking in the main lobby of the aquarium to avoid logistics bottlenecks and congestion in the exhibit lobby area.

"Effective strategies for managing guest flow are imperative for the successful operation of the aquarium, and we trust Georgia Tech's logistics advice 100 percent," said Davis. "As the Georgia Aquarium continues to grow and expand, we will always look to Georgia Tech's expertise to maximize the experience for our guests." rh

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"We offered Georgia Aquarium leaders accurate predictions on how the new AT&T Dolphin Tales exhibit would impact guest flow within the aquarium and how to optimize the operations logistics, efficiency and show schedules for the new exhibit."

— Eva K. Lee, professor in the H. Milton Stewart School of Industrial and Systems Engineering

Systems engineering researchers at Georgia Tech determined the best strategies for loading and unloading the Georgia Aquarium's new AT&T Dolphin Tales theater, which holds more than 1,800 people for performances.

Photo: Georgia Aquarium

Advanced manufacturing is a major area of research at Georgia Tech, involving faculty members from academic colleges as well as the Georgia Tech Research Institute and the Enterprise Innovation Institute. Activities focus on developing new manufacturing technologies, addressing key factory-floor issues, designing innovative manufacturing systems and processes, helping manufacturers improve their products and making manufacturing more sustainable.

Photos: GTRI, Robert Combier

(Above) A new production-line system automatically inspects the quality of sandwich buns exiting the oven and adjusts oven temperatures. (Below) Students and a faculty member from the Aerospace Systems Design Laboratory's manufacturing branch display a poster detailing work in manufacturing-influenced design methodology.

Advanced Manufacturing Research:

Georgia Tech Innovations Help Expand U.S. Industrial Capabilities and Enhance Competitiveness

By Rick Robinson

In a bustling laboratory at the Fuller E. Callaway Jr. Manufacturing Research Center, a researcher from the Georgia Tech School of Mechanical Engineering is using novel digital technology to cast complex metal parts directly from computer designs, dramatically reducing both development and manufacturing time.

Nearby, at the School of Industrial and Systems Engineering, researchers are working with a large U.S. avionics maker to speed new product production using specialized software that automatically generates simulations of the manufacturing process. And across campus in the College of Architecture, a team is working with an international corporation on digital techniques that allow entire concrete walls to be custom-manufactured to architectural specifications.

The Georgia Institute of Technology was founded in 1885 with a mandate to develop manufacturing capabilities in the state of Georgia. Today, researchers whose work directly supports manufacturers can be found throughout Georgia Tech's academic colleges; in the Georgia Tech Research Institute, which focuses on applied research; and in the Enterprise Innovation Institute, which assists business and industry.

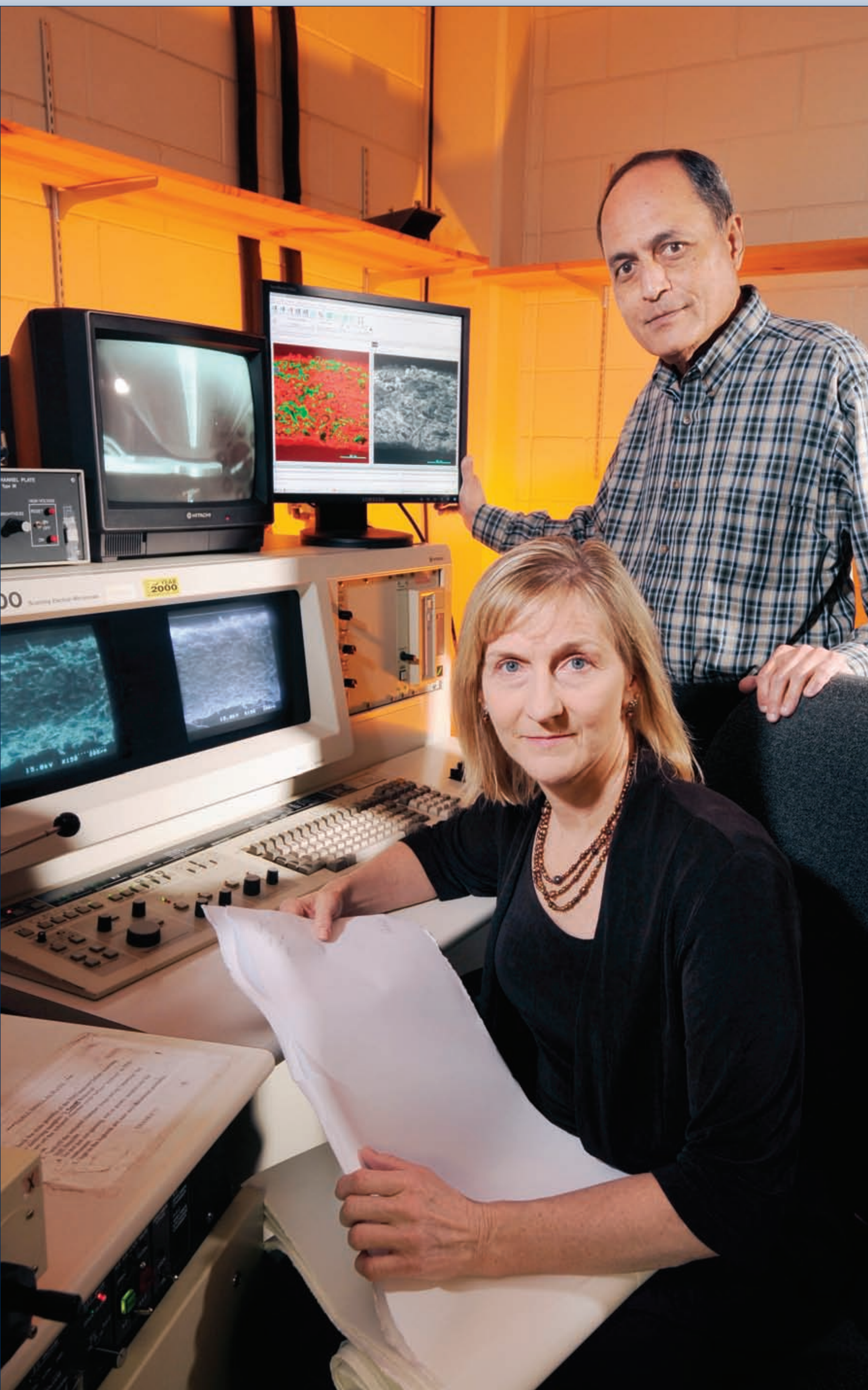
Georgia Tech's role in supporting industry was highlighted in June 2011 when President Barack Obama named Georgia Tech President G.P. "Bud" Peterson to the steering committee of the Advanced Manufacturing Partnership (AMP). Georgia Tech joined five other leading universities – the Massachusetts Institute of Technology, Carnegie Mellon University, Stanford University, the University of California Berkeley and the University of Michigan – in the AMP's $500 million push to guide investment in emerging technologies, increase overall U.S. global competitiveness and boost the supply of high-quality manufacturing jobs.

"We applaud this initiative, and Georgia Tech is honored to collaborate to identify ways to strengthen the manufacturing sector to help create jobs in Georgia and across the United States," Peterson said. "Many of our challenges can be solved through innovation and fostering an entrepreneurial environment, as well as collaboration between industry, education and government to create a healthy economic environment and an educated workforce."

Advanced manufacturing involves not only new ways to manufacture existing products, but also the development of new products emerging from advanced technologies, observed Stephen E. Cross, Georgia Tech's executive vice president for research.

"Georgia Tech's mandate has always been to support manufacturing and technology development in the state and in the nation – to conduct research with relevance – so supporting industry comes very naturally to us," Cross said. "The leading-edge research across the Institute combines thought leadership with a focus on real-world problems and opportunities. Through this we will help lead a renaissance in advanced manufacturing in the United States."

The university's research initiatives on behalf of manufacturers are many and varied. These efforts include multiple areas of manufacturing-related research and involve collaboration across a variety of disciplines.



In the GTRI Materials Analysis Center, director Lisa Detter-Hoskin, left, and research engineer Gautam Patel use a high-resolution scanning electron microscope and energy dispersive X-ray systems to study the behavior of polymer retention aids and mineral fillers used in paper manufacturing.

Photo: Gary Meek

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Photo: Gary Meek

Assistant professor of architecture Tristan Al-Haddad, left, and research scientist Karl Brohammer examine architectural cladding prototypes that have been digitally fabricated using ultra-high-performance concrete.

Developing Novel Manufacturing Technologies

Advancing Digital Manufacturing

Suman Das, a professor in the George W. Woodruff School of Mechanical Engineering, has developed a technology that could transform how industry creates and produces complex metal parts through "lost wax" investment casting. In an ambitious project sponsored by the Defense Advanced Research Projects Agency (DARPA), he has created an all-digital approach that automates how part designs are turned into the real thing.

Currently, such metal parts are devised on computers using computer-aided design (CAD) software. But the next step – creating the ceramic mold with which the part is cast – involves a complex 12-step process that uses hundreds of tooling pieces and extensive manual labor. The result is a lengthy, costly and low-yield process that typically produces many scrap parts along with a few usable ones, said Das, who directs the Direct Digital Manufacturing Laboratory in Georgia Tech's Manufacturing Research Center (MaRC).

By contrast, the approach used by Das involves building ceramic molds directly from a CAD design. Called large area maskless photopolymerization (LAMP), this high-resolution, direct digital manufacturing technology builds the molds, layer by layer, by projecting patterns of ultraviolet light onto a mixture of photosensitive resins and ceramic particles.

After a mold is formed, it is thermally post-processed at high temperatures to burn away the polymer and sinter the ceramic particles. That process forms a structure into which molten metal can be poured for casting.

"The LAMP process can reduce the time required to turn a CAD design into a test-worthy part from several months to about a week, and it can produce parts of a complexity that designers could only dream of before," Das said. "It also can reduce costs by 25 percent and the number of unusable waste parts by more than 90 percent, while eliminating 100 percent of the tooling."

Das is currently working with turbine-engine airfoils – complex parts used in aircraft jet engines – in collaboration with the University of Michigan, PCC Airfoils and Honeywell International Inc. He believes LAMP technology will become pervasive and will be effective in the production of many other types of metal parts.

Das said that LAMP can create not only testable prototypes, but could also be used in the actual manufacturing process, facilitating the mass production of complex metal parts at lower costs in a variety of industries.

A prototype LAMP alpha machine is currently building six typical airfoil molds in six hours. Das predicts that a larger beta machine – currently being built at Georgia Tech and scheduled for installation at a PCC Airfoils facility in Ohio in 2012 – will produce 100 molds in about 24 hours.

"When you can achieve those volumes, you have gone beyond rapid prototyping to true rapid manufacturing," he said.

Customizing Building Components

Researchers at the College of Architecture are also helping to automate the process of turning CAD designs into manufactured products. A team in the Digital Building Laboratory is collaborating with Lafarge North America to develop ways to manufacture customized wall structures directly from parametric digital models.

The new process involves custom-molding entire curtain walls from rubber negatives to produce a unitized system called the "Liquid Wall," constructed with Ductal®, Lafarge's ultra-high-performance concrete (UHPC), and stainless steel. The Liquid Wall, created by Peter Arbour of RFR Consulting Engineers and collaborator Coreslab Structures Inc., won the 2010 AIANY Open Call for Innovative Curtain-Wall Design.

"We don't want to just pick standardized products out of catalogs anymore," said Tristan Al-Haddad, an assistant professor in the College of Architecture who is involved in the collaboration with Lafarge, along with assistant professor Minjung Maing and others. "We're developing the protocols and research to manufacture high-end customized architectural products economically, safely and with environmental responsibility."

The Liquid Wall approach is challenging, explained professor Charles Eastman, who is director of the Digital Building Laboratory and has a joint appointment in the College of Computing. The process involves creating rubber negatives using wall-form designs created with parametric modeling software, then planning production procedures and mapping out ways to install the completed, full-size walls on actual buildings.

"When you're creating a completely new process like the Liquid Wall, you're faced with developing a whole new manufacturing process for this kind of material," Eastman said.

Individualizing Mass Production

Industrial designer Kevin Shankwiler, an associate professor in the College of Architecture, creates objects that can be both customized and mass-produced. By utilizing advances in flexible manufacturing technology, Shankwiler and his students develop furniture designs that can be changed to meet individual needs – such as those of persons with disabilities – while being built cost-effectively using mass production methods.

Today's designers can build responsiveness to individual needs into the computer models used in production, Shankwiler said. Current manufacturing methods – such as computer-numerically-controlled (CNC) and 3-D printing techniques – are capable of creating furniture and other goods that can meet users' specific requirements without resorting to an institutional look.

"In one research effort, we took a dining room chair in the Craftsman style, and we designed and built a model that could accommodate both wheelchair users of differing

CONTINUED ON PAGE 11

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MaRC: Celebrating 20 Years of Manufacturing Research at Georgia Tech

Ben Wang is executive director of Georgia Tech's Manufacturing Research Center (MaRC).

When the Manufacturing Research Center (MaRC) celebrated its 20th anniversary in October 2011, it looked back on a long record of support for industry, the creation of multiple research clusters and the development of numerous spinout companies and licensable patents.

The interdisciplinary center also looked forward – to a new executive director who says America can experience a far-reaching manufacturing renaissance. Ben Wang, who took over as executive director of the MaRC in January 2012, advocates increasingly entrepreneurial approaches to manufacturing research based on innovations that offer commercial or economic value.

"Manufacturing is the biggest creator of wealth and high-quality jobs, and the United States has more inventions than the rest of the world combined," said Wang, formerly director of the High-Performance Materials Institute at Florida State University. "It's not a lack of good ideas that we should be concerned about when we talk of reinvigorating U.S. manufacturing. The problem is that we haven't paid enough attention to translating our good ideas and new discoveries into products that sell well in the global marketplace."

Wang advocates the creation of many "collaboratories," where academia, industry and government can work cooperatively on early-stage manufacturing technologies in a co-located multidisciplinary environment. He described the proposed venues as "the physical embodiment of an innovation ecosystem."

MaRC's unique 110,000-square-foot headquarters contains 27,500 square feet of research laboratories, 14,500 square feet of high-bay shop bays, a Class 1,000 clean room and more than 100 faculty and student offices totaling 20,500 square feet.

Some 70 percent of the center's funding comes from industry sources. Spinout companies based on research performed at MaRC include Radatec, CAMotion, InterCAX LLC, Great Technical Collaborations Inc. (GTC), Qcept Technologies and AkroMetrix LLC.

"There are three elements to MaRC – space, people and funding," said Shreyes Melkote, who served as MaRC's interim director after longtime director Steven Danyluk stepped down in 2010. "MaRC has provided facilities that enable groups of faculty to form research centers or clusters, along with seed funding that has allowed them to develop larger industry or government funding opportunities."

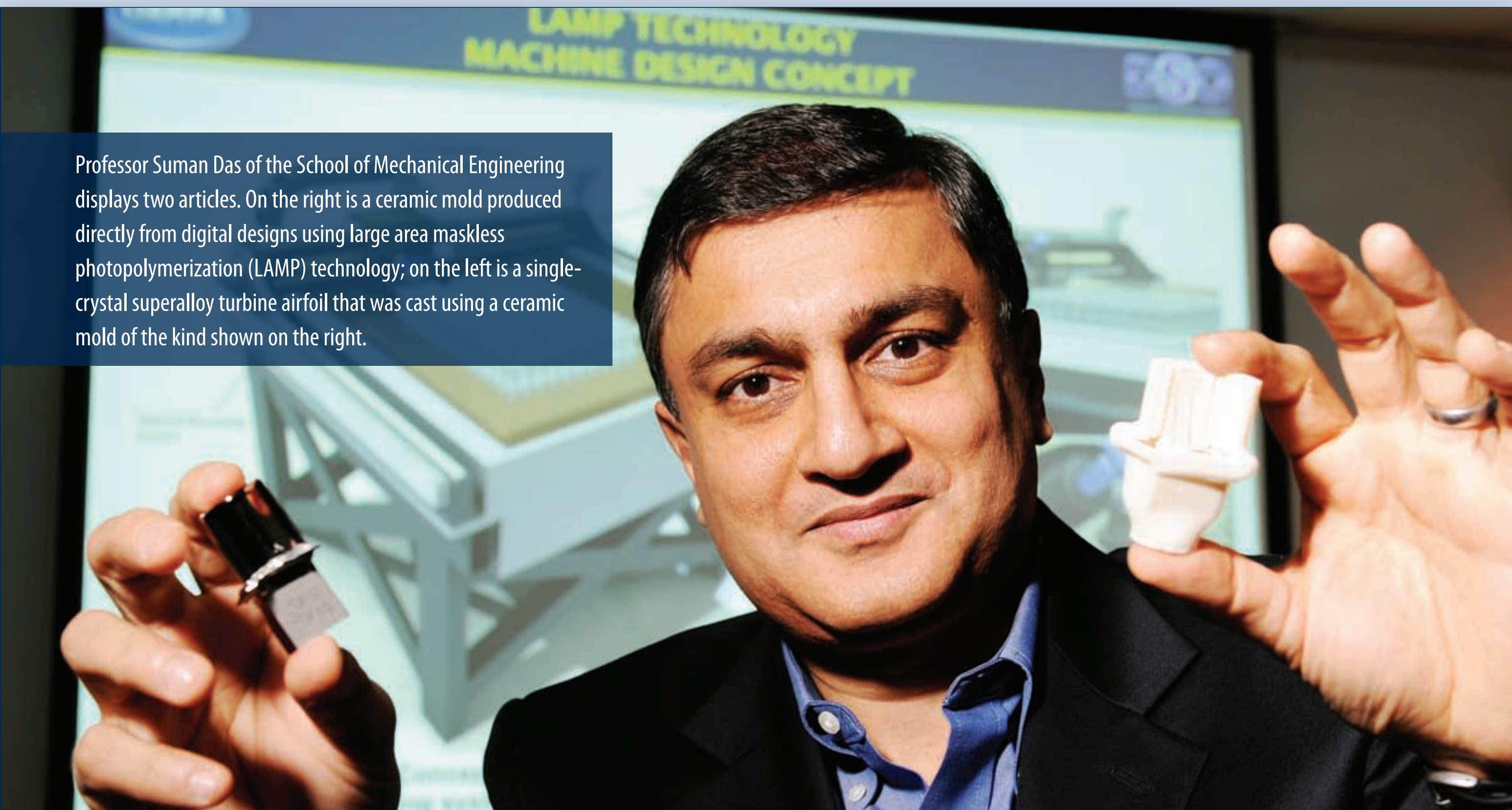
MaRC research centers and clusters include:

- Direct Digital Manufacturing Laboratory, led by Professor Suman Das of the School of Mechanical Engineering;
- Factory Information Systems Group, led by Andrew Dugenske, manager of research services in MaRC;
- Model-Based Systems Engineering Center, led by Leon McGinnis, MaRC associate director and professor in the School of Industrial and Systems Engineering;
- Precision Machining Research Center, led by Shreyes Melkote, who holds the Morris M. Bryan Jr. professorship in the School of Mechanical Engineering;
- Rapid Prototyping/Direct Digital Manufacturing, led by David Rosen, professor in the School of Mechanical Engineering; and
- Sustainable Design & Manufacturing Program, led by Bert Bras, professor in the School of Mechanical Engineering.

Other significant MaRC activities include:

- The Center for Surface Engineering & Tribology, led by Professor Steven Danyluk, Morris M. Bryan Jr. Chair for Advanced Manufacturing Systems in the School of Mechanical Engineering, and Richard Cowan, a senior research scientist and deputy director of MaRC;
- The Modeling and Simulation Testbed, led by Russell Peak, a senior research engineer in MaRC;
- The Photovoltaic Manufacturing Lab, led by professors Steven Danyluk and Shreyes Melkote, both of the School of Mechanical Engineering; and
- The Manufacturing Education Certificate Program, led by professor Shreyes Melkote.

Photo: Gary Meek



Professor Suman Das of the School of Mechanical Engineering displays two articles. On the right is a ceramic mold produced directly from digital designs using large area maskless photopolymerization (LAMP) technology; on the left is a single-crystal superalloy turbine airfoil that was cast using a ceramic mold of the kind shown on the right.

abilities and fully ambulatory people," Shankwiler said. "We have to ask – how should the human need affect the manufactured output and what are the best methods for achieving that?"

Pursuing Micro-scale Machining

J. Rhett Mayor, an associate professor in the School of Mechanical Engineering, is investigating techniques that allow effective machining of metal surfaces at 50 microns – one 2,000ths of an inch – or less. He is also developing unique applications based on advanced micro-machining, such as tiny channels in metal that enhance heat transfer between surfaces.

At present, Mayor explained, the ability to cut micro-features into surfaces is limited to metal sections about 1 centimeter square, a size that offers little cooling capability. Research being conducted by Mayor and his group focuses on scaling up micro-machining capabilities so that micro features can be cut in larger metal sheets.

"We can currently make hundreds of features on a square centimeter," Mayor said. "What we need are millions of features on a square foot."

One type of micro-scale feature – micro-channel heat exchangers – could play an important role in cooling factory-floor devices, as well as in the development of closed-loop systems that could generate power using recycled heat. For example, today's factories typically use large electrical motors that vent their heat inside the plant, wasting energy.

In related work, Mayor and his team are developing optimization routines and thermal models that could enhance electrical machine design through the application of micro-machining and other technologies. The aim is to create machines that are smaller, yet offer high energy outputs thanks to more efficient cooling and to energy recycling.

Another application of large scale micro-machining could involve the development of lightweight electric actuators that would take the place of hydraulics in aircraft. Such electric actuators would need plenty of power to replicate the high torque provided by hydraulics; those power requirements would demand effective cooling strategies.

Tackling Issues on the Factory Floor

Promoting Factory Robotics

Henrik Christensen, a professor in the College of Computing, is working with the Boeing Company to advance robotic manufacturing in the aircraft maker's facilities.

In one project, Christensen and his team are working on an initiative that makes fundamental changes to how pieces are handled on the factory floor. In this approach, robots reverse the standard procedure by moving processing machines to a given part, rather than moving the part through an assembly line.

"Think of a large airplane structure," Christensen said. "Having a machine move along the body of the aircraft, rather than moving the body itself, could result in much more efficient use of the machine."

The team is employing a movable platform in the MaRC building that supports a robotic processing machine. Tests have already been performed using mobile painting and drilling capabilities that could lead to similar implementations at Boeing facilities.

Christensen has also developed automation technology that helps Boeing inspect parts and sub-assemblies that arrive from suppliers. The mobile robotic system scans each arriving piece to confirm that it is the correct item and conforms to the stipulated dimensions.

The technology allows Boeing to identify shipping errors almost immediately, before the mistake can delay production. It also saves on labor costs and allows workers to be assigned to less routine tasks.

The Boeing projects are part of the Aerospace Manufacturing Initiative (AMI), which was established in 2008 when Boeing identified Georgia Tech as a strategic university partner and agreed to collaborate on innovative manufacturing technologies for aerospace products. The AMI, which involves multiple research projects across Georgia Tech, is led by Steven Danyluk, who is the Morris M. Bryan Jr. Chair in Mechanical Engineering for Advanced Manufacturing Systems. Since 2008, Siemens USA and CAMotion Inc. have also become AMI participants.

In another project just getting launched with a major French manufacturing company, Christensen is pursuing novel technology that would allow a factory-floor robot to learn tasks via direct human demonstration. Rather than having each robotic operation mapped out laboriously on a control computer, a worker would demonstrate the optimal way to perform a job and the robot would then mimic the human.

This human-model approach to robotic learning could have applications across a number of industries, he added; both Boeing and General Motors have expressed interest in the technology. Other application areas for this technique include health care and biotechnology, where it could help automate both manufacturing procedures and laboratory testing.

Improving Online Production

Jianjun (Jan) Shi, a professor in the H. Milton Stewart School of Industrial and Systems Engineering (ISYE), conducts research that addresses system informatics and control. He uses his training in mechanical and electrical engineering to integrate system data – comprising design, manufacturing, automation and performance information – into models that seek to reduce process variability.

In one effort, Shi is working with nGimat Co., a Norcross, Ga.-based company that is currently evaluating ways to mass produce a type of nanopowder used in high-energy, high-density batteries for electric cars. With sponsorship from the Department of Energy (DOE), Shi is supporting nGimat as it works to increase nanopowder output by several orders of magnitude.

"This product has very good characteristics, and the task here is to scale up production while maintaining the quality," said Shi, who holds the Carolyn J. Stewart Chair in ISyE. "We must identify the parameters – what to monitor, what to control – to reduce any variability, and do so in an environmentally friendly way."

In work focusing on the steel industry, Shi is pursuing multiple projects including the investigation of sensing technologies used to monitor very high temperature environments in steel manufacturing. With DOE support, he is working with OG Technologies Inc. to develop methods that use optical sensors to provide continuous high-speed images of very hot surfaces – between 1,000 and 1,450 degrees Celsius.

"We want to catch defect formation in the very early stages of manufacturing," Shi said. "By using imaging data of the product effectively with other process data to eliminate defects, we can help optimize the casting process."

In another project, sponsored by the National Science Foundation (NSF), Shi is investigating ways to use process measurements and online adjustments to improve quality control in the manufacturing of the silicon wafers used in semiconductors. He is working with several manufacturers to examine the root causes of undesirable geometric defects in wafer surfaces.

Anticipating System Failure

Nagi Gebraeel, an associate professor in the School of Industrial and Systems Engineering, conducts research in detecting and preventing failure in engineering systems as they degrade over time. The goal is to avoid both expensive downtime and unnecessary maintenance costs.

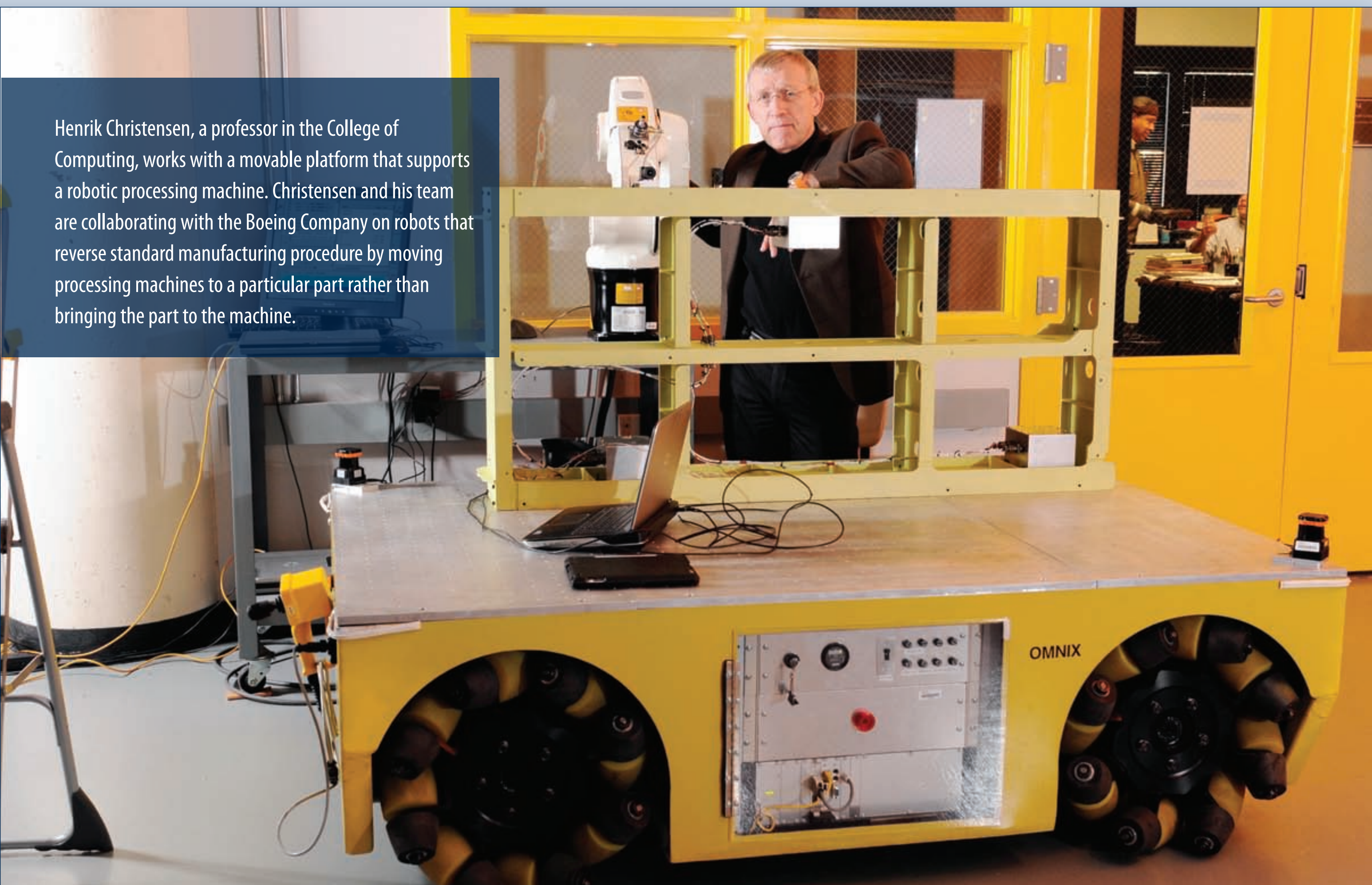
"We could be talking about a fleet of aircraft, trucks, trains, ships – or a manufacturing system," Gebraeel said. "In any of these cases, it's extremely useful for numerous reasons to be able to accurately estimate the remaining useful lifetime of a system or its components."

With NSF funding, Gebraeel has examined some of the key challenges in accurately predicting failures of complex engineering systems. Specific challenges include the ability to account for the uncertainty associated with degradation processes of these systems and their components, the effects of future environmental/operational conditions, and the dependencies and interactions that exist in multi-component systems.

In one project, Gebraeel and his team worked with Rockwell Collins, a maker of avionics and electronics, to monitor and diagnose the performance of circuit boards that control vital aircraft communications systems.

With equipment funding provided by Georgia Tech, Gebraeel has developed an adaptive prognostics system (APS), a custom research tool that allows him to investigate how quickly components degrade under stresses, using sensor-detected signals such as vibration.

Photos: Gary Meek



Henrik Christensen, a professor in the College of Computing, works with a movable platform that supports a robotic processing machine. Christensen and his team are collaborating with the Boeing Company on robots that reverse standard manufacturing procedure by moving processing machines to a particular part rather than bringing the part to the machine.

Professor Nagi Gebraeel from the School of Industrial and Systems Engineering prepares to test the accuracy of degradation models that he has developed. These models use real-time sensor signals to predict failure in complex engineering systems.

"There's a real need for information about the remaining life of components, so that users can find the economical middle ground between the cost of scheduled replacements and the cost of failure," he said.

Maximizing Throughput with Software

Three faculty members in the School of Industrial and Systems Engineering – Shabbir Ahmed, George Nemhauser and Joel Sokol – recently completed a project supporting a major maker of float glass. The manufacturer was automating a process in which finished glass plates are packed for shipment.

The company was concerned that new machines – which pick up and remove glass from the production line – might fall behind, allowing valuable plates to be damaged. They wanted the capability to carefully schedule production sequences so the machines could function at maximum capacity without wasting plates.

The team tackled development of new software that could minimize production problems. They devised algorithms that allowed the machines to work at their maximum efficiency and enabled them to handle input data with more than 99 percent efficiency.

"The algorithms we delivered can also be used strategically, to determine how many machines of each type should be installed on a production line," Sokol said.

Sokol, Nemhauser and Ahmed are also collaborating on a project with a large international corporation to support production throughput at a semiconductor manufacturing facility.

The challenge involves the physical movement of semiconductors from one processing station to another throughout the factory. Because the routing of semiconductors between processing machines can differ from item to item, there's no linear assembly line procedure; instead, hundreds of automated vehicles pick up items from one processing point and move them to the next step.

Due to the facility's layout, these automated vehicles often encounter congestion that can delay the production schedule, said Nemhauser, who is the A. Russell Chandler III Chair and Institute professor. The team is developing methods to best route and schedule the vehicles to minimize congestion and to move items between machines in ways that don't delay production.

Increasing Manufacturing Precision

Shreyes Melkote, who is the Morris M. Bryan Jr. professor in mechanical engineering, directs the Precision Machining Research Center, one of numerous centers based in MaRC. Melkote researches precision manufacturing issues in several areas, including the production of precision metal parts and photovoltaic substrates.

In a project sponsored by The Timken Company, Melkote is investigating methods for faster and more efficient machining of hardened steel materials using a hybrid process called "Laser Assisted Hard Machining." Results from successful machining trials have demonstrated that this hybrid process has the potential to reduce machining time as well as cutting tool cost by prolonging tool life.

In a Boeing-sponsored project, Melkote is developing thin-film sensors capable of monitoring high-speed machining operations. The goal is to give operators in-depth feedback for more effective control of high-speed rotating machines used to produce aerospace parts.

Traditional piezoelectric sensors are costly and unreliable, Melkote said, and installing them on a given machine can alter its dynamic characteristics. By contrast, sensors made from low-cost piezoelectric polymer film can be attached to a rotating device without affecting its operation. A patent application is being filed on this sensor technology.

"Thin-film sensors allow us to accurately measure what's happening between the tool and the work-piece, in terms of forces, vibrations, deflections and other process responses," he said. "We have demonstrated that the quality of information we are getting from a $200 sensor is as good as from one that costs $30,000."

Innovations in Manufacturing Systems and Processes

Automating Manufacturing Simulations

Professor Leon McGinnis of the School of Industrial and Systems Engineering focuses on model-based systems engineering, an approach that uses computational methods to enable capture and reuse of systems knowledge. McGinnis is pursuing several sponsored projects in this area.

In one effort, McGinnis and his team have been working with Rockwell Collins, a maker of avionics and electronics, to help speed the introduction of new products by automating a process that simulates the requirements of production.

To optimize the resources needed to make products at the required rate, McGinnis explained, Rockwell Collins creates a computerized simulation of the manufacturing processes. Development of these models has traditionally been the province of experts skilled in taking initial system designs and painstakingly translating them into simulations of actual production.

"This is not a trivial task – producing a simulation model requires some 100 to 200 hours per product," said McGinnis, who is associate director of MaRC. "The company was only able to generate a few production models at a time, which created something of a bottleneck."

To understand the process of developing simulation models, a team interviewed the Rockwell Collins experts on the

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Enterprise Innovation Institute: Supporting Manufacturing Throughout Georgia

The Enterprise Innovation Institute is Georgia Tech's primary business assistance and economic development organization. It directly supports advanced manufacturing in the state through a comprehensive set of programs.

The **Georgia Manufacturing Extension Partnership** (GaMEP) supports new and existing Georgia companies and provides numerous services for improving manufacturing competitiveness. It offers direct technical and engineering assistance, as well as continuing education courses and networking opportunities.

GaMEP's staff of nearly 40 engineers and other professionals works from Georgia Tech regional offices throughout the state. They offer broad expertise to client companies, and tap the extensive resources and expertise at the main campus.

"In fiscal 2010, the GaMEP team helped manufacturing companies reduce operating costs by $55 million, increase sales by $130 million and create or save 1,450 jobs," said Chris Downing, P.E., a mechanical engineer who directs the Enterprise Innovation Institute's Industry Services unit.

The **Advanced Technology Development Center (ATDC)** is a startup company accelerator that is part of the Enterprise Innovation Institute's services to entrepreneurs. With more than 500 member companies throughout Georgia, ATDC is believed to be the largest such incubator in the United States.

ATDC has graduated 135 new enterprises – many of them involved in manufacturing in one way or another – which together have raised more than $1 billion in outside financing. Among other kudos, the center has been named to *Forbes* magazine's list of 10 top U.S. technology incubators.

Georgia Tech VentureLab helps faculty members and other research staff members launch new companies based on Georgia Tech intellectual property. In 2010, it evaluated 125 research innovations and helped form 16 new companies.

The Georgia Tech Lean Consortium advances the effective use of lean business principles through shared learning and peer-to-peer relationships among members. Directed by Larry Alford, the Lean Consortium helps Georgia manufacturing companies and other businesses adopt techniques that save millions of dollars annually.

"A lean enterprise focuses on eliminating waste throughout the business – waste that costs time and money but adds no value for customers," Alford said.

The **Program in Science, Technology, and Innovation Policy** performs research related to manufacturing. Led by Philip Shapira, a professor in the Ivan Allen College of Liberal Arts, and Jan Youtie, a principal research associate at the Enterprise Innovation Institute and an adjunct associate professor in Ivan Allen, the program produces the Georgia Manufacturing Survey (www.gms-ei2.org), performs comparative analysis of manufacturing extension programs in a number of countries and develops assessments of the U.S. Manufacturing Extension Partnership program.

Shapira was recently appointed to chair a National Academies panel titled, "21st Century Manufacturing: The Role of the Manufacturing Extension Partnership Program of the National Institute of Standards and Technology."

Other manufacturing support programs include:

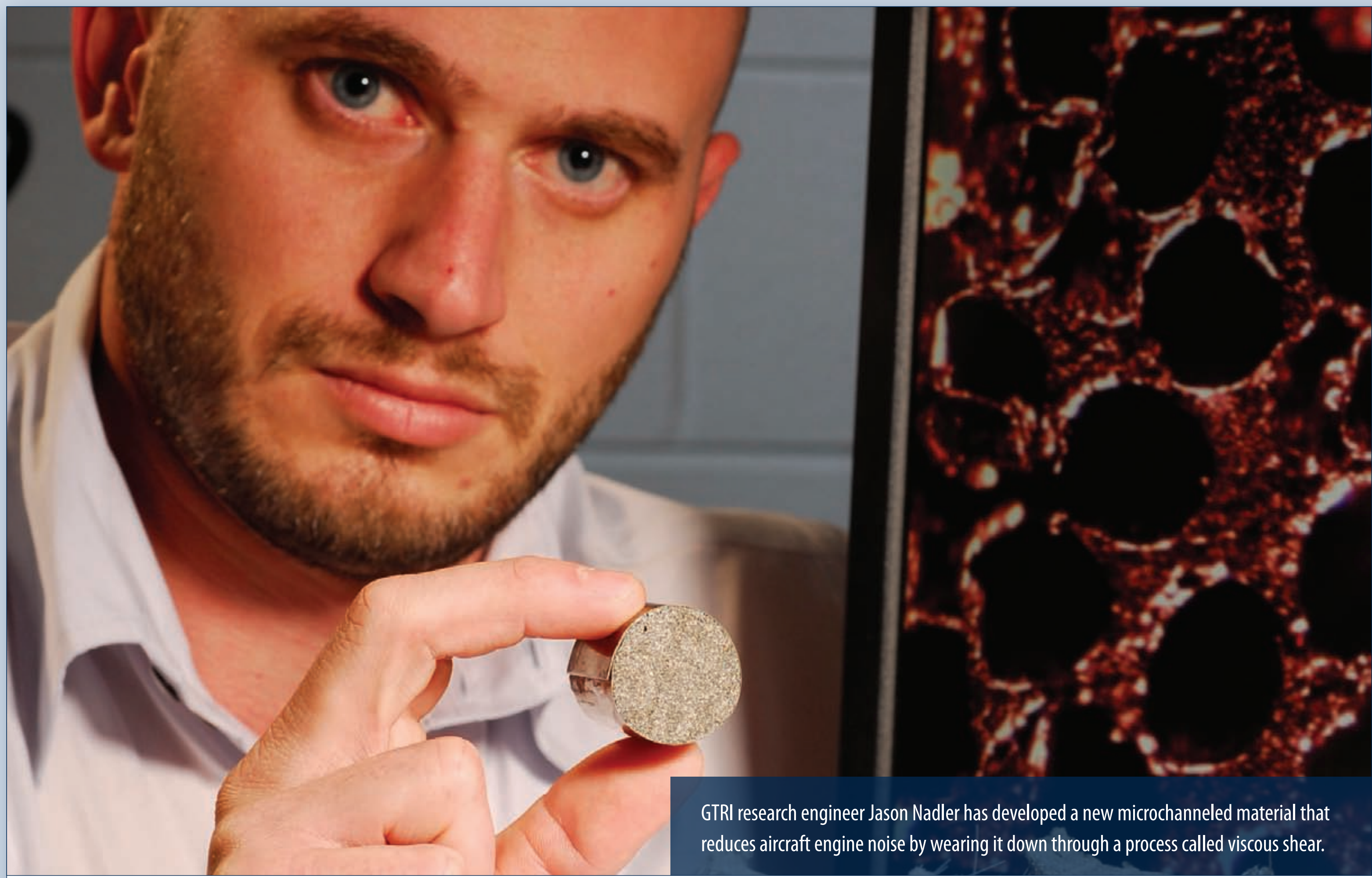
SBIR/STTR – helps Georgia companies secure federal seed grants for research and technology transfer.

Southeast Trade Adjustment Assistance Center – aids regional manufacturers facing intensive competition from imported products via funding that helps implement competitive strategies.

Strategic Partners Office – helps new and expanding companies find research and technology solutions available at Georgia Tech. It uses university resources to recruit high technology jobs to Georgia in collaboration with other state agencies.

Dr. Ric Hollstrom (left), owner of OrthoCare Labs, discusses the company's products with Derek Woodham, a Georgia Tech regional manager. Woodham helped the company redesign its manufacturing process to boost production by 200 percent.

Photo: Gary Meek



GTRI research engineer Jason Nadler has developed a new microchanneled material that reduces aircraft engine noise by wearing it down through a process called viscous shear.

methods they used to develop such models. Then the Georgia Tech researchers turned to SysML, a programming language that enables the computerized modeling of complex systems, including multiple related factors such as people, machinery and product flows.

By using SysML to describe the evolution of a given product, the researchers were able to automate its movement from design to simulation. Even more important, the team created a domain-specific version of SysML that was customized to the Rockwell Collins environment. That achievement allowed any of the company's new products and systems to be plugged into a SysML-based automation process.

This new way of doing things appears to reduce the time required to build simulation models by an order of magnitude, said McGinnis, who leads the Model-Based Systems Engineering Center in MaRC.

In another project, McGinnis and his team are collaborating with the School of Mechanical Engineering and MaRC to develop semantics for manufacturing processes under a DARPA contract. In other work, McGinnis is collaborating with the Tennenbaum Institute – a Georgia Tech organization that supports research for enterprise transformation – to address the challenges of identifying and mitigating risks in global manufacturing enterprise networks.

Developing Future Factories

A research team from the Georgia Tech Research Institute (GTRI) is working with the General Motors Co. to develop novel sensor and computer technologies for manufacturing.

The project, known as the Factory of the Future, seeks to establish a manufacturing model based on approaches and technologies that are largely new to factory design and processes. Among other things, the researchers are investigating the use of biologically inspired software algorithms to help maximize plant floor efficiency.

"The future factory is one with an extremely agile environment, allowing the manufacturing plant to be reconfigured in real time to meet the objectives for production," said Gisele Bennett, director of the Electro-Optical Systems Laboratory at GTRI.

At the heart of this process improvement approach is a robust combination of sensor and intelligent algorithm technologies, said Bennett, who is leading the project. The resulting optimization algorithms would utilize asset visibility of supplies, machines and vehicle-assembly status to optimize the manufacturing process, based on current requirements that could include energy savings, throughput or cost.

The goal is a broad, centralized view of all aspects of the manufacturing process, available in real time. This big-picture capability could lead to greater efficiency and productivity due to improved routing, inventory control and visibility into the health of the manufacturing equipment.

"Among other things, these techniques could support a capability for just-in-time car building," Bennett said. "A consumer could go into a dealership, choose the car they wanted – and as soon as the car is specified, its assembly would begin remotely."

Advancing the Adaptive Process

A multidisciplinary team of Georgia Tech researchers is taking part in the Adaptive Vehicle Make (AVM) program. The four-year DARPA program, announced in the first half of 2011, fosters novel approaches to the design, verification and manufacturing of complex defense systems and vehicles. Funding for Georgia Tech's share of the work is expected to exceed $10 million.

The AVM effort consists of three primary programs: META, Instant Foundry Adaptive through Bits (iFAB) and Fast Adaptable Next-Generation Ground Vehicle (FANG). FANG includes the vehicleforge.mil project and the Manufacturing Experimentation and Outreach (MENTOR) effort.

Georgia Tech is collaborating with Vanderbilt University on the META program and the related Component, Context, and Manufacturing Model Library (C2M2L) program. Led by professor Dimitri Mavris, director of the Aerospace Systems Design Lab, and research engineer Johanna Ceisel, Georgia Tech's META effort focuses on dramatically improving the existing systems engineering, integration and testing processes for defense systems.

Rather than utilizing one particular alternative technique, metric or tool, META aims to develop model-based design methods for cyber-physical systems that are far more complex and heterogeneous than those in use today.

Shreyes Melkote, a professor in the School of Mechanical Engineering, leads an iFAB team that is developing manufacturing-process capabilities and model libraries to enable automated planning for the design and manufacture of military ground vehicles.

A GTRI team led by Vince Camp is also supporting iFAB, providing process guidance for development of the libraries. In addition, researchers from four Georgia Tech units, along with companies InterCAX LLC and Third Wave Systems Inc., are supporting this iFAB effort.

The vehicleforge.mil project, led by GTRI researchers Jack Zentner and Nick Bollweg, is creating a secure central website and other web-based tools capable of supporting collaborative vehicle development. The core website – vehicleforge.mil – would allow individuals and teams to share data, models, tools and ideas to speed and improve the design process.

"The aim here is to fundamentally change the way in which complex systems are taken from concept to reality," said Zentner, a senior research engineer. "By enabling many designers in varied locations to work together in a distributed manner, we're confident that vehicles – and eventually other systems – can be developed with greater speed and better results."

The C2M2L model library is part of the overall effort. C2M2L seeks to develop domain-specific models to enable the design, verification and fabrication of the FANG infantry fighting vehicle using the META, iFAB and vehicleforge.mil infrastructure.

The MENTOR effort will engage high school-age students in a series of collaborative design and distributed manufacturing prize-challenge experiments, with the goal of inspiring America's manufacturing and technology workforce of tomorrow.

DARPA envisions that the prize challenges will include up to 1,000 high schools in teams distributed across the nation and around the world, using computer-numerically-controlled (CNC) additive manufacturing machines – also known as 3D printers. The goal is help students collaboratively design and build systems of moderate complexity, such as mobile ground and aerial robots and energy systems.

MENTOR is led by professor Daniel Schrage of the School of Aerospace Engineering and director of the Integrated Product Lifecycle Engineering Laboratory, and by professor David Rosen of the School of Mechanical Engineering, who is also director of the Rapid Prototyping & Manufacturing Institute in MaRC.

Strengthening Supply Chains

Vinod Singhal, who is the Brady Family Professor of Operations Management in the College of Management, investigates supply chain disruptions and their relation to corporate performance. In one project, he is evaluating recent disruptions at manufacturing companies and other businesses, where he documents the magnitude of drop in stock prices, loss of revenue and increase in costs due to supply chain disruptions.

"Traditional approaches to supply chain management have focused only on efficiency," Singhal said. "Newer approaches involve avoiding value destruction by instituting a reliable, responsive and robust supply chain."

Singhal has developed a detailed framework that helps enterprises manage their supply chain risks. His research instructs companies on how to prioritize risks, making supply chain vulnerabilities more visible and ensuring that top management learns to recognize the issue as critical to corporate success.

Modeling Flexibility

In the College of Management, Regents' professor Cheryl Gaimon studies technology management in manufacturing and service enterprises. In one study, Gaimon and former Ph.D. student Alysse Morton analyzed the value of flexibility in high-

Production Focused: Georgia Tech Photovoltaic Research Generates Manufacturing Results

The **University Center of Excellence in Photovoltaics** (UCEP) at Georgia Tech performs cutting-edge research into the modeling and fabrication of low-cost, high-efficiency silicon solar cells. The center, sponsored by the U.S. Department of Energy, is led by Ajeet Rohatgi, a Regents' professor in the School of Electrical and Computer Engineering.

In late 2008, technology devised by Rohatgi became the basis for Suniva Inc., the Southeast's first solar-cell manufacturer. The company makes high-efficiency crystalline-silicon photovoltaic cells at a 100,000-square-foot facility in Norcross, north of Atlanta. Suniva's startup was assisted by VentureLab, a unit of Georgia Tech's Enterprise Innovation Institute that helps convert research discoveries into new companies.

The **Nanotechnology Laboratory** of the Georgia Tech Research Institute (GTRI) is led by Jud Ready, a researcher with GTRI and an adjunct professor in the School of Materials Science and Engineering. Ready and his team have developed three-dimensional photovoltaic arrays which use unique light-trapping structures to capture more of the sun's energy. The technology was recently licensed by Bloo Solar Inc., a California-based designer and maker of solar photovoltaic modules.

In a project with Encell Technology Co., a GTRI team composed of Ready, Jason Nadler and Brent Wagner is facilitating battery manufacturing using porous metal foams and quantum dots. The metal foams are used to form extremely high surface-area electrodes for efficient and reliable batteries targeted at renewable energy and smart grid applications, while the quantum dots enhance the electrochemistry between the electrodes and electrolyte.

The **Photovoltaic Manufacturing Laboratory** (PML) located in the Manufacturing Research Center (MaRC), studies ways to reduce costs in solar-cell manufacture. Led by professors Steven Danyluk and Shreyes Melkote of the School of Mechanical Engineering, the lab's work focuses on reducing losses during the production of the crystalline-silicon substrate used in many photovoltaic cells.

Today's companies are bringing down costs and speeding up production by using thinner cells, Melkote explained. That trend can create problems, because the silicon substrate is brittle enough that breakage becomes an issue.

The PML's research, funded by a National Science Foundation industry/university consortium that includes Georgia Tech and North Carolina State University, studies stresses and defects in substrate material and how they affect breakage during handling and processing. Among the subjects of study are tools and techniques that can avoid breakage and even enhance the mechanical integrity of the substrate.

volume manufacturing of products with short life cycles, such as computer components.

The researchers developed a model showing how companies could link internal manufacturing capabilities with swiftly changing external market forces. They demonstrated how these businesses could exploit manufacturing efficiencies, early market entry and quick shifts between product generations, combined with optimal pricing policies.

"Our results demonstrated that firms need to work closely with their equipment suppliers to achieve more flexible technology, and that even a less-efficient facility can realize a long-term competitive advantage through an earlier market-entry strategy," Gaimon said.

Lowering Quality-Failure Impact

Assistant Professor Manpreet Hora of the College of Management conducts research in several areas of business and manufacturing, including the recall of products such as automobiles. In a recent study, he looked at the risks that can sometimes be created by today's lean manufacturing methods.

In studying automotive recalls, Hora discovered that because companies often share components across multiple vehicle lines to maintain lean practices, a potential defect in such components can greatly increase the cost and the magnitude of a recall. He concluded that increased quality checks of shared and critical parts are essential in lowering the impact of quality failures from recalls.

Helping Manufacturers Improve Products

Reducing Engine Noise

In a project sponsored by EADS North America, a large aerospace and defense company, GTRI researcher Jason Nadler tackled the problem of helping the manufacturer reduce noise produced by commercial and military jet aircraft.

Nadler and his team used innovative materials that make possible a new approach to the physics of noise reduction. They found that honeycomb-like structures composed of many tiny tubes or channels can reduce sound more effectively than conventional methods.

"This approach dissipates acoustic waves by essentially wearing them out," Nadler said. "It's a phenomenological shift, fundamentally different from traditional techniques that absorb sound using a more frequency-dependent resonance."

Nadler's research involves broadband acoustic absorption, a method of reducing sound that doesn't depend on frequencies or resonance. Instead of resonating, sound waves plunge into the channels and dissipate through a process called viscous shear.

He has developed what could be the world's first superalloy micro honeycomb using a nickel-based superalloy. He estimates that this new approach could provide better sound attenuation than any acoustic liner currently available.

Improving Poultry Production

The Food Processing Technology Division of GTRI performs a broad spectrum of research for the food industry, including numerous projects that support the state's nearly $20 billion poultry industry. Research areas include advanced imaging and sensor technologies; robotics and automation systems; environmental and biological systems; food and product safety research; and worker safety research.

In one project, GTRI researchers are employing image processing, statistical modeling, modeling of biomaterials and high-speed force control to bring automated chicken deboning to poultry processors. The Intelligent Deboning System aims to match or exceed the efficiency of the manual process.

Initial tests of the deboning prototype system, including cutting experiments, have shown the system's ability to recognize bone during a cut and thus avoid bone chips. The work has demonstrated the validity of GTRI's approach.

"There are some very major factors in play in this project," said Gary McMurray, chief of the Food Processing Technology Division and project director. "These include food safety – because bone chips are a major hazard for boneless breast fillets – and yield, because every 1 percent loss of breast meat represents about $2.5 million to each of Georgia's 20 processing plants."

Controlling Baking Systems

GTRI has developed a production line system that automatically inspects the quality of sandwich buns exiting the oven and adjusts oven temperatures if it detects unacceptable products.

Working with baking company Flowers Foods and AMF/BakeTech, a baking equipment manufacturer, GTRI researchers Douglas Britton and Colin Usher have tested their industrial-quality prototype system. Made of stainless steel, the system is dust-and-water-resistant, and mounts on existing conveyor belts as wide as 50 inches.

The researchers tested the system in a Flowers Foods bakery.

"We have closed the loop between the quality inspection of buns and the oven controls to meet the specifications required by food service and fast-food customers," said Britton. "By creating a more accurate, uniform and faster assessment process, we are able to minimize waste and lost product."

Testing Manufacturing Materials

The GTRI Materials Analysis Center (MAC), led by Lisa Detter-Hoskin, supports manufacturers and other groups using advanced analytical tools and methodologies that address materials characterization, failure analysis and corrosion issues for manufacturers and other companies. MAC annually manages research projects and evaluates samples for hundreds of corporations and agencies.

For example, the center supports CE-Tech LLC of Alpharetta, Ga., in numerous areas, including conducting analyses of competitive products and resins. The objective is to lower raw-material costs for CE-Tech clients through the substitution of lower-cost resins.

In another instance, GTRI works with Fairfield, Conn.-based Acme United Corp., a maker of cutting, measuring and safety products, to evaluate the chemistry and structure of new surface coatings. In one project, GTRI personnel tested a proprietary Acme United physical vapor deposition technology used to impart a hard outer shell onto steel blades.

"We frequently need to test," said Larry Buchtmann, vice president for technology for Acme United. "GTRI has the specialized equipment and trained engineering staff to meet our ongoing needs for these services."

Assessing Advanced Electronics

GTRI's Electromagnetic Test and Evaluation Facilities (EMTEF) and Electromagnetic Phenomenology Laboratory test facilities provide ongoing research and support for manufacturers. Both commercial customers and the U.S. government use these assets to aid design and manufacture of antennas and antenna-related sensors for wireless systems, cell and base station antennas, aircraft antennas and related applications.

Photo: Rob Felt

Leon McGinnis, a professor in the School of Industrial and Systems Engineering, studies model-based systems engineering, using computational methods that enable the capture of systems knowledge. In one effort, McGinnis and his team helped accelerate new-product introductions in the Rockwell Collins manufacturing operation.

"These multi-purpose ranges allow antenna manufacturers or design engineers to confirm modeling designs, diagnose performance problems, and to confirm performance against advertised specifications," said GTRI researcher Barry Mitchell.

In one past instance, Mitchell recalls, a maker of aircraft weather radar was encountering problems with false alarms coming from wind-shear detection systems in flight. A GTRI team tested a waveguide antenna array on a planar near-field range belonging to the research institute, and the resulting aperture holograms revealed leakage points from brazed joints on the array. Eventually the problem was traced to a defect in the dip-brazing process during manufacturing, enabling corrective measures.

Making Manufacturing More Sustainable

Supporting Sustainable Manufacturing

School of Mechanical Engineering professor Bert Bras, who leads the Sustainable Design and Manufacturing (SDM) Program in the MaRC, focuses on reducing the environmental impact of materials, products and manufacturing processes, while increasing their competitiveness.

The SDM group gets a large share of its research funding from industry. Together with MaRC research engineer Tina Guldberg, Bras and his group are currently working with Ford, GM and Boeing on projects related to sustainable manufacturing. Much of their work centers on a better understanding of the overall effect of manufacturing operations, as well as potential unintended consequences of product, process and business decisions over their life cycle.

One technique developed by Bras and his students involves the inclusion of environmental impact measures such as energy and water consumption in activity-based cost models. In this way, a single assessment model can quantify financial and environmental consequences of manufacturing process choices.

With Marc Weissburg, a professor in the School of Biology and co-director of the Center for Bio-Inspired Design, Bras and his team are working on an NSF-funded project focused on the role of biologically inspired design in industrial manufacturing networks.

Bras is also collaborating with professor Nancey Green Leigh of the School of City and Regional Planning and professor Steven French of the College of Architecture on an NSF-funded project that studies methods of boosting product and material recovery in urban areas for use in local manufacturing. Leigh and French are also focusing in this grant on quantifying the amount of carpet and electronic waste generated in a metropolitan area and the economic benefits of diverting it from landfills, thereby creating business and job opportunities.

Recovering and Reusing Waste

Jane Ammons, who is the H. Milton and Carolyn J. Stewart School Chair in the School of Industrial and Systems Engineering, collaborates on reverse production systems with Matthew Realff,

Photo: Gary Meek

A robotic device used in the Intelligent Deboning project prepares to slice through the shoulder joint of a chicken. The system, developed by the GTRI Food Processing Technology Division, is pursuing two goals: cutting close to the bone to maximize breast-meat yield and ensuring food safety by avoiding creation of bone chips.

a professor in the School of Chemical & Biomolecular Engineering. For more than 10 years, the team has focused on two important areas: the recovery and reuse of carpet wastes and ways to reduce electronic waste.

Ammons, Realff and their teams have developed a mathematical framework to support the growth of used-carpet collection networks. Such networks could help to recycle much of the 3.4 billion pounds of carpet waste currently produced in the United States annually. Research indicates that successful reuse of that carpet has a potential value of at least $850 million, versus a disposal cost of at least $60 million for simply sending it to landfills.

In other work, the team is studying the problem of e-waste – unwanted electronic components such as televisions, monitors and computer boards and chips. The e-waste stream includes hazardous materials such as lead and other toxins, yet effective management and reuse of e-components can be profitable. Ammons and Realff have devised mathematical models that address the complexities of e-waste processing, with the goal of helping recycling companies stay economically viable.

Promoting Manufacturing Sustainability

In a recent project, associate professor Chen Zhou in the School of Industrial and Systems Engineering, working with professor Leon McGinnis, tackled sustainability issues for a major U.S. manufacturer. The issue involved shipping gearbox components from China to the United States in ways that would minimize not only cost but also greenhouse gas emissions and waste.

It turned out that packaging was at the heart of the issue. The researchers had to configure component packaging so that the maximum number of components could be placed in a cargo container, yet also allow for optimal recycling of the packing materials to avoid waste and unnecessary cost.

"This was definitely a complex problem," Zhou said. "You must track every piece of packaging from its source to its final resting place, when it either goes into another product or into a landfill."

The team created a model – a globally sourced auto parts packaging system – that optimized cargo container space. The model also enabled the use of packing materials that were fully reusable; some materials went back to China for use in future shipments, while the rest was recycled into plastics for new vehicles.

Clearly, Georgia Tech's broad-based involvement in advanced manufacturing research reflects both the talents of its faculty and the determination of U.S. industry to reinvent itself with the help of university-based research.

The United States generates more inventions than the rest of the world combined, and Georgia Tech will continue to work with business and government to help turn the nation's vast innovative capabilities into an American industrial renaissance. rh

Abby Robinson also contributed to this article.

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New information on the role of insoluble dust particles in forming cloud droplets could improve the accuracy of regional climate models, especially in areas of the world that have significant amounts of mineral aerosols in the atmosphere. A more accurate accounting for the role of these particles could also have implications for global climate models.

Cloud Formation:

Study Shows Insoluble Dust Particles Can Form Cloud Droplets That Affect Global and Regional Climate

By John Toon

Photo: Gary Meek

These containers hold samples of mineral dust studied by Georgia Tech scientists as part of research into the role of insoluble dust particles in the formation of cloud droplets.

New information on the role of insoluble dust particles in forming cloud droplets could improve the accuracy of regional climate models, especially in areas of the world that have significant amounts of mineral aerosols in the atmosphere. A more accurate accounting for the role of these particles could also have implications for global climate models.

Cloud properties can have a significant impact on climate, yet the effects of aerosols like dust are among the uncertain components of climate change models. Scientists have long recognized the importance of soluble particles, such as sea salt and sulfates, in creating the droplets that form clouds and lead to precipitation. Until now, however, the role of insoluble particles – mostly dust swept into the atmosphere from such sources as deserts – hasn't figured significantly in climate models.

Using a combination of physics-based theory and laboratory measurement of droplet formation, Georgia Tech researchers have developed a model that can be added to existing regional and global climate simulations. The impacts of these refinements on cloud condensation nuclei (CCN) activity and droplet activation kinetics are still being studied.

"Understanding that insoluble dust forms more droplets than we thought it could, and that those droplets form close to the sources of the particles, could change our picture of how precipitation is formed in areas like the Mediterranean, Asia and other climate-stressed regions," said Athanasios Nenes, a professor in the Georgia Tech School of Earth and Atmospheric Sciences.

The research was supported by the National Science Foundation (NSF), the National Oceanic and Atmospheric Administration (NOAA) and NASA. The findings were described at the Fall 2011 meeting of the American Chemical Society, and reported in the journals *Geophysical Research Letters*, *Journal of Geophysical Research* and *Atmospheric Chemistry and Physics*.

Soluble particles nucleate droplets by absorbing water under conditions of high humidity. Insoluble materials such as dust cannot absorb water, so it was thought that they played little role in the formation of clouds and precipitation.

Nonetheless, Nenes and his collaborators realized that these dust particles could nucleate droplets in a different way: by adsorbing moisture onto their surfaces, much as moisture condenses on window glass during temperature changes. Some insoluble particles containing clay materials may also absorb moisture, even though the particles don't dissolve in it.

Working with Irina Sokolik, also a professor in the School of Earth and Atmospheric Sciences, Nenes and graduate student Prashant Kumar studied aerosol particles created from samples of desert soils from several areas of the world, including North Africa, East Asia/China and North America. In laboratory conditions simulating those of a saturated atmosphere, these insoluble particles formed cloud droplets, though the process was slower than producing droplets from soluble materials.

"We generated particles in the laboratory from materials we find in the atmosphere," explained Nenes, who also holds a faculty appointment in Georgia Tech's School of Chemical and Biomolecular Engineering. "These particles take up water using a mechanism that had not been considered before in models. It turns out that this process of adsorption soaks up enough water to form cloud droplets."

The laboratory work showed that smaller particles were more likely than expected to generate droplets, and that their effectiveness as cloud condensation nuclei was affected by the type of minerals present, their size, morphology and processes affecting them in the atmosphere. The dust particles ranged in size from 100 nanometers up to a few microns.

These mineral aerosols may consist of iron oxides, carbonates, quartz and clays. They mainly originate from arid and semi-arid regions, and can remain suspended in the atmosphere for as long as several weeks, allowing them to be transported long distances from their original sources. In the atmosphere, the dust particles tend to accumulate soluble materials as they age.

Clouds play an important role in governing climate, so adding new information about their formation could improve the accuracy of complex climate models.

"The reason that we care about particle-cloud interactions is that they introduce a lot of uncertainties in climate model predictions," Nenes said. "Anything that can be done to improve these predictions by providing more specific cloud information would be helpful to projecting climate change." rh

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"Understanding that insoluble dust forms more droplets than we thought it could, and that those droplets form close to the sources of the particles, could change our picture of how precipitation is formed in areas like the Mediterranean, Asia and other climate-stressed regions."

— Athanasios Nenes, professor in the School of Earth and Atmospheric Sciences

Georgia Tech professors Irina Sokolik and Athanasios Nenes (front row, l-r) pose with graduate students Richard Moore and Terry Lathem (back row, l-r) in their laboratory. The researchers are studying the role of insoluble dust particles in the formation of cloud droplets.

Photo: Gary Meek

Studies of radio waves transmitted through simulated atmospheres will help NASA interpret data from its Juno Mission, which will begin sending back data from the planet Jupiter in 2016. Researchers simulated a variety of atmospheric conditions using a 2,400-pound pressure vessel and microwave-frequency test equipment.

Simulated Atmosphere:

Georgia Tech Scientists Will Help NASA Interpret Data from the Juno Mission to Jupiter

By John Toon

Photo: NASA

The planet Jupiter has been largely unchanged since its formation at the birth of our solar system. Studying it may resolve questions about how the solar system evolved.

In August 2016, when NASA's Juno Mission begins sending back information about the atmosphere of the planet Jupiter, research done by Georgia Tech engineers using a 2,400-pound pressure vessel will help scientists understand what the data means. The Juno probe was launched in August 2011 from Cape Canaveral Air Force Station in Florida.

Because Jupiter has been largely unchanged since its formation at the birth of our solar system, scientists hope Juno will resolve unanswered questions not only about the massive planet, but also about how our solar system evolved. Among the key questions are how much water exists there and how that water evolved from the hydrogen-rich early solar system.

"Jupiter collected much of the original solar nebula, that sheet of material that surrounded our sun when it formed," said Paul Steffes, a professor in Georgia Tech's School of Electrical and Computer Engineering and a member of the Juno Mission Team. "Knowing how much water is in the atmosphere of Jupiter is going to give us real insight into how the whole solar system has evolved. Understanding Jupiter really helps us understand how we got started."

To detect and measure water, Juno carries a radiometer that can measure radio emissions produced by the planet itself at microwave frequencies. As those signals pass through Jupiter's atmosphere, they are altered by the water and other constituents. The probe will receive microwave signals at six different frequencies that scientists know are emitted at various levels of the planet's atmosphere.

"The intensity of the microwave radiation at specific frequencies gets weaker depending on how much water is there," Steffes explained. "We'll be able to not only say whether or not there's water there, but we'll also be able to say at what altitude it exists based on the signatures of the microwaves coming out of the planet's atmosphere."

Interpreting that data will require knowledge that Steffes and his students are developing by simulating the Jupiter atmosphere in their pressure vessel, which is located inside an oven on the roof of Georgia Tech's Van Leer Building.

Though Jupiter is a long way from the sun, the planet's gravitational forces create high temperatures and tremendous pressures in the lower layers of the atmosphere where the water is believed to exist. The laboratory atmospheric simulations allow Steffes and his students to study the behavior of microwave signals passing through ammonia, hydrogen sulfide, helium, hydrogen and water vapor at pressures up to 100 times those of the Earth.

The researchers, including graduate student Danny Duong, have made thousands of measurements at different temperatures, pressures and microwave frequencies as the signals pass through different combinations of gases. The laboratory work, which is supported by NASA, is expected to be completed during 2012.

"The measurements we've made will allow the radiometer on Juno to be calibrated," Steffes noted. "When Juno gets to Jupiter, we'll know what conditions each microwave signature corresponds to."

Earlier attempts to quantify the water on Jupiter – the solar system's largest planet – produced conflicting information. Steffes assisted the Galileo Mission, which dropped a probe into the planet's atmosphere in 1995 and found surprisingly little water. Yet when the Comet Shoemaker-Levy crashed into Jupiter in 1994, it stirred up oxygen that led scientists to believe water was abundant.

Once Juno reaches the planet, it will go into an elliptical polar orbit to avoid Jupiter's radiation belts, which would harm the probe's electronic systems. Juno is scheduled to make 30 orbits, each of which will take 11 days. The researchers then expect to take about 18 months to process the information sent back to Earth.

Beyond measuring water on Jupiter, Juno will also study the planet's gravitation field in an effort to determine whether a solid core exists and how the giant body rotates. It will also measure magnetic fields and investigate Jupiter's auroras, which are the strongest in the solar system. And it will take a look at the planet's polar areas for the first time.

Steffes has been studying planetary atmospheres for more than 25 years, and has simulated conditions on Venus, Neptune, Saturn and Uranus in addition to Jupiter. The work has continued under the same contract since 1984. Georgia Tech's research into other planets goes back more than 50 years, Steffes said.

NASA's Jet Propulsion Laboratory in Pasadena, Calif., manages the Juno Mission for the principal investigator, Scott Bolton of Southwest Research Institute in San Antonio, Texas.

This research is supported by the National Aeronautics and Space Administration (NASA). Any opinions, findings and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of NASA.

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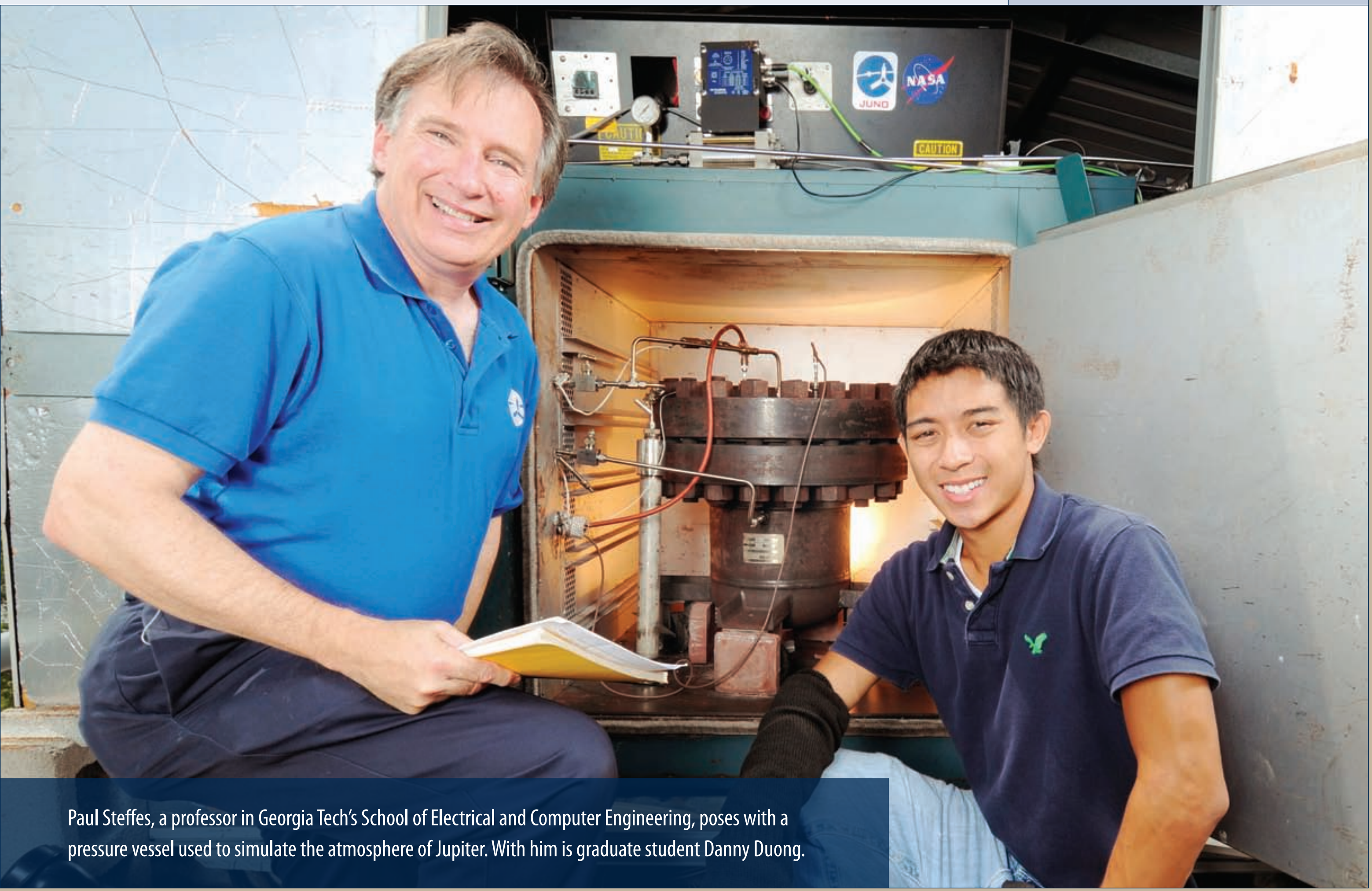
"Jupiter collected much of the original solar nebula, that sheet of material that surrounded our sun when it formed. Knowing how much water is in the atmosphere of Jupiter is going to give us real insight into how the whole solar system has evolved. Understanding Jupiter really helps us understand how we got started."

— Paul Steffes, professor in the School of Electrical and Computer Engineering



Paul Steffes, a professor in Georgia Tech's School of Electrical and Computer Engineering, poses with a pressure vessel used to simulate the atmosphere of Jupiter. With him is graduate student Danny Duong.

Photo: Gary Meek

News Media Report on Work of Georgia Tech Researchers

Georgia Tech researchers have developed a prototype wireless sensor capable of detecting trace amounts of ammonia, a key ingredient found in many explosives. The device, which employs carbon nanotubes and is printed on paper or paper-like material using standard inkjet technology, could be deployed in large numbers to alert authorities to the presence of explosives. The research was reported in more than 50 news outlets, including *Design News*, Discovery News, *ECN*, Electronics News, ElectroIQ, Engadget, *The Engineer*, Gizmag, Homeland Security Newswire, MSNBC.com, *Product Design and Development*, Quality Digest, Sensors and United Press International. The principal investigator is Krishna Naishadham in the Georgia Tech Research Institute (GTRI). (See the story on page 28 of this issue of *Research Horizons*.)

By looking to Mother Nature for solutions, researchers have identified a promising new binder material for lithium-ion battery electrodes that may not only boost energy storage, but also eliminate the use of toxic compounds now employed in manufacturing the components. Known as alginate, the material is extracted from common, fast-growing brown algae. In tests so far, it has helped boost energy storage and output for both graphite-based electrodes used in existing batteries and silicon-based electrodes being developed for future generations of batteries. The research, which was conducted in collaboration with Clemson University, has generated media coverage from *Chemical & Engineering News, Chemistry World*, Electronics Weekly, Energy Harvesting Journal, Green Car Congress, *Laboratory Equipment, National Defense*, Reuters, *Scientific American* and *Technology Review*. The principal investigator is Gleb Yushin in the School of Materials Science and Engineering. (See the story on page 46 of this issue of *Research Horizons*.)

Georgia Tech studies of how radio waves are altered when they pass through simulated planetary atmospheres will help NASA interpret data returned from its Juno Mission, which will begin sending back information from the planet Jupiter in 2016. Researchers simulated a variety of Jupiter's atmospheric conditions using a 2,400-pound pressure vessel housing microwave-frequency test equipment. News media reporting on the work included LiveScience.com, *Microwaves & RF*, MSNBC.com, *Space Daily*, Space.com and Yahoo! News. The research is led by Paul Steffes in the School of Electrical and Computer Engineering. (See the story on page 24 of this issue of *Research Horizons*.)

Using a technique known as thermochemical nanolithography (TCNL), researchers have developed a new way to fabricate nanometer-scale ferroelectric structures directly on flexible plastic substrates that would be unable to withstand the processing temperatures normally required to create such nanostructures. The technique, which uses a heated atomic force microscope (AFM) tip to produce patterns, could facilitate high-density, low-cost production of complex ferroelectric structures for energy harvesting arrays, sensors and actuators in nano-electromechanical systems (NEMS) and micro-electromechanical systems (MEMS). Media outlets reporting on the work include ASM International, *Ceramic Tech, Design News*, *Electronic Design News*, *Electronic Engineering Times,* ElectroIQ, Materials Insight, Nanotimes, New Electronics, Photonics.com and Sensors. Nazanin Bassiri-Gharb from the School of Mechanical Engineering and Elisa Riedo in the School of Physics are leading the project. (See the story on page 38 of this issue of *Research Horizons*.)

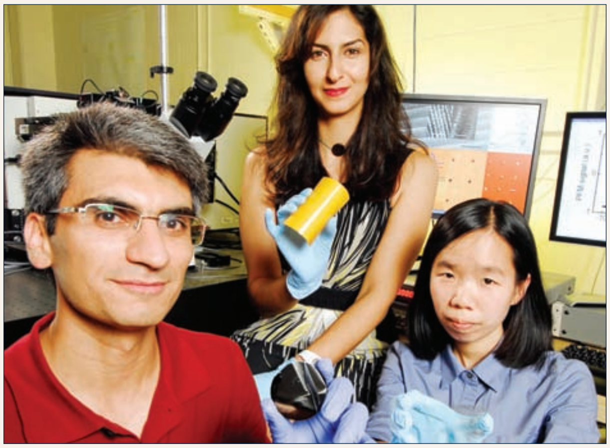
Photo: Gary Meek

Georgia Tech School of Electrical and Computer Engineering professor Manos Tentzeris (left) and Ph.D. candidate Rushi Vyas work with an inkjet system that can print components, circuits and antennas using novel "inks" that contain silver nanoparticles. The technique is used to produce ammonia sensors.

Photo: Gary Meek

Paul Steffes, a professor in Georgia Tech's School of Electrical and Computer Engineering, and graduate student Danny Duong, examine instrumentation on a pressure vessel used to simulate the atmosphere of Jupiter.

Photo: Gary Meek



Georgia Tech researchers display samples of materials on which ferroelectric nanostructures have been fabricated by thermochemical nanolithography. They are (l-r) graduate research assistant Yaser Bastani with silicon, assistant professor Nazanin Bassiri-Gharb with polyimide and postdoctoral fellow Suenne Kim with glass.

Georgia Tech Faculty and Staff Receive Recognition

Seven researchers were elected as IEEE Fellows: electrical and computer engineering professors **Magnus Egerstedt**, **Erik Verriest** and **Guotong Zhou**, principal research engineer **Mark Richards** and adjunct professor **Yucel Altunbasak**; interactive computing professor **Irfan Essa**; and mechanical engineering professor **Yogendra Joshi**.

Materials science and engineering professor **Vladimir Tsukruk** was appointed a Fellow of the Materials Research Society.

Eberhard Voit, biomedical engineering professor, was elected as a Fellow of the American Institute of Medical and Biological Engineering.

Four Georgia Tech faculty members were elected as Fellows of the American Association for the Advancement of Science: electrical and computer engineering professors **Ali Adibi**, **Robert Butera** and **Paul Steffes**, and computing professor **David Bader**.

Aerospace engineering professors **Tim Lieuwen** and **Massimo Ruzzene** were elected Fellows of the American Society of Mechanical Engineers.

Mathematics professor **Rafael de la Llave** was named Fellow of the Institute of Physics.

Eric Barnhart, GTRI principal research engineer, was selected as senior member of the IEEE.

Psychology associate professor **Bruce Walker** was named a senior member of the Association of Computing Machinery.

Thomas Barker, biomedical engineering assistant professor, received the Junior Investigator Award from the American Society for Matrix Biology.

Regents' professor in the School of Chemistry and Biochemistry **Seth Marder** received the 2011 Arthur C. Cope Scholar Award, which is administered by the American Chemical Society.

Rao Tummala, professor in electrical and computer engineering and materials science and engineering, received the IEEE Field Award.

GTRI senior research scientist **Danielle Ayan** received the 2011 Outstanding Service Award from the National States Geographic Information Council.

Julie Swann, associate professor in the Stewart School of Industrial and Systems Engineering, was among the "rising stars" included in this year's Atlanta Business Chronicle 40 Under 40 listing.

Christine Payne, assistant professor in chemistry and biochemistry, was honored with a DARPA Young Faculty Award.

The U.S. Senate confirmed **Arnold Stancell**, emeritus professor in the School of Chemical & Biomolecular Engineering, to the National Science Board.

Maria Westdickenberg, associate professor of mathematics, received a Presidential Early Career Award for Scientists and Engineers.

Earth and atmospheric sciences professor **Athanasios Nenes** received the Kenneth Whitby Award from the American Association for Aerosol Research.

Ron Bohlander, GTRI principal research scientist, was selected to receive the 2012 Society of Manufacturing Engineers Award of Merit.

Stewart School of Industrial and Systems Engineering professor **Sigrun Andradottir** received the Harold W. Kuhn Award during the 2011 INFORMS National Meeting.

Ravi Bellamkonda was named the Carol Ann and David D. Flanagan Chair in Biomedical Engineering.

Chemical & biomolecular engineering assistant professor **Mark Styczynski** received a Junior Faculty Enhancement Award from Oak Ridge Associated Universities.

Tom Conte, who holds a joint appointment in the School of Electrical and Computer Engineering and the School of Computer Science, was elected as the IEEE Computer Society First Vice President.

Chemistry and biochemistry professor **John Reynolds** received the American Chemical Society Award in Applied Polymer Science.

Frank Durso, professor of psychology, won the Franklin V. Taylor Award for Outstanding Contributions to Applied Experimental and Engineering Psychology.

Stewart School of Industrial and Systems Engineering assistant professor **Turgay Ayer** was named the first place winner for the Doing Good with Good Operations Research Competition during the 2011 INFORMS Annual Meeting.

The **GTRI Communications Office** won two awards at the International Association of Business Communicators Atlanta Chapter Golden Flame Awards.

Mechanical engineering professor **Andrés García** received the 2012 Clemson Award for Basic Research from the Society for Biomaterials.

Willie Pearson, sociology professor in the School of History, Technology, and Society, was honored recently by Sigma Xi, the international Scientific Research Society, during its 125th anniversary.

The Biomedical Engineering Society announced biomedical engineering professor **Gilda Barabino** as the organization's next president.

GTRI's Homeland Open Security Technology (HOST) program, led by research scientist **Josh Davis**, won the Open Source for America 2011 Government Deployment of Open Source Award.

Biomedical engineering research engineer **Cassie Mitchell** won two world championships at the 2011 Union Cycliste International (UCI) Paracycling World Championships in the individual time trial and road race events.

The Georgia Tech MBDA Business Center, led by **Donna Ennis**, received two awards from the Department of Commerce MBDA Atlanta National Enterprise Center: one for a successful year of performance and another for being one of the top-performing centers that helped its client secure an indefinite delivery indefinite quantity (IDIQ) contract during 2010.

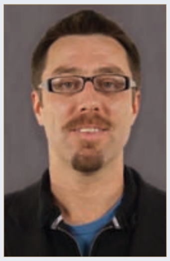
Robin Thomas, Regents' professor in the School of Mathematics, received the Neuron Lifetime Achievement Award for mathematics by Nadacni Fond Karla Janecka, an organization dedicated to supporting long-term cutting-edge science and research in the Czech Republic.

– Compiled by Abby Robinson


David Bader

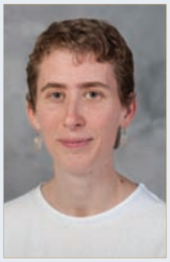

Gilda Barabino


Tom Conte


Magnus Egerstedt


Julie Swann


Bruce Walker


Maria Westdickenberg

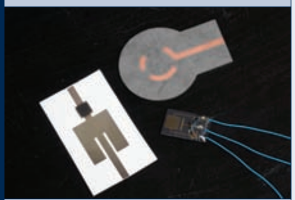
Researchers have developed a prototype wireless sensor capable of detecting trace amounts of a key ingredient found in many explosives. The device, which employs carbon nanotubes and is printed on paper or paper-like material using standard inkjet technology, could be deployed in large numbers to alert authorities to the presence of explosives, such as improvised explosive devices (IEDs).

Printed Protection:

Low-cost Paper-based Wireless Sensor Could Help Detect Explosive Devices

By Rick Robinson

Photos: Gary Meek



(Above) Image shows samples of three wireless devices that use carbon nanotubes to achieve high sensitivity to ammonia. (Below) Professor Manos Tentzeris holds a sensor (left) and an ultra-broadband spiral antenna that were printed on paper using inkjet technology.

Researchers have developed a prototype wireless sensor capable of detecting trace amounts of ammonia, a key ingredient found in many explosives. The device, which employs carbon nanotubes and is printed on paper or paper-like material using standard inkjet technology, could be deployed in large numbers to alert authorities to the presence of explosives, such as improvised explosive devices (IEDs).

"This prototype represents a significant step toward producing an integrated wireless system for explosives detection," said Krishna Naishadham, a principal research scientist who is leading the work at the Georgia Tech Research Institute (GTRI). "It incorporates a sensor and a communications device in a small, low-cost package that could operate almost anywhere."

Other types of hazardous-gas sensors are based on expensive semiconductor fabrication and gas chromatography, Naishadham said, and they consume more power, require human intervention and typically do not operate at ambient temperatures. Furthermore, those sensors have not been integrated with communication devices such as antennas.

The wireless component for communicating the sensor information – a resonant lightweight antenna – was printed on photographic paper using inkjet techniques devised by professor Manos Tentzeris of Georgia Tech's School of Electrical and Computer Engineering. Tentzeris is collaborating with Naishadham on development of the sensing device.

The sensing component, based on functionalized carbon nanotubes (CNTs), has been fabricated and tested for detection sensitivity by Xiaojuan (Judy) Song, a GTRI research scientist. The device relies on carbon-nanotube materials optimized by Song.

A presentation on this sensing technology was given in July 2011 at the IEEE Antennas and Propagation Symposium in Spokane, Wash., by Hoseon Lee, a Ph.D. student co-advised by Tentzeris and Naishadham.

This is not the first inkjet-printed ammonia sensor that has been integrated with an antenna on paper, said Tentzeris. His group produced a similar integrated sensor last year in collaboration with the research group of C.P. Wong, a Regents' professor and Smithgall Institute Endowed Chair in the School of Materials Science and Engineering at Georgia Tech.

"The fundamental difference is that this newest CNT sensor possesses dramatically improved sensitivity to miniscule ammonia concentrations," Tentzeris said. "That should enable the first practical applications to detect trace amounts of hazardous gases in challenging operational environments using inkjet-printed devices."

Tentzeris explained that the key to printing components, circuits and antennas lies in novel "inks" that contain silver nanoparticles in an emulsion that can be deposited by the printer at low temperatures – around 100 degrees Celsius. A process called sonication helps to achieve optimal ink viscosity and homogeneity, enabling uniform material deposition and permitting maximum operating effectiveness for paper-based components.

"Inkjet printing is low-cost and convenient compared to other technologies such as wet etching," Tentzeris said. "Using the proper inks, a printer can be used almost anywhere to produce custom circuits and components, replacing traditional clean-room approaches."

Low-cost materials – such as heavy photographic paper or plastics like polyethylene terephthalate – can be made water-resistant to ensure greater reliability, he added. Inkjet component printing can also use flexible organic materials, such as liquid crystal polymer (LCP), which are known for their robustness and weather resistance. The resulting components are similar in size to conventional components but can conform and adhere to almost any surface.

Naishadham explained that the same inkjet techniques used to produce radio-frequency (RF) components, circuits and antennas can also be used to deposit the functionalized carbon nanotubes used for sensing. These nanoscale cylindrical structures – about one-billionth of a meter in diameter, or 1/50,000th the width of a human hair – are functionalized by coating them with a conductive polymer that attracts ammonia, a major ingredient found in many IEDs.

"The optimized carbon nanotubes are applied as a sensing film, with specific functionalization designed for a particular gas or analyte," Song said. "The GTRI sensor detects trace amounts of ammonia usually found near explosive devices, and it can also be designed to detect similar gases in household, health care and industrial environments at very low concentration levels."

The resulting integrated sensing package can potentially detect the presence of trace explosive materials without endangering human lives. This approach, called standoff detection, involves the use of RF technology to identify explosive materials at a relatively safe distance. The GTRI team has designed the device to send an alert to nearby personnel when it detects ammonia.

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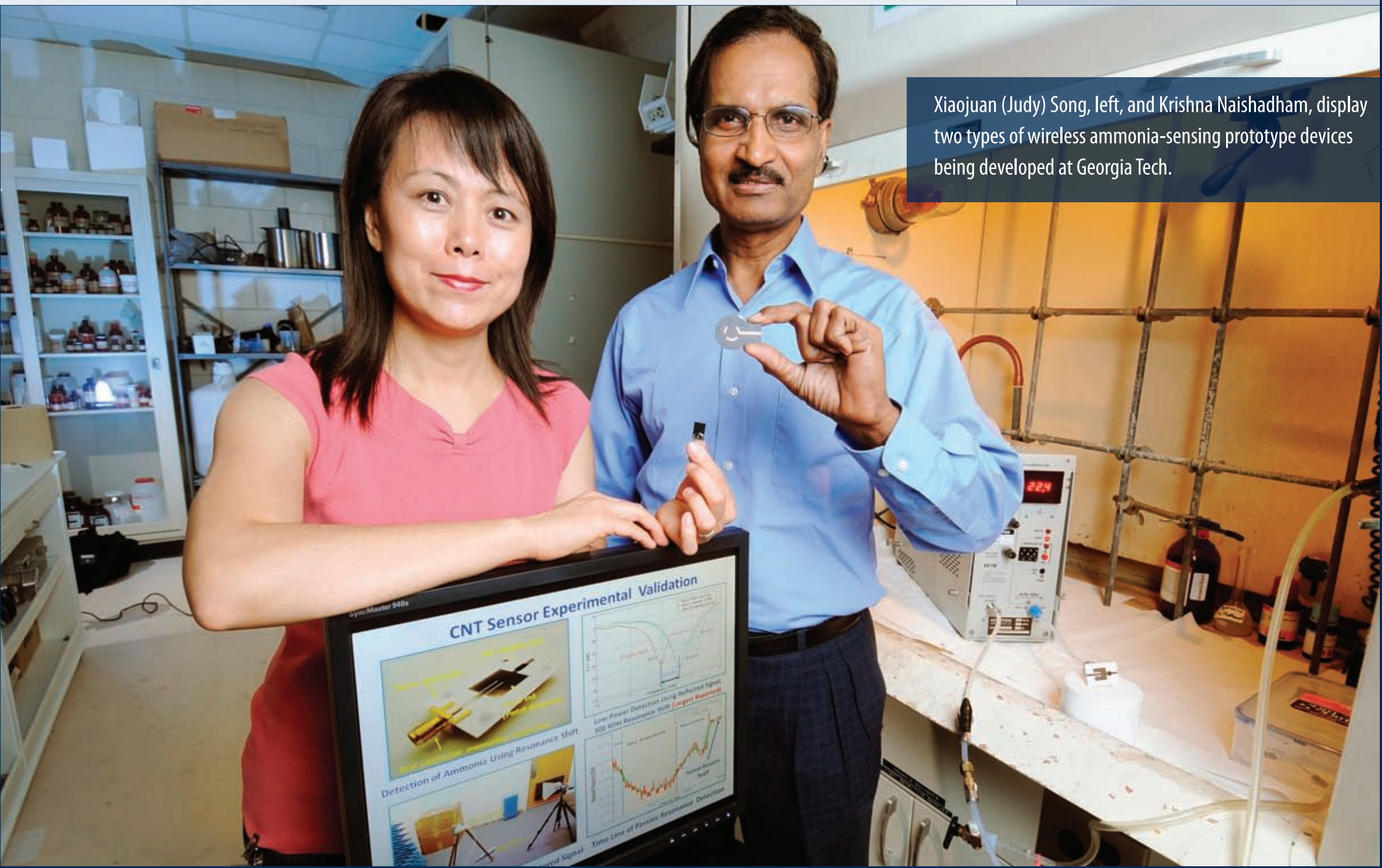
"This prototype represents a significant step toward producing an integrated wireless system for explosives detection. It incorporates a sensor and a communications device in a small, low-cost package that could operate almost anywhere."

— Krishna Naishadham, principal research scientist in the Georgia Tech Research Institute (GTRI)

Photo: Gary Meek



Xiaojuan (Judy) Song, left, and Krishna Naishadham, display two types of wireless ammonia-sensing prototype devices being developed at Georgia Tech.

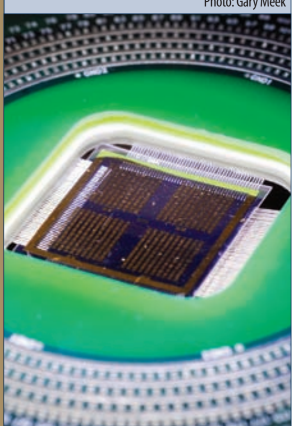
Taking advantage of the unique properties of zinc oxide nanowires, researchers have demonstrated a new type of piezoelectric resistive switching device in which the write-read access of memory cells is controlled by electromechanical modulation. Operating on flexible substrates, arrays of these devices could provide a new way to interface the mechanical actions of the biological world to conventional electronic circuitry.

Biological Interface:

Piezotronic Switches Based on Nanowires Produce Electrical Signals from Mechanical Actions

By John Toon

Photo: Gary Meek



An array of piezoelectrically modulated resistive memory (PRM) cells is shown being studied in an optical microscope.

Taking advantage of the unique properties of zinc oxide nanowires, researchers have demonstrated a new type of piezoelectric resistive switching device in which the write-read access of memory cells is controlled by electromechanical modulation. Operating on flexible substrates, arrays of these devices could provide a new way to interface the mechanical actions of the biological world to conventional electronic circuitry.

These piezoelectrically modulated resistive memory (PRM) devices take advantage of the fact that the resistance of piezoelectric semiconducting materials such as zinc oxide (ZnO) can be controlled through the application of strain from a mechanical action. The change in resistance can be detected electronically, providing a simple way to obtain an electronic signal from a mechanical action.

"We can provide the interface between biology and electronics," said Zhong Lin Wang, a Regents' professor in the Georgia Tech School of Materials Science and Engineering. "This technology, which is based on zinc oxide nanowires, allows communication between a mechanical action in the biological world and conventional devices in the electronic world."

The research was reported online June 22, 2011, in the journal *Nano Letters*. The work was sponsored by the Defense Advanced Research Projects Agency (DARPA), the National Science Foundation (NSF), the U.S. Air Force and the U.S. Department of Energy.

In conventional transistors, the flow of current between a source and a drain is controlled by a gate voltage applied to the device.

The piezotronic memory devices developed by Wang and graduate student Wenzhuo Wu take advantage of the fact that piezoelectric materials like zinc oxide produce a charge potential when they are mechanically deformed or otherwise put under strain. These PRM devices use the piezoelectric charge created by the deformation to control the current flowing through the zinc oxide nanowires that are at the heart of the devices. The charge creates polarity in the nanowires, and increases the electrical resistance much like gate voltage in a conventional transistor.

"We are replacing the application of an external voltage with the production of an internal voltage," Wang explained. "Because zinc oxide is both piezoelectric and semiconducting, when you strain the material with a mechanical action, you create a piezo potential. This piezo potential tunes the charge transport across the interface – instead of controlling channel width as in conventional field effect transistors."

The mechanical strain could come from mechanical activities as diverse as signing a name with a pen, the motion of an actuator on a nanorobot or biological activities of the human body such as a heart beating.

"We control the charge flow across the interface using strain," Wang explained. "If you have no strain, the charge flows normally. But if you apply a strain, the resulting voltage builds a barrier that controls the flow."

The piezotronic switching affects current flowing in just one direction, depending on whether the strain is tensile or compressive. That means the memory stored in the piezotronic devices has both a sign and a magnitude. The information in this memory can be read, processed and stored through conventional electronic means.

Taking advantage of large-scale fabrication techniques for zinc oxide nanowire arrays, the Georgia Tech researchers have built non-volatile resistive switching memories for use as a storage medium. They have shown that these piezotronic devices can be written, that information can be read from them and that they can be "erased" for reuse.

The zinc oxide nanowires, which are about 500 nanometers in diameter and about 50 microns long, are produced with a physical vapor deposition process that uses a high-temperature furnace. The resulting structures are then treated with oxygen plasma to reduce the number of crystalline defects – which helps to control their conductivity. The arrays are then transferred to a flexible substrate.

Wang believes this new memory will become increasingly important as devices become more closely connected to individual human activities. The ability to build these devices on flexible substrates means they can be used in the body – and with other electronic devices now being built on materials that are not traditional silicon.

"As computers and other electronic devices become more personalized, we will need to develop new types of signals, interfacing mechanical actions to electronics," he said. "Piezoelectric materials provide the most sensitive way to translate these gentle mechanical actions into electronic signals that can be used by electronic devices." rh

This research is supported by the Defense Advanced Research Projects Agency (DARPA), the U.S. Air Force (USAF), the National Science Foundation (NSF) and the U.S. Department of Energy (DOE). Any opinions, findings and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of DARPA, the USAF, NSF or DOE.

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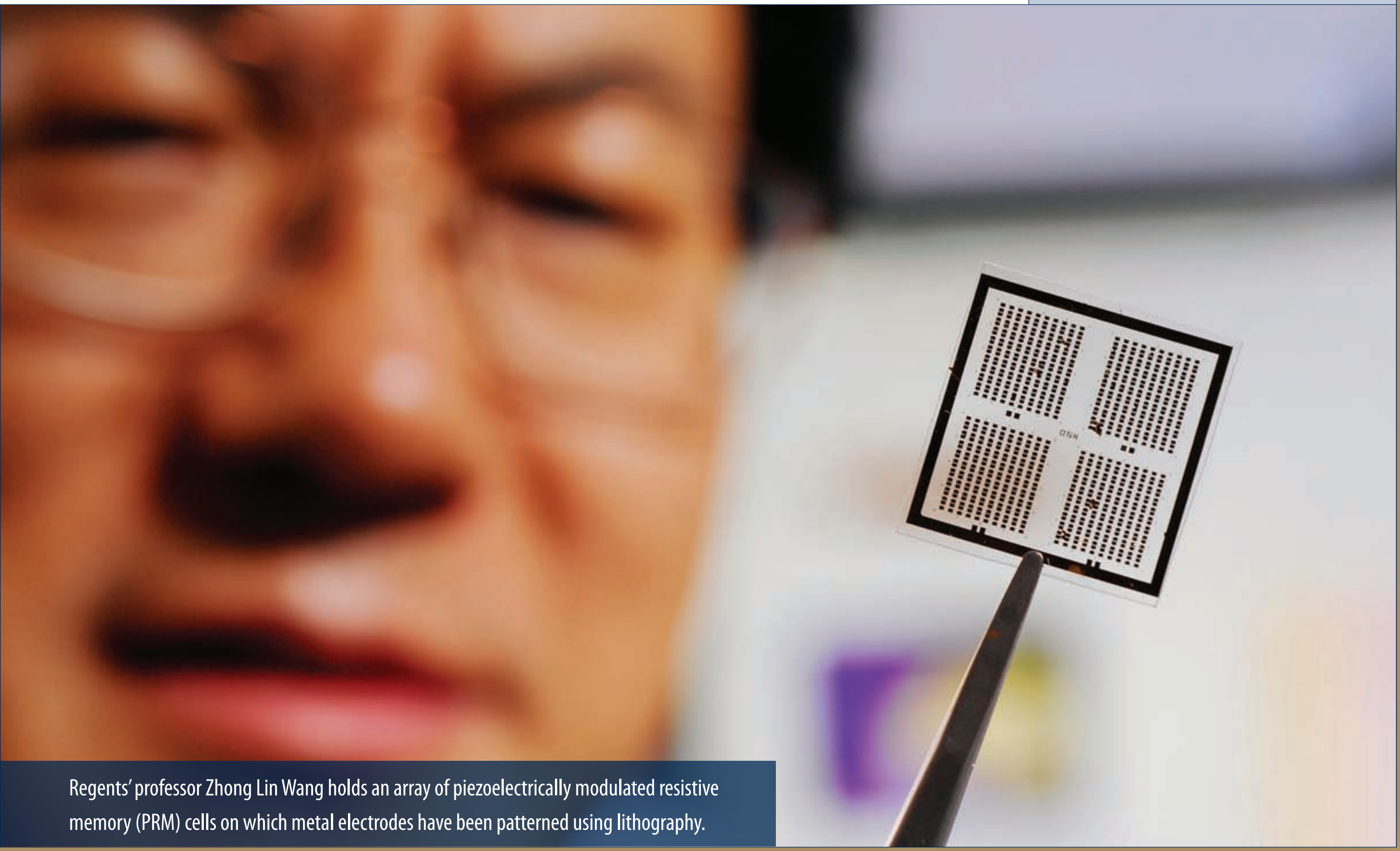
"We can provide the interface between biology and electronics. This technology, which is based on zinc oxide nanowires, allows communication between a mechanical action in the biological world and conventional devices in the electronic world."

— Zhong Lin Wang, Regents' professor in the School of Materials Science and Engineering



Regents' professor Zhong Lin Wang holds an array of piezoelectrically modulated resistive memory (PRM) cells on which metal electrodes have been patterned using lithography.

Photo: Gary Meek

With R&D assistance from the Georgia Tech Research Institute (GTRI), an Atlanta-based company is developing what it hopes will be the next-generation instrument for optimizing eyesight for the hundreds of millions of people who wear glasses or contacts – or who are candidates for corrective surgery. To be used by optometrists and ophthalmologists, the instrument – known as the VisionOptimizer – is intended to provide more accurate vision measurements.

Optimizing Eyesight:

R&D Collaboration Focuses on Next-Generation System for Measuring Human Vision

By John Toon

With research and development assistance from the Georgia Tech Research Institute (GTRI) and seed funding from the Georgia Research Alliance (GRA), an Atlanta-based company is developing what it hopes will be the next-generation instrument for optimizing eyesight for the hundreds of millions of people who wear glasses or contacts – or who are candidates for corrective surgery.

To be used by optometrists and ophthalmologists, the instrument – known as the VisionOptimizer – is intended to provide more accurate vision measurements, along with a more patient-friendly and engaging vision test. The company believes its system will facilitate the custom-manufacturing of spectacles and contact lenses that provide better eyesight and improved wearing comfort compared to conventional prescriptions.

Image: DigitalVision

Rendering shows how patients would interact with the VisionOptimizer. In an exam room, patients would view images on the mirror in front of them and provide feedback via a hand controller.

Using a mockup of the company's VisionOptimizer system, DigitalVision chief technology officer Jose Garcia points to a 24-inch telescope grade spherical mirror that a patient will view from the exam chair. Also shown are company chief executive officer Keith Thompson and GTRI's David Roberts and Leanne West.

Photo: Gary Meek

"We've known for a long time that many prescriptions produced by existing methods really didn't optimize the patient's vision, but until now we haven't had a way to make more accurate measurements or to use that information to produce better lenses," said Keith Thompson, a surgeon and ophthalmologist who is also the CEO of DigitalVision LLC, the company developing the VisionOptimizer.

Eye doctors currently prescribe glasses and contact lenses using measurements obtained with the phoropter, an instrument that has, in principle, changed little since it was introduced in the early 1900s. During a conventional vision test, the patient looks through the phoropter at an eye chart while the doctor dials different corrective lenses into position. The patient is asked to choose which set of lenses provides the clearest view of letters on the eye chart.

Phoropter measurements are limited to increments of a quarter of a diopter of resolution. The resulting glasses or contact lenses often fail to provide all of the vision improvement now possible with modern computer-controlled lens fabrication technology, Thompson noted. And errors cause as many as one in seven prescriptions to be remade.

During the 1970s, a system called the Humphrey Vision Analyzer was introduced to measure vision more accurately than the phoropter, and to provide a better patient experience. Instead of viewing an eye chart through a bulky lens dial, the system projected images onto a mirror and the patients adjusted a set of knobs to improve image quality. The Humphrey system, which is no longer in production, used a unique sliding lens system to evaluate smaller incremental changes than the phoropter could measure.

With help from GTRI, DigitalVision is producing a new system that adds patented measurement technology and other improvements to the Humphrey concept. Using computer algorithms not available in the 1970s, the GTRI researchers have redesigned the instrument's optical system for higher performance. The original assembly of pulleys and wires used to move the lenses will be replaced by microcontrollers and inexpensive actuators.

"We believe we have solved all of the fundamental issues that needed to be addressed," said David Roberts, a GTRI senior research scientist who is leading the research and development project. "The challenges are now down to engineering – controlling all the tolerances and keeping everything in alignment."

The result, according to DigitalVision, will be a system in which a patient sits in an exam chair and looks at images in a two-foot-diameter telescope-grade mirror while providing feedback through a hand controller. The system will measure the amount of nearsightedness, farsightedness and astigmatism present and determine higher-order aberrations that the phoropter cannot detect.

"It's more real-world than what eye doctors are using today, and has commonalities with video games for a population that is accustomed to interacting with computers," said Leanne West, a GTRI senior research scientist who is also working on the project. "For today's population, the new vision test will be a fun and engaging experience."

A patent-pending eye-and-head tracking system developed by GTRI is expected to improve the accuracy of the test by eliminating alignment errors. GTRI's tracking system will also eliminate the need for restraining the patient's head, and should allow easier examinations of children, the elderly and people with disabilities.

"As you move your head around, the images will go with you," explained Jose Garcia, the company's chief technology officer. "One of the issues with testing young patients, as well as older patients and people with disabilities, is that patient movement during the vision test leads to errors. With GTRI's eye-and-head tracking system, we expect that these groups can be tested with confidence that they are seeing the image properly and responding to the test."

The Georgia Research Alliance, a public-private organization that supports the development of technology companies in Georgia, has provided the company with seed funding for commercialization. rh

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"It's more real-world than what eye doctors are using today, and has commonalities with video games for a population that is accustomed to interacting with computers. For today's population, the new vision test will be a fun and engaging experience."

— Leanne West, senior research scientist at the Georgia Tech Research Institute (GTRI)

Researchers are working with the Atlanta-based Plastics Environmental Council (PEC) to develop the first standard specifications for the landfill biodegradation of petroleum-based plastics that have been treated with special additives. The standards could facilitate expanded use of the additives, which speed the breakdown of plastics in landfills without affecting their performance during use.

Photo: John Toon

A majority of the petroleum-based plastic containers produced each year in the United States wind up in landfills. Georgia Tech researchers are working on a set of standards that could expand the use of an additive that facilitates biodegradation of the plastics.

Breaking Down Plastics:

New Standard Specification May Expand Use of Additives That Trigger Landfill Biodegradation of Oil-Based Plastics

By John Toon

Despite efforts to encourage the recycling of plastic water bottles, milk jugs and similar containers, a majority of the plastic packaging produced each year in the United States ends up in landfills. To address that problem for traditional petroleum-based plastics, Georgia Tech researchers are working with the Plastics Environmental Council (PEC) to help expand the use of chemical additives that cause such items to biodegrade in landfills.

Added during production of the plastic packaging, the compounds encourage anaerobic landfill bacteria and fungi to break down the plastic materials and convert them to the biogas methane, carbon dioxide and biogenic carbon – also known as humus. The additives, simple organic substances that build on the known structures of materials that induce polymer biodegradation, don't affect the performance of the plastics during use, introduce heavy metals or other toxic chemicals, or prevent the plastics from being recycled in current channels.

If widely used, these additives could help reduce the volume of polyethylene, polypropylene, Styrofoam and PET plastic waste in landfills and permit much of the hydrocarbon resource tied up in the plastic to be captured as methane, which can be burned for heating or to generate electricity.

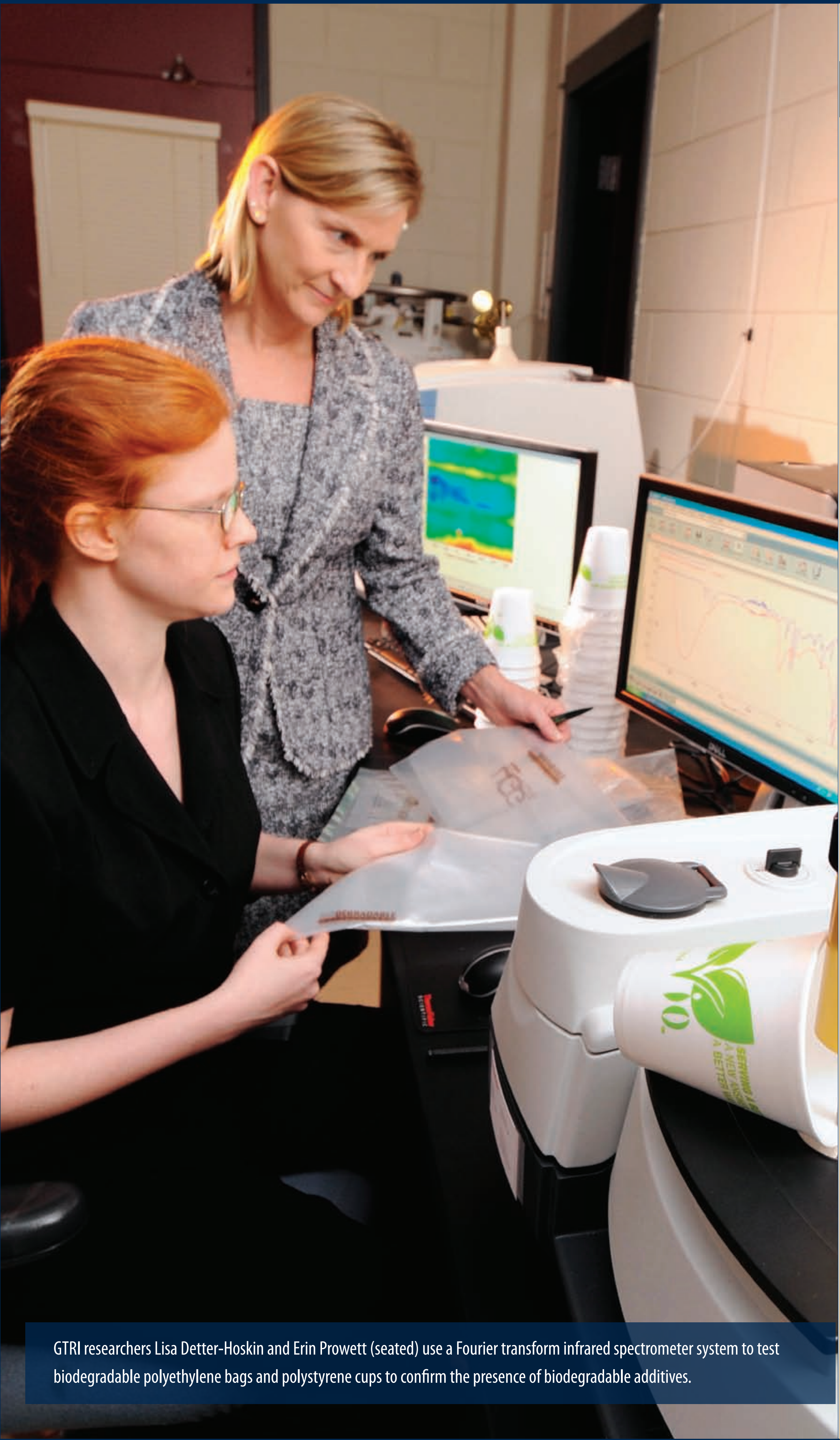
"Research done so far using standard laboratory test methods suggests that the treated plastics could biodegrade completely at rates comparable to those of common wastes today, depending on landfill conditions," said Lisa Detter-Hoskin, a principal research scientist in the Georgia Tech Research Institute (GTRI) and co-chair of the PEC's technical advisory committee. "However, legislators, regulatory agencies and consumers need more assurance that these products will perform as expected in actual landfills. We need to provide more information to help the public make informed buying decisions."

To provide this information, Detter-Hoskin and other Georgia Tech researchers are working with the Atlanta-based PEC and with the ASTM to develop a set of standard specifications that would ensure accuracy and consistency in the determination and communication of the plastic products' biodegradation performance.

"We are working to develop a new standard specification for anaerobically biodegradable conventional plastics," Detter-Hoskin said. "This specification is intended to establish the requirements for accurate labeling of materials and products made from oil-derived plastics as anaerobically biodegradable in municipal landfill facilities. The specification, along with a certifying mark, will allow consumers, government agencies and recyclers to know that the item carrying it is both anaerobically biodegradable and recyclable."

The standard specification will provide detailed requirements and test performance criteria for products identified as anaerobically biodegradable, and will include rates for anaerobic biodegradation in typical U.S. landfills. These rates will be based on biodegradation test data and results from research being undertaken by Georgia Tech and North Carolina State University.

With support from the PEC and its member companies, Detter-Hoskin has directed testing efforts that show mechanistically how the additives work, and are showing that the degraded plastic leaves behind no toxic materials. With that part of the project largely completed, she now leads the development of the



GTRI researchers Lisa Detter-Hoskin and Erin Prowett (seated) use a Fourier transform infrared spectrometer system to test biodegradable polyethylene bags and polystyrene cups to confirm the presence of biodegradable additives.

Photo: Gary Meek

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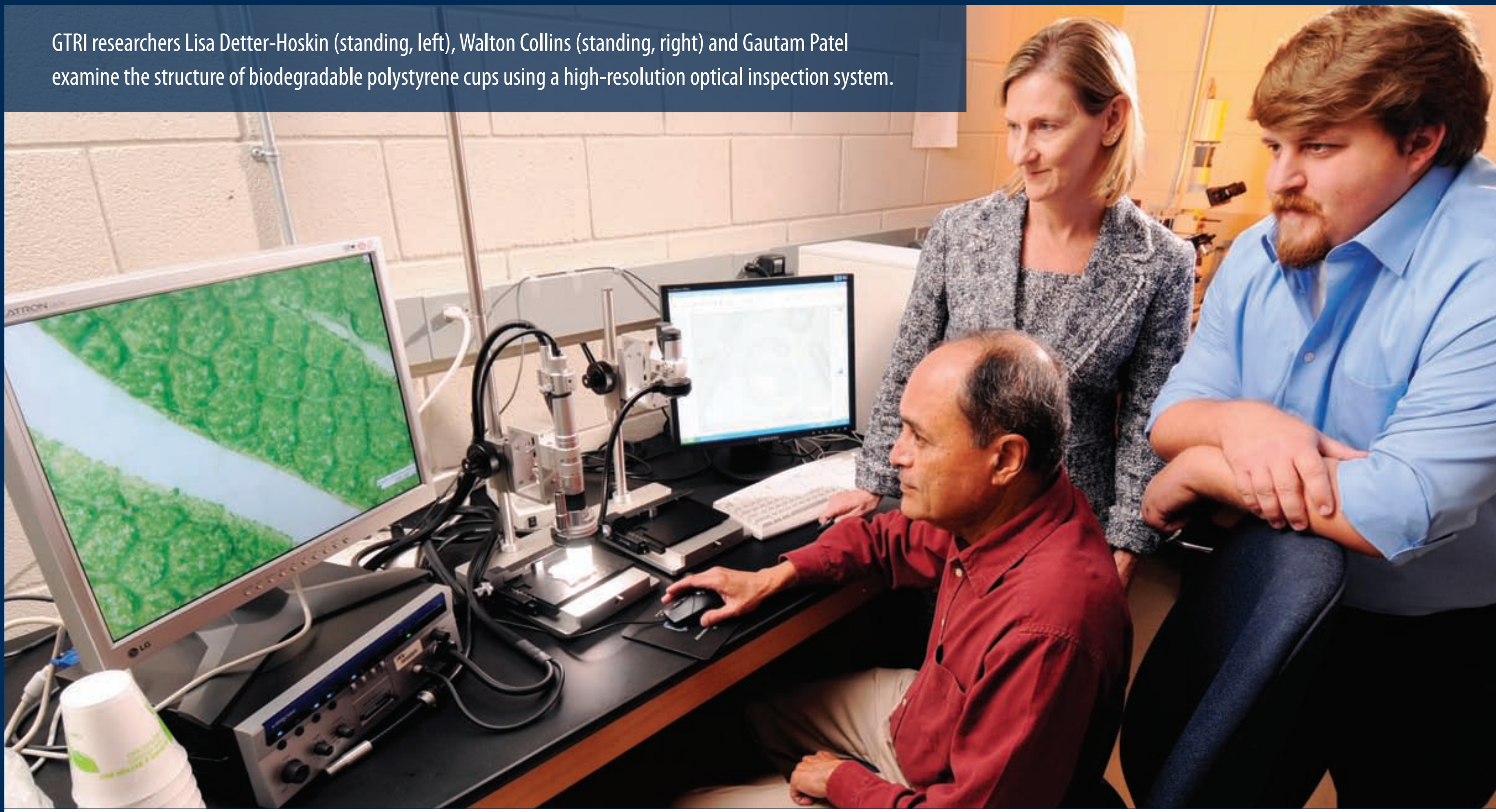
"We are working to develop a new standard specification for anaerobically biodegradable conventional plastics. This specification is intended to establish the requirements for accurate labeling of materials and products made from oil-derived plastics as anaerobically biodegradable in municipal landfill facilities."

— Lisa Detter-Hoskin, principal research scientist at the Georgia Tech Research Institute (GTRI)

Photo: Gary Meek



GTRI researchers Lisa Detter-Hoskin (standing, left), Walton Collins (standing, right) and Gautam Patel examine the structure of biodegradable polystyrene cups using a high-resolution optical inspection system.

standard specification and certifying mark, and plans to organize a network of accredited laboratories that will test products made with the additives to certify that plastic items made with them do degrade within a specific period of time.

Full development and adoption of the new standard specification by ASTM International is in progress and will likely take between 12 and 18 months, Detter-Hoskin said. The project will involve research using landfill simulations at North Carolina State University and other independent laboratories.

Using information from laboratory-scale anaerobic reactors operated under a range of temperatures, moisture levels and solids contents, researchers will compare the time required to break down known anaerobically biodegradable materials – such as newsprint, office waste and grass clippings – against the time required to degrade those same wastes in real landfills. That information will be used to project the biodegradation rate for the treated plastics in a range of real landfills, which vary considerably in moisture and other factors.

Though they are recyclable, plastics made from hydrocarbons had not been biodegradable until development of microbe-triggering additives. Bioplastics such as those made from corn may be composted, while a small percentage of specialized plastic products, known as oxobiodegradables, are designed to degrade when exposed to oxygen and ultraviolet light. But the bulk of the plastic resins used in bottles and other containers are made from materials that will last virtually forever in landfills, said Charles Lancelot, executive director of the PEC.

Many communities operate recycling programs for plastics and other materials such as newsprint, aluminum and steel cans or cardboard. But because the cost of collecting, sorting, cleaning and reprocessing most plastics can be more than the cost of producing new products, such programs struggle financially unless they are subsidized, he noted.

"If you can make a product like a bread tray and use it over and over again, that is the most efficient alternative," said Lancelot, who developed successful business-to-business recycling programs while working at Rubbermaid. "But if you can't reuse it and it's not cost-effective to recycle it, where is the product going to go? The fact is that despite the best wishes of everybody involved, 75 to 85 percent of the plastics used today end up in landfills. We are addressing that unfortunate reality."

Although biodegradation occurs to varying extents in all U.S. landfills receiving waste today, many of today's landfills are optimized for biodegradation, he said. Moist conditions and recirculation of leachate liquids accelerate the activity of the anaerobic bacteria that attack the plastic materials containing the additives. Such landfills typically do a better job of collecting and beneficially using the methane biogas, Lancelot said.

"When the anaerobic microorganisms that thrive in landfills contact these treated plastics, they begin to colonize on the surface of the plastic and adapt to the base resin," he explained. "Until the bugs come in contact with the plastic, the additives remain inert and do not affect the properties of the plastic container. We are not changing the overall plastics production process, and the base plastic is the same."

The compounds, which have been approved by the U.S. Food and Drug Administration (FDA), are typically added to the plastic resin in small amounts, 1 percent or less by weight.

Expanding the use of anaerobically biodegradable additives must be done in such a way that doesn't detract from recycling programs, said Matthew Realff, a professor in Georgia Tech's School of Chemical & Biomolecular Engineering and co-chair of the PEC's technical advisory committee.

"From a life cycle perspective, it is important to quantify the benefit of recycling over landfill disposal with methane recovery to energy, and to continue to make the case that whenever possible, recycling is significantly better than disposal, even if you have methane production and capture from biodegradation," he said.

While the biodegradation of plastic materials may solve one problem, the production of methane and carbon dioxide – both atmospheric warming gases – could worsen global climate change, he noted.

"Landfill capture of methane is not 100 percent efficient, nor does it begin immediately after the material is put into the landfill," Realff said. "Therefore, there will be emissions from biodegradation that will reach the atmosphere. It is important to be aware of how accelerating the production of methane would change overall emissions."

A 45-year veteran of the U.S. plastics industry, Lancelot said he is pleased to be working with Georgia Tech on a potential solution to the problem of plastics in landfills. The research will help close a gap in plastics "end-of-life" options where reuse or recycling are not feasible.

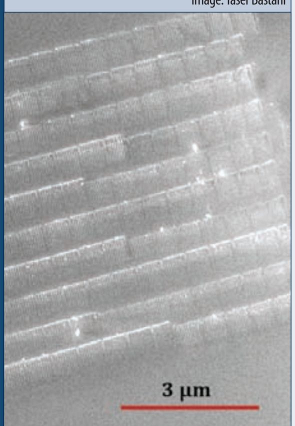
"Nobody had commercially biodegraded petroleum-based commodity plastics like polyethylene, polypropylene and polystyrene before these additives became available," he said. "This is ground-breaking work that is based on a solid scientific platform that defines biodegradability as a practical and useful end result." rh

Photo: John Toon

This photograph shows plastic containers awaiting recycling. Researchers at the Georgia Tech Research Institute are working with the Plastics Environmental Council to advance the use of additives that would encourage biodegradation of the materials in landfills if the plastics aren't recycled.

Using a technique known as thermochemical nanolithography (TCNL), researchers have developed a new way to fabricate nanometer-scale ferroelectric structures directly on flexible plastic substrates that would be unable to withstand the processing temperatures normally required to create such nanostructures.

Image: Yaser Bastani



This scanning electron microscope image shows a large PZT line array crystallized on a 240-nanometer thick precursor film on a platinized silicon wafer.

Writing Nanostructures:

Heated AFM Tip Allows Plastic and CMOS-Compatible Fabrication of Ferroelectric Piezoelectric Structures

By John Toon

Using a technique known as thermochemical nanolithography (TCNL), researchers have developed a new way to fabricate nanometer-scale ferroelectric structures directly on flexible plastic substrates that would be unable to withstand the processing temperatures normally required to create such nanostructures.

The technique, which uses a heated atomic force microscope (AFM) tip to produce patterns, could facilitate high-density, low-cost production of complex ferroelectric structures for energy harvesting arrays, sensors and actuators in nano-electromechanical systems (NEMS) and micro-electromechanical systems (MEMS). The research was reported July 15, 2011, in the journal *Advanced Materials*.

"We can directly create piezoelectric materials of the shape we want, where we want them, on flexible substrates for use in energy harvesting and other applications," said Nazanin Bassiri-Gharb, co-author of the paper and an assistant professor in the Georgia Tech School of Mechanical Engineering. "This is the first time that structures like these have been directly grown with a CMOS-compatible process at such a small resolution."

The research was sponsored by the National Science Foundation and the U.S. Department of Energy. In addition to the Georgia Tech researchers, the work also involved scientists from the University of Illinois Urbana-Champaign and the University of Nebraska Lincoln.

The researchers have produced wires approximately 30 nanometers wide and spheres with diameters of approximately 10 nanometers using the patterning technique. Spheres with potential application as ferroelectric memory were fabricated at densities exceeding 200 gigabytes per square inch – currently the record for this perovskite-type ferroelectric material, said Suenne Kim, the paper's first author and a postdoctoral fellow in the laboratory of Elisa Riedo, an associate professor in Georgia Tech's School of Physics.

Ferroelectric materials are attractive because they exhibit charge-generating piezoelectric responses an order of magnitude larger than those of materials such as aluminum nitride or zinc oxide. The polarization of the materials can be easily and rapidly changed, giving them potential application as random access memory elements.

But the materials can be difficult to fabricate, requiring temperatures greater than 600 degrees Celsius for crystallization. Chemical etching techniques produce features only comparable to the original thin films' grain size, which is usually larger than the nanoscale features that researchers would like to produce, while physical etching processes damage the structures and reduce their attractive properties. Until now, these challenges required that ferroelectric structures be grown on a single-crystal substrate compatible with high temperatures, and then transferred to a flexible substrate for use in energy-harvesting.

The thermochemical nanolithography process, which was invented at Georgia Tech in 2007, addresses those challenges by using extremely localized heating to form structures only where the resistively heated AFM tip contacts a precursor material. A computer controls the AFM writing, allowing the researchers to create patterns of crystallized material where desired. To create energy-harvesting structures, for example, lines corresponding to ferroelectric nanowires can be drawn along the direction in which strain would be applied.

"The heat from the AFM tip crystallizes the amorphous precursor to make the structure," Bassiri-Gharb explained. "The patterns are formed only where the crystallization occurs."

To begin the fabrication, the sol-gel precursor material is first applied to a substrate with a standard spin-coating method, and then briefly heated to approximately 250 degrees Celsius. The researchers have used polyimide, glass and silicon substrates, but in principle any material able to withstand the 250-degree heating step could be used.

"We still heat the precursor at the temperatures required to crystallize the structure, but the heating is so localized that it does not affect the substrate," explained Riedo, co-author of the paper.

The heated AFM tips were provided by William King, a professor in the Department of Mechanical Science and Engineering at the University of Illinois Urbana-Champaign.

"Thermochemical nanolithography is a very powerful nanofabrication technique that, through heating, is like a nanoscale pen that can create nanostructures useful in a variety of applications, including protein arrays, DNA arrays and graphene-like nanowires," Riedo explained. "We are really addressing the problem caused by the existing limitations of photolithography at these size scales. We can envision creating a full device based on the same fabrication technique without the requirements of costly clean rooms and vacuum-based equipment. We are moving toward a process in which multiple steps are done using the same tool to pattern at the small scale."

In addition to those already mentioned, the research team included Yaser Bastani from the George W. Woodruff School of Mechanical Engineering at Georgia Tech; Seth Marder and Kenneth Sandhage, both from Georgia Tech's School of Chemistry and Biochemistry and School of Materials Science and Engineering; and Alexei Gruverman and Haidong Lu from the Department of Physics and Astronomy at the University of Nebraska Lincoln. rh

This research is supported by the U.S. Department of Energy (DOE) and the National Science Foundation (NSF). Any opinions, findings and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of DOE or NSF.

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"We can directly create piezoelectric materials of the shape we want, where we want them, on flexible substrates for use in energy harvesting and other applications. This is the first time that structures like these have been directly grown with a CMOS-compatible process at such a small resolution."

— Nazanin Bassiri-Gharb, assistant professor in the Woodruff School of Mechanical Engineering

Georgia Tech researchers Yaser Bastani, Nazanin Bassiri-Gharb and Suenne Kim examine microscope images of ferroelectric nanostructures produced by thermochemical nanolithography on various substrates, including polyimide, silicon and glass.

Photo: Gary Meek

When RNA component units called ribonucleotides become embedded in genomic DNA, they can distort the DNA double helix, resulting in genomic instability and altered DNA metabolism. A new study provides a mechanistic explanation of how ribonucleotides embedded in genomic DNA are recognized and removed from cells through two different mechanisms.

Repairing DNA:

Study Identifies Mechanisms Cells Use to Remove Bits of RNA from DNA Strands

By Abby Robinson

Photo: Gary Meek

Georgia Tech School of Biology graduate student Ying Shen (front) and assistant professor Francesca Storici set up the polymerase chain reaction machine to detect ribonucleotide-driven mutations in DNA.

When RNA component units called ribonucleotides become embedded in genomic DNA, which contains the complete genetic data for an organism, they can cause problems for cells. It is known that ribonucleotides in DNA can distort the DNA double helix, resulting in genomic instability and altered DNA metabolism, but not much is known about the fate of these ribonucleotides.

A new study provides a mechanistic explanation of how ribonucleotides embedded in genomic DNA are recognized and removed from cells. Two mechanisms, enzymes called ribonucleases (RNases) H and the DNA mismatch repair system, appear to interact to root out the RNA components.

"We believe this is the first study to show that cells utilize independent repair pathways to remove mispaired ribonucleotides embedded in chromosomal DNA, which can be sources of genetic modification if not removed," said Francesca Storici, an assistant professor in the Georgia Tech School of Biology. "The results also highlight a novel case of genetic redundancy, where the mismatch repair system and RNase H mechanisms compete with each other to remove misincorporated ribonucleotides and restore DNA integrity."

The findings were reported Dec. 4, 2011, in the advance online publication of the journal *Nature Structural & Molecular Biology*. The research was supported by the Georgia Cancer Coalition, National Science Foundation and Georgia Tech Integrative BioSystems Institute.

Storici and Georgia Tech biology graduate students Ying Shen and Kyung Duk Koh conducted the study in collaboration with Bernard Weiss, a professor emeritus in the Department of Pathology and Laboratory Medicine at Emory University.

"We wanted to understand how cells of the bacterium *Escherichia coli* and the yeast *Saccharomyces cerevisiae* tolerate the presence of different ribonucleotides embedded in their genomic DNA. We found that the structure of a ribonucleotide tract embedded in DNA influenced its ability to cause genetic mutations more than the tract's length," said Storici.

With double-stranded DNA, when wrong bases are paired or one or few nucleotides are in excess or missing on one of the strands, a mismatch is generated. If mismatches are not corrected, they can lead to mutations.

The researchers found that single mismatched ribonucleotides in chromosomal DNA were removed by either the mismatch repair system or RNase H type

2. Mismatched ribonucleotides in the middle of at least four other ribonucleotides required RNase H type 1 for removal.

"We were excited to find that a DNA repair mechanism like mismatch repair was activated by RNA/DNA mismatches and could remove ribonucleotides embedded in chromosomal DNA," explained Storici. "In future studies, we plan to test whether other DNA repair mechanisms, such as nucleotide-excision repair and base-excision repair, can also locate and remove ribonucleotides in DNA."

Using gene correction assays driven by short nucleic acid polymers called oligonucleotides, the researchers showed that when ribonucleotides embedded in DNA were not removed they served as templates for DNA synthesis and produced a mutation in the DNA. If both the mismatch repair system and RNase H repair mechanisms are disabled, ribonucleotide-driven gene modification increased by a factor of 47 in the yeast and 77,000 in the bacterium.

Defects in the mismatch repair system are known to predispose a person to certain types of cancer. Because the mismatch repair system is conserved from unicellular to multicellular organisms, such as humans, this study's findings open up the possibility that defects in the mismatch repair system could have consequences more critical than previously thought.

The results also provide new information on the capacity of RNA to play an active role in DNA editing and remodeling, which could be the basis of an unexplored process of RNA-driven DNA evolution. rh

This project was supported by the National Science Foundation (NSF) (Award No. MCB-1021763). The content is solely the responsibility of the principal investigators and does not necessarily represent the official views of the NSF.

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"We believe this is the first study to show that cells utilize independent repair pathways to remove mispaired ribonucleotides embedded in chromosomal DNA, which can be sources of genetic modification if not removed. The results also highlight a novel case of genetic redundancy."

— Francesca Storici, assistant professor in the School of Biology

Georgia Tech School of Biology graduate student Ying Shen, assistant professor Francesca Storici and graduate student Kyung Duk Koh (l-r) analyze data showing RNase H cleavage of ribonucleotides embedded in DNA.

Photo: Gary Meek

Air Force Funds Fundamental Studies of Plasma Interactions with Containers

Photo: Gary Meek

Mitchell Walker, an associate professor in the Georgia Tech School of Aerospace Engineering; Gregory Thompson, an associate professor in the Department of Metallurgical and Materials Engineering at the University of Alabama; and Jud Ready, a principal research engineer in the Georgia Tech Research Institute (GTRI), examine a Hall Effect thruster in Walker's laboratory.

Researchers from Georgia Tech and the University of Alabama have received $2.5 million from the U.S. Air Force Office of Scientific Research (AFOSR) to conduct fundamental research into the ways in which plasmas interact with the walls of the structures containing them. The research will also examine potential improvements to materials used for the walls.

The five-year research program could lead to improvements in a broad range of areas, including higher performance satellite thrusters, improved tubes for Department of Defense radar and communications systems, more efficient high-intensity lamps, and new spray-coating processes.

The researchers will use new analysis techniques, including a terahertz-frequency laser for non-intrusively studying the plasma sheath, which is the portion of the plasma that interacts with the wall. The researchers will use atomic-probe technology to study how the plasmas – a state of matter that contains ionized particles – interact with and are affected by the walls. Modeling and simulation techniques will also help predict how plasmas may interact with improved wall materials.

"In these systems, the plasma is dumping energy into the wall, and the wall may be giving back some particles or energy that affect the plasma," explained Mitchell Walker, an associate professor in the Georgia Tech School of Aerospace Engineering. "There is a dance between the plasma and the wall that needs to be understood so we can improve the materials across a range of applications."

Plasmas are created when electrons are added to or removed from atoms, giving them a charge. The interaction between the resulting ionized gas and wall can be complex, involving the transfer of mass, charge and energy from the plasma to the wall – and sometimes from the wall back to the plasma. This energetic interaction may damage the wall, eroding the surfaces and leading to failure.

Existing plasma wall materials have been developed largely by trial-and-error. Developing a fundamental understanding of the plasma-wall interaction will help researchers develop better wall materials.

"We need to get at the fundamental issues, then use that knowledge to make the materials better," said Jud Ready, a principal research engineer in the Georgia Tech Research Institute (GTRI). "Before we can produce better materials to make better applications, we need to understand the environment in which the materials have to operate."

Improving the wall materials will also depend on detailed knowledge of how the plasma affects them. For that information, the research team will work with Gregory Thompson, an associate professor in the Department of Metallurgical and Materials Engineering at the University of Alabama, to study plasma atoms that may be embedded in the walls.

This material is based upon work conducted under contract FA9550-11-1-0160. Any opinions, findings and conclusions or recommendations expressed are those of the researchers and do not necessarily reflect the views of the Air Force Office of Scientific Research.

— John Toon

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GTRI Opens New Compact Range for Antenna, Radar Cross Section Studies

The Georgia Tech Research Institute (GTRI) has opened a new compact range that will be used for radar cross section measurements and antenna testing. The facility, which is shielded against electromagnetic interference, will be used for defense-related research projects and collaborations with outside organizations.

Located on GTRI's midtown Atlanta campus, the new range has a test zone that is approximately 6 feet wide, 4 feet tall and 6 feet deep. It can test at frequencies ranging from two gigahertz (GHz) to 100 GHz, and that range can be extended down to 800 megahertz (MHz). The facility is 18 feet high, 24 feet wide and 60 feet long, with a 10-foot-by-12-foot door for bringing in items to be tested.

"This facility was designed for measuring small prototypes or for portions of larger systems," said Stephen Blalock, a GTRI senior research technologist who manages the facility. "We will use it primarily for measuring radar signatures and for determining antenna characteristics. It will help us iterate on new designs and be certain that we've met design requirements."

The new range is completely surrounded by metal walls and doors designed to keep out electromagnetic energy from a broad range of sources.

"When we go into the chamber and close the doors, it is very electromagnetically quiet," Blalock said. "When we want to make measurements that require a quiet facility, we can be isolated from outside interference from radio and television broadcast stations, and anything else. This gives us an important new capability."

The range was designed with a novel integrated mobile absorber wall that can be deployed to cover the compact range reflector, allowing the facility to be used as an anechoic chamber. "This mode will be used for testing at lower frequencies, or when the compact range reflector is not needed," Blalock explained. "This provides us with a more versatile, reconfigurable test facility."

Since the 1970s, GTRI has operated a compact range on its midtown campus, but that facility is not electromagnetically shielded and is designed for a different frequency range.

The new compact range will be used to support a variety of GTRI research projects, and will be made available for testing and collaborative research with outside organizations.

Because of their unique design, compact ranges can test phenomena that would otherwise require much larger outdoor test facilities. For instance, radar beam patterns normally take several miles to spread out and become flat once they leave a transmitter. The unique reflector design used in compact ranges spreads out the pattern in a few dozen feet, allowing testing to be done indoors under controlled conditions.

— John Toon

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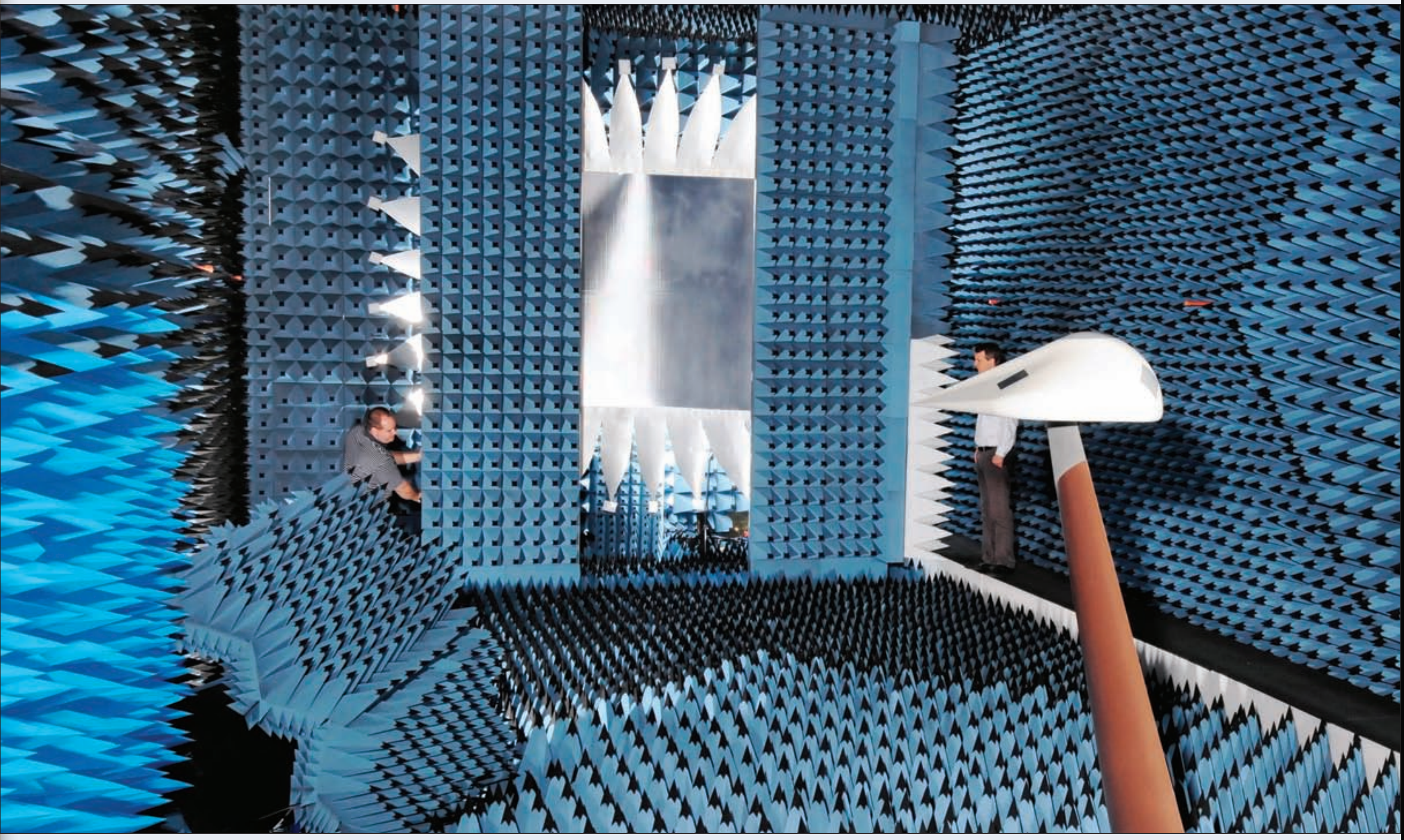
Photo: Gary Meek

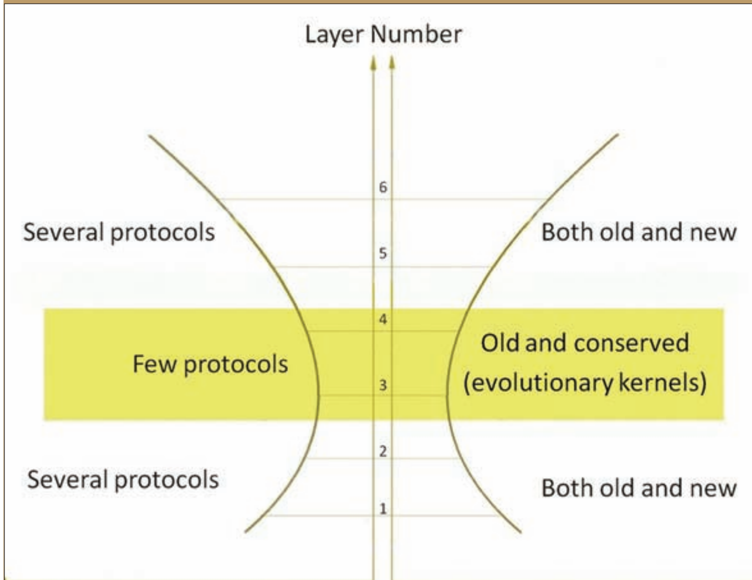


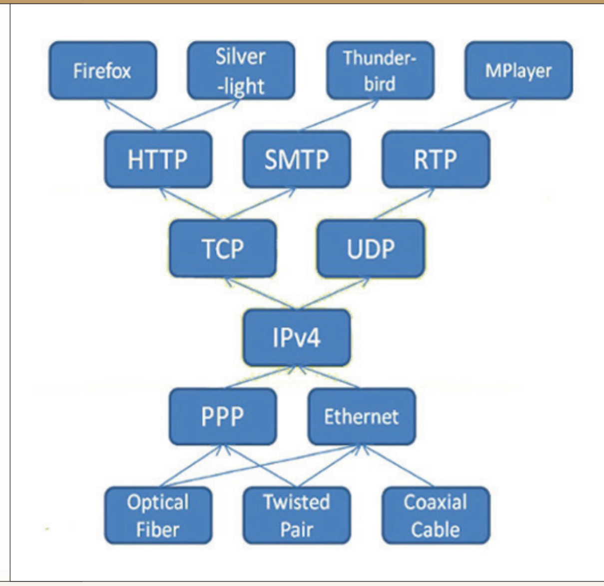
The Georgia Tech Research Institute's (GTRI) new compact range is designed with a mobile absorber wall that can be deployed to cover the compact range reflector, allowing the facility to be used as an anechoic chamber.

RESEARCH NOTES

How the Internet's Architecture Got its Hourglass Shape

Images: Constantine Dovrolis





(Left) Illustration shows the number and age of protocols in each layer of the Internet architecture. In the middle layers, there are only a few protocols that are old and conserved. (Right) This illustration of the hourglass Internet architecture shows the six layers, from top to bottom: specific applications, application protocols, transport protocols, network protocols, data-link protocols and physical layer protocols.

In the natural world, species that share the same ecosystem often compete for resources, resulting in the extinction of weaker competitors. A new computer model that describes the evolution of the Internet's architecture suggests something similar has happened among the layers of protocols that have survived – and become extinct – on the worldwide network.

Understanding this evolutionary process may help computer scientists as they develop protocols to help the Internet accommodate new uses and protect it from a wide range of threats. But the model suggests that unless the new Internet avoids such competition, it will evolve an hourglass shape much like today's Internet.

"To avoid the ossification effects we experience today in the network and transport layers of the Internet, architects of the future Internet need to increase the number of protocols in these middle layers, rather than just push these one- or two-protocol layers to a higher level in the architecture," said Constantine Dovrolis, an associate professor in Georgia Tech's School of Computer Science.

The research was presented in August 2011 at SIGCOMM, the annual conference of the Special Interest Group on Data Communication. The research was supported by the National Science Foundation.

From top to bottom, the Internet architecture consists of six layers: (1) specific applications, such as Firefox; (2) application protocols, such as Hypertext Transfer Protocol (HTTP); (3) transport protocols, such as Transmission Control Protocol (TCP); (4) network protocols, such as Internet Protocol (IP); (5) data-link protocols, such as Ethernet; and (6) physical layer protocols, such as DSL.

Layers near the top and bottom contain many items, called protocols, while the middle layers do not. The central transport layer contains two protocols and the network layer contains only one, creating an hourglass architecture.

Dovrolis and graduate student Saamer Akhshabi created an evolutionary model called EvoArch to study the emergence of the Internet's hourglass structure. In the model, the architecture of the network changed with time as new protocols were created at different layers and existing protocols were removed as a result of competition with other protocols in the same layer.

EvoArch showed that even if future Internet architectures are not built in the shape of an hourglass initially, they will probably acquire that shape as they evolve.

The model revealed a plausible explanation for the Internet's hourglass shape. At the top, protocols are so specialized and selective in what underlying building blocks they use that they rarely compete with each other. When there is very little competition, the probability of extinction for a protocol is close to zero.

"In the top layers of the Internet, many new applications and application-specific protocols are created over time, but few things die, causing the top of the hourglass to get wider over time," said Dovrolis. "It is not true that the best protocols always win the competition. Often, the kernels of the architecture are lower-quality protocols that were created early and with just the right set of connections."

— Abby Robinson

This project is supported by the National Science Foundation (NSF) (Award No. 0831848). The content is solely the responsibility of the principal investigator and does not necessarily represent the official views of the NSF.

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Microspectrometer Design Achieves High Resolution, Wide Bandwidth

A new microspectrometer architecture that uses compact disc-shaped resonators could address the challenges of integrated lab-on-chip sensing systems that now require a large off-chip spectrometer to achieve high resolution.

Spectrometers have conventionally been expensive and bulky bench-top instruments used to detect and identify molecules by shining light on a sample and measuring different wavelengths of the emitted or absorbed light. Previous efforts toward miniaturizing spectrometers have reduced their size and cost, but these reductions have typically resulted in lower-resolution instruments.

"For spectrometers, it is better to be small and cheap than big and bulky – provided that the optical performance targets are met," said Ali Adibi, a professor in the Georgia Tech School of Electrical and Computer Engineering. "We were able to achieve high resolution and wide bandwidth with a compact single-mode on-chip spectrometer through the use of an array of microdonut resonators, each with an outer radius of two microns."

The 81-channel on-chip spectrometer designed by Georgia Tech engineers achieved 0.6-nanometer resolution over a spectral range of more than 50 nanometers with a footprint of less than 1 square millimeter. The simple instrument – with its ultra-small footprint – can be integrated with other devices, including sensors, optoelectronics, microelectronics and microfluidic channels for use in biological, chemical, medical and pharmaceutical applications.

The microspectrometer architecture was described in a paper published in the June 20, 2011, issue of the journal *Optics Express*. The research was supported by the Air Force Office of Scientific Research and the Defense Advanced Research Projects Agency.

"This architecture is promising because the quality-factor of the microdonut resonators is higher than that of microrings of the same size," said Richard Soref, a research scientist in the U.S. Air Force Research Laboratory at Hanscom Air Force Base. "Having such small resonators is also an advantage because they can be densely packed on a chip, enabling a large spectrum to be sampled."

Adibi's group is currently developing the next generation of these spectrometers, which are being designed to contain up to 1,000 resonators and achieve 0.15-nanometer resolution with a spectral range of 150 nanometers and footprint of 200 square micrometers.

Adibi, graduate student Zhixuan Xia and research engineer Ali A. Eftekhar, and former research engineers Babak Momeni and Siva Yegnanarayanan, designed and implemented the microspectrometer using CMOS-compatible fabrication processes. The key building element was an array of miniaturized microdonut resonators, essentially microdiscs perforated in their centers. This research built on former Georgia Tech graduate student Mohammad Soltani's work to develop miniature microresonators.

"The microspectrometer we designed may allow individuals to replace the big, bulky, high-resolution spectrometers with a large bandwidth that they are currently using with an on-chip spectrometer the size of a penny," noted Adibi. "Our device has the potential to be a high-resolution, lightweight, compact, high-speed and versatile microspectrometer with a large dynamic range that can be used for many applications."

Current graduate students Qing Li and Maysamreza Chamanzar also contributed to this work.

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— Abby Robinson

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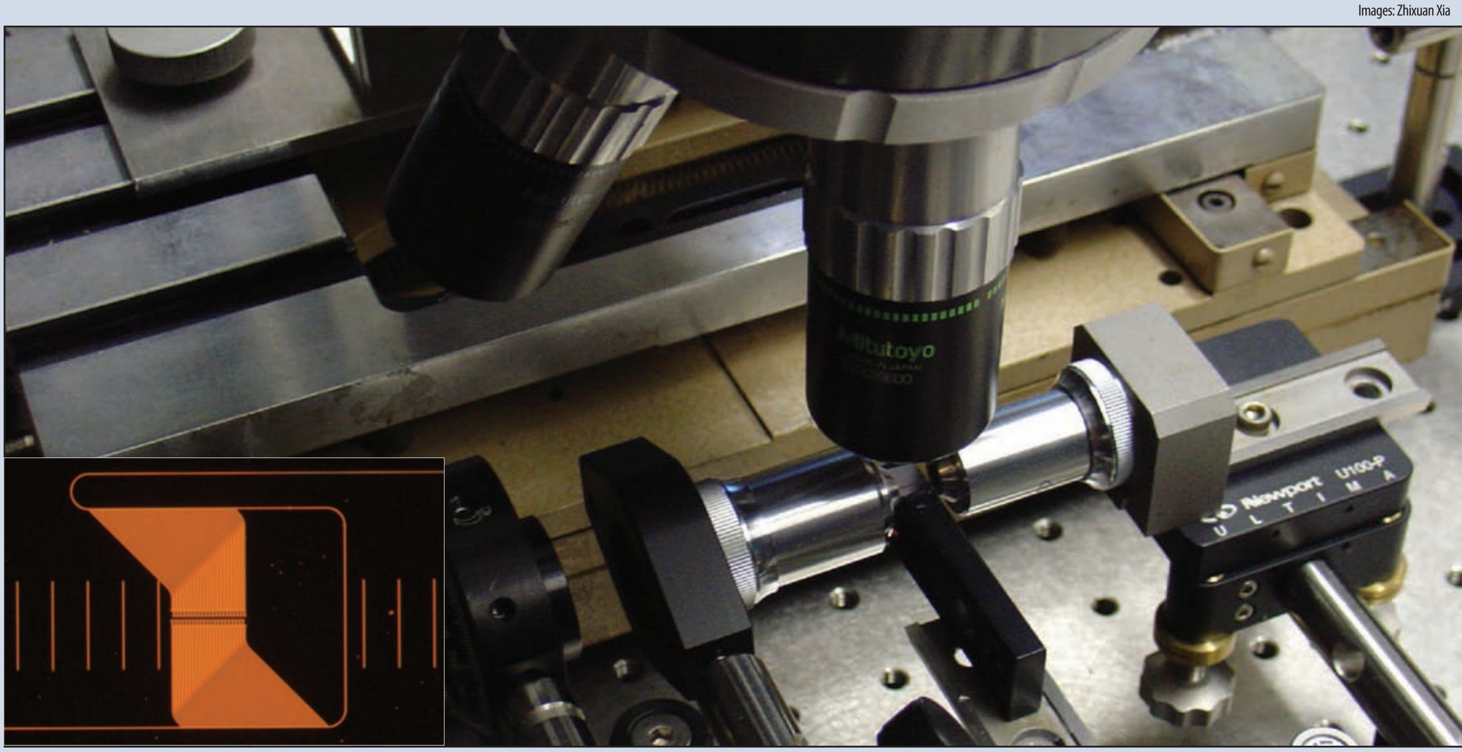
Images: Zhixuan Xia



Experimental setup used to test the 81-channel on-chip microspectrometer designed by Georgia Tech engineers. (Inset) Micrograph of the microspectrometer.

Polymer from Brown Algae May Improve Electrodes in Lithium-Ion Batteries

Images: Wikipedia Commons, Gleb Yushin

Scientists and engineers from Georgia Tech and Clemson University are studying a new binder material based on a polymer derived from from common brown algae. (Inset) The Georgia Tech research team included Igor Kovalenko and Alexandre Magasinski (sitting, l-r) and Benjamin Hertzberg and Prof. Gleb Yushin (standing, l-r)

By looking to Mother Nature for solutions, researchers have identified a promising new binder material for lithium-ion battery electrodes that could not only boost energy storage, but also eliminate the use of toxic compounds now employed in manufacturing the components.

Known as alginate, the material is extracted from common, fast-growing brown algae. In tests so far, it has helped boost energy storage and output for both graphite-based electrodes used in existing batteries and silicon-based electrodes being developed for future generations of batteries.

The research is a collaboration among scientists and engineers at Georgia Tech and Clemson University. The findings were reported in the Oct. 7, 2011, issue of the journal *Science*. The project was supported by the two universities, as well as by a Honda Initiation Grant and a grant from NASA.

"Making less expensive batteries that can store more energy and last longer with the help of alginate could provide a large and lasting impact on the community," said Gleb Yushin, an assistant professor in Georgia Tech's School of Materials Science and Engineering. "These batteries could contribute to building a more energy-efficient economy with extended-range electric cars, as well as cell phones and notebook computers that run longer on battery power – all with environmentally friendly manufacturing technologies."

Working with Igor Luzinov at Clemson University, the researchers looked for ways to improve binder materials in batteries. The binder is a critical component that suspends the silicon or graphite particles that actively interact with the electrolyte that provides battery power.

The researchers specifically looked for potential binder materials that had evolved in natural systems, such as aquatic plants growing in salt water with a high concentration of ions.

Finding just the right material is an important step toward improving the performance of lithium-ion batteries. The lightweight batteries work by transferring lithium ions between two electrodes – a cathode and an anode – through a liquid electrolyte. The more efficiently the lithium ions can enter the two electrodes during charge and discharge cycles, the larger the battery's capacity will be.

Existing lithium-ion batteries rely on anodes made from graphite. Silicon-based anodes theoretically offer as much as a ten-fold capacity improvement over graphite anodes, but silicon-based anodes have so far not proven stable enough for practical use.

Among the challenges for binder materials are that anodes to be used in future batteries must allow for the expansion and contraction of the silicon nanoparticles, and that existing electrodes use a polyvinylidene fluoride binder manufactured using a toxic solvent.

Thus far, the researchers have demonstrated that the alginate can produce battery anodes with reversible capacity eight times greater than that of today's best graphite electrodes. The anode also demonstrates a coulombic efficiency approaching 100 percent and has been operated through more than 1,000 charge-discharge cycles without failure.

— John Toon

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Tiltable Head Could Improve Robot's Ability to Navigate Disaster Debris

Photos: Daniel Goldman, Gary Meek

(Left) Georgia Tech researchers showed that by tilting this robot's head up and down slightly, they could control its vertical motion as it traveled forward within a granular medium. (Right) The sandfish lizard, with its wedge-shaped head that helps it swim in sand, provided the biological inspiration for the Georgia Tech robot.

Robots able to navigate through complex dirt and rubble environments could have helped rescuers after recent earthquakes, but building such machines is challenging. Georgia Tech researchers have designed a robot that can "swim" through granular material, and in a new study, they showed that varying the shape or adjusting the inclination of the robot's head affects its movement in complex environments.

"We discovered that by changing the shape of the sand-swimming robot's head or by tilting its head up and down slightly, we could control the robot's vertical motion as it swam forward within a granular medium," said Daniel Goldman, an assistant professor in the Georgia Tech School of Physics.

Results of the study were presented in May 2011 at the 2011 IEEE International Conference on Robotics and Automation in Shanghai. Funding for this research was provided by the Burroughs Wellcome Fund, National Science Foundation and Army Research Laboratory.

The study was conducted by Goldman, bioengineering doctoral graduate Ryan Maladen, physics graduate student Yang Ding and physics undergraduate student Andrew Masse, all from Georgia Tech, and Northwestern University mechanical engineering adjunct professor Paul Umbanhowar.

"The biological inspiration for our sand-swimming robot is the sandfish lizard, which inhabits the Sahara desert in Africa and rapidly buries into and swims within sand," explained Goldman. "We were intrigued by the sandfish lizard's wedge-shaped head that forms an angle of 140 degrees with the horizontal plane, and we thought its head might be responsible for or be contributing to the animal's ability to maneuver in complex environments."

For their experiments, the researchers attached a wedge-shaped block of wood to the head of their robot, which was built with seven connected segments, powered by servo motors, packed in a latex sock and wrapped in a spandex swimsuit. The doorstop-shaped head – which resembled the sandfish's head – had a fixed lower length of approximately 4 inches, height of 2 inches and a tapered snout. The researchers examined whether the robot's vertical motion could be controlled simply by varying the inclination of the robot's head as it swam through a test chamber filled with plastic spheres.

The researchers investigated the vertical movement of the robot when its head was placed at five different degrees of inclination. They found that when the sandfish-inspired head with a leading edge that formed an angle of 155 degrees with the horizontal plane was set flat, negative lift force was generated and the robot moved downward into the media. As the tip of the head was raised from zero to 7 degrees relative to the horizontal, the lift force increased until it became zero. At inclines above 7 degrees, the robot rose out of the medium.

"The ability to control the vertical position of the robot by modulating its head inclination opens up avenues for further research into developing robots more capable of maneuvering in complex environments, like debris-filled areas produced by an earthquake or landslide," noted Goldman.

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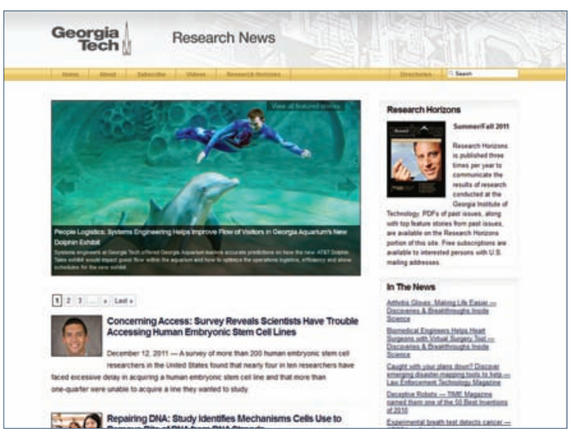

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