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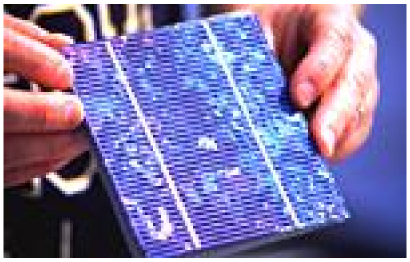

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By John Toon

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Research Horizons
Georgia Institute of Technology

TRANSPORTATION / ELECTRICAL & COMPUTER ENGINEERING

Electrifying Transportation

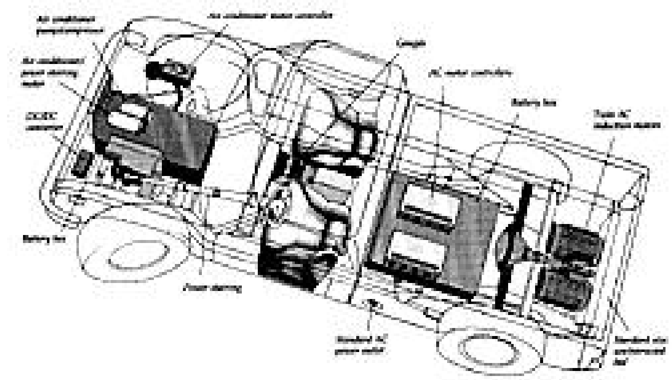
Georgia Tech is helping design the electric and electric-hybrid vehicles of tomorrow

By Amy Stone

UNLIKE MEMORIES of the oil embargoes of the 1970s, the United States' reliance on foreign sources of fossil fuels has not faded, largely due to Americans' love affair with the car. This nationwide phenomenon causes an additional problem — pollution. In a project that will address both dependence on foreign oil and air pollution reduction, a group of researchers at the Georgia Institute of Technology is helping design vehicles of the future — electric and electric-hybrid vehicles.

Electric vehicles are quiet, generate no tailpipe pollution and would be the most efficient mechanism of transportation — but completely electric vehicles have some design hurdles that must be overcome before they can be mass produced. Hybrid-electric vehicles, a cross between electric vehicles and those that use internal combustion engines, run more cleanly than conventional internal combustion vehicles while maintaining the extended range that travelers have come to expect.

courtesy of Solectria Corp.



Batteries and motors are hidden beneath the standard-size bed of the Solectria electric pickup truck. (Click on picture to see larger (58k) version.)

An added benefit of hybrid vehicles is that they could run on domestic fuels, such as ethanol, methanol, natural gas, propane or biodiesel. Therefore, pursuing the development of both types of vehicles simultaneously is wise, considering their differing strengths.

"Hybrid vehicles are more expensive because they have many redundant parts when compared to purely electric vehicles," says Robert Michelson, principal research engineer in the Georgia Tech Research Institute's (GTRI) Aerospace and Transportation Laboratory, and manager of the electric and hybrid vehicles program. "Therefore, the first users of this technology will be those who find tremendous advantage in tripling the fuel economy, such as public transportation or the military establishment."

Already, researchers at Georgia Tech have a prototype hybrid vehicle, a city bus in Augusta, Ga., which uses batteries and burns hydrogen to produce electricity. This bus will furnish data on real-world running conditions, allowing researchers to fine-tune its workings.

Electric and Hybrid-Electric Vehicle Research

Electric and hybrid-electric vehicles would offer benefits for many users, ranging from consumers' desires for a non-polluting, economical form of transportation to the military's need for quiet, energy-saving tanks. In fact, the military, through the Defense Advanced Research Projects Agency (DARPA), funds much of Georgia Tech's electric vehicle program.

Georgia Tech is collaborating with the Southwest Research Institute, the University of Hawaii, and the University of Texas to identify current and needed technologies and to model these technologies into a complete vehicle. The collaborating team shares the task of modeling the hybrid-electric vehicle, and Georgia Tech is responsible for the following areas.

Pulsed Battery Charging and Advanced Battery Electrochemistry

One of the problems with using batteries as a power source is the length of time required to recharge them after they have been depleted of energy. Current modes of recharging can take up to eight hours, which creates problems for consumers used to jumping in their cars whenever they need them, or for soldiers who depend on the readiness of their vehicles for mobility and survival.

Dr. Yi Ding, a researcher in GTRI's Aerospace and Transportation Laboratory, is developing a method for quickly charging batteries that could reduce the time from eight hours to about 15 minutes and increase energy efficiency — essential for the long-term commercial success of electric vehicles. Ding's method will also help electric vehicle users get the same amount of energy for their vehicle battery from an electric vehicle "filling station" or from their home electrical outlet; his method is much more efficient in transferring the electric energy into battery chemical energy compared to conventional methods.

photo courtesy Edison EV

Drivers can charge their electric vehicles at stations provided by Edison EV.

Conventional attempts to quick-charge batteries have used high currents, which resulted in excess amounts of heat and vented gas, which in turn, damaged the battery. By using a pulsed current, in which very high charges are given for short durations of time to charge the battery, Ding's design minimizes the production of heat and gas as byproducts, increases the cycle life, and prevents the premature loss of battery capacity — a significant consideration since some lead acid battery packs can cost $1,500 to $2,000 and generally last about three years.

Additionally, being able to quick charge the batteries helps address the problem of limited endurance of current batteries. Current batteries can only propel a vehicle for about 80 miles due to their low energy density. Until new battery technology solves this problem, the ability to quickly recharge current batteries will ease the strain of frequent chargings.

There is another benefit to being able to quickly recharge a battery: consumer acceptance. "If you make electric vehicles familiar to the user, consumers will accept the technology more easily," says Ding. "By charging the batteries quickly, it will be similar to filling a tank with gasoline."

New methods of charging batteries, such as Ding's, have been called "smart charging" because they will understand the state of the battery before charging and adjust accordingly.

From a theoretical point, one of the major limitations in the design of electric vehicles has been the lack of a model that would simulate battery use in real-world conditions. By collaborating with colleagues in the School of Electrical and Computer Engineering, Ding is helping to solve that problem by designing a model of battery power sources for electric and hybrid-electric vehicle designers and users (see "Modeling and Simulation," page 9). An additional problem is that there is no precise gauge to measure how much energy is left in the battery, as in the fuel gauge in a gasoline-powered automobile. Ding is also creating mathematical and real-time models of the average battery to develop a fuel gauge that takes into consideration temperature, speed, age of battery and driving conditions, allowing the user to know how much energy remains.

Thermal Management

Another important component of designing an electric vehicle is the management of heat and cold. Dr. Krishan Ahuja, Regents researcher in GTRI's Aerospace and Transportation Laboratory and professor of aerospace engineering, along with graduate student Baha Suleiman, is developing a model that integrates heating, ventilation and air conditioning. The model does this by taking into consideration variables such as outside temperature, wind speed, location of the car (through the use of the Global Positioning System or by entering the latitude and longitude) and the number of passengers.

"Modern vehicles of the 21st century will be responsive to consumers' needs," says Ahuja. "For example, you park your car in the garage and it's -20 F outside. You want to get into a nice, cozy interior the next morning. Our model is capable of predicting how long it will take to reach a certain temperature. It will be possible to automatically turn the car heater on before you wake up, using the electric plug in the garage."

To develop the thermal load application, Ahuja and Suleiman divided the car body surfaces across which heat transfer takes place into many panels. They gathered information, such as wind speed and outside temperature, in order to calculate the energy balance — how much energy was coming into the car, in forms such as solar heat or radiation of body heat, and how much was leaving.

The calculations used in the approach will:

- indicate how many watts of heat are needed to maintain a given temperature in the vehicle's interior for certain conditions;

- aid in decision-making about materials and insulation to be used when the car is being designed;

- allow future cars to automatically adjust to appropriate temperatures, based on sensors and on-board computers.

"Additionally, this technology can be applied to military vehicles, such as tanks, helicopters, and submarines, and also to homes and large buildings," notes Ahuja.

Ahuja and Suleiman have just completed development of a theoretical model and computer code of their technique. The next step will be model testing in a wind tunnel, followed by similar testing using an actual electric vehicle, to validate their predictions.

Modeling and Simulation

Aiding all aspects of electric and hybrid vehicle creation is a simulator, created in collaboration with the Southwest Research Institute, the University of Hawaii and the University of Texas. Dr. Tom Habetler and his colleagues in Georgia Tech's School of Electrical and Computer Engineering have created the electrical components of the simulator, including the generator, motors and power electronics. The simulator allows people in the vehicle industry, such as engineers and manufacturers, to enter variables, such as weight of the proposed vehicle, the size of motors and their rated values, the voltage of batteries, and air and rolling resistance, among many others. The simulator then synthesizes the information and supplies predictions about the whole machine.

"You can even input how the driver positions the throttle, or gas pedal," says Habetler. "The simulator will help develop the battery, motor, controller, and integrated heating, ventilation and air conditioning models for the prototype vehicle."

The simulator is named PATHS, for Performance Assessment Toolbox for Hybrid Systems, and is programmed in Matlab/Simulink. Parts of PATHS have been uplinked to the national database in Hawaii and are already in use by certain military agencies.

Georgia Tech's electric and hybrid vehicle program has made great strides in a relatively short time. However, cautions Charles Stancil, chief of the Advanced Transportation Branch at GTRI, the bottom line is economic viability.

"This technology has to pass what we call the 'so what?' test, which means the models we develop have to be useable by consumers," says Stancil. "If not, people confronted with it will just say 'so what?'"

Other Georgia Tech Electric Vehicle Activities

Additional activities on the electric and hybrid-electric vehicle scenes include the following:

- Georgia Tech has been instrumental in fostering electric vehicle research in the Southeast and has been an active member of the Southern Coalition for Advanced Transportation since its inception.

- Georgia Lottery funds totaling $170,000 were used to complete the new "Advanced Vehicle Development and Integration Laboratory" located at GTRI's Cobb County Research Facility. The money was used to buy test equipment and outfit lab space into two reconfigurable bays for design, construction, and integration of advanced air, land, and sea vehicles — especially unmanned systems.

- The Georgia Department of Transportation has provided start-up funding to Georgia Tech for a multi-disciplinary center called the Georgia Transportation Institute, which will conduct research, development, education, and technology transfer pertaining to all forms of transportation in the State of Georgia. The Institute will coordinate and enhance the involvement of Georgia Tech and other state universities doing research in transportation.

Further information is available from Robert Michelson, Aerospace and Transportation Laboratory, Georgia Tech Research Institute, Georgia Institute of Technology, Atlanta, GA 30332-0844. (Telephone: 770/528-7568) (E-mail: robert.michelson@gtri.gatech.edu)

Research Horizons
Georgia Institute of Technology

INTERDISCIPLINARY RESEARCH

Striking Gold

New materials are the first to exhibit charge-quantization effects in a macroscopically obtained material, for which every cluster behaves identically.

By John Toon

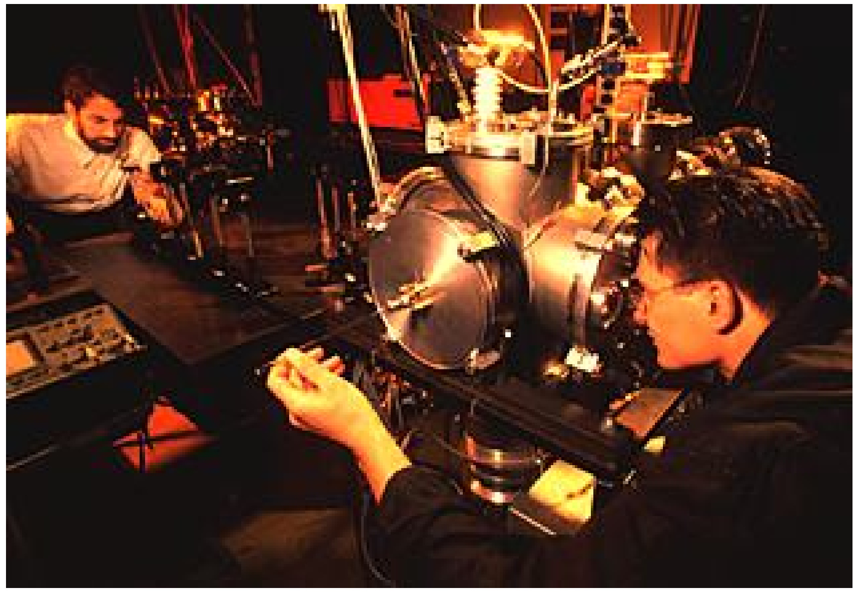
AN INTERDISCIPLINARY TEAM of researchers at the Georgia Institute of Technology has isolated a new series of highly stable and massive gold-cluster molecules possessing a set of "extraordinary" quantum properties.

"With these properties, the molecules are very attractive building blocks for testing one type of ultra-miniaturized architecture envisioned by some for 21st-century nanoelectronics, as well as for other chemical and molecular-biological applications,"

says Dr. Robert L. Whetten, professor of physics and chemistry. The work is supported by the National Science Foundation, the U.S. Office of Naval Research, the Packard Foundation and the Georgia Tech Foundation.

Each molecule in the new series has a compact, crystalline gold core. This pure metallic core, just one-to-two billionths of a meter (1 to 2 nanometers) across, is encapsulated within a shell of tightly packed hydrocarbon chains linked to the core via sulfur atoms.

photo by Stanley Leary



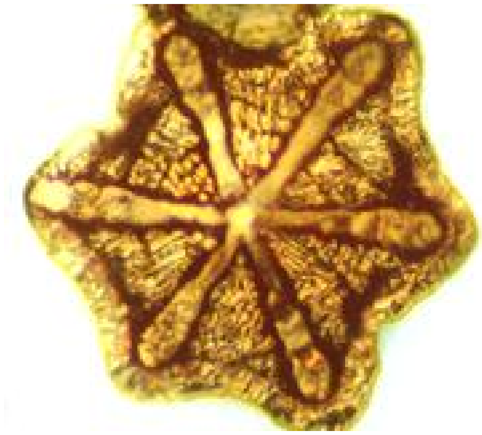
Graduate Students Igor Vezmar and Joseph Khoury use a high-mass spectrometer to analyze the new series of gold clusters. (200-dpi JPEG version - 237k)

The principal members of the series have core-masses of about 7,500, 14,000, 22,000 and 28,000 protons, corresponding to about 38, 75, 110 and 145 gold atoms, respectively. They are thus in the same mass range as larger protein molecules, as reported by M. M. Alvarez, T.G. Schaaff and colleagues in papers published recently in Chemical Physics Letters and the Journal of Physical Chemistry. These differ, both in size and the higher yield with which they are obtained, from their heavier analogs described in 1996 by Whetten and colleagues in Advanced Materials.

The precise structures of the cores are as yet unknown, but theoretical and experimental evidence suggests they are faceted with a particular gemstone shape, as reported in a recent paper by Whetten, Dr. Uzi Landman, and their co- workers in the Physical Review Letters.

"The surrounding chains can be of any length, and can be modified to confer particular chemical properties, so that they can be incorporated into various solid-state and solution structures, or even in a peptide modification, into aqueous media," Whetten notes. "Most importantly, each member of the series behaves as a substance composed of infinitely replicated molecules, which can be separated from other members of the series to yield pure substances with precisely defined properties."

The gold cluster molecules emerge spontaneously during the decomposition of certain gold-thiolate polymers of the type commonly used in decorative gold paints and in gold anti-arthritis drugs. With sufficient control of the decomposition process, this series can be



This optical microscope image shows a 150-micron crystal grown from 1.7 nanometer gold nanocrystals. (200-dpi JPEG version - 248k)

isolated without concurrent production of larger gold crystals. It is then relatively easy to separate the principal members of the series from each other to obtain the necessary homogeneity. Once purified, the molecules spontaneously assemble into crystalline thin films, powders, or macrocrystals, while preserving the discrete properties of the individual gold nanocrystal cores.

Gold is important technically not only for its inertness — once made, the clusters are immune to corrosion — but also for its highly stable surfaces, which find application as junctions in critical microelectronic applications.

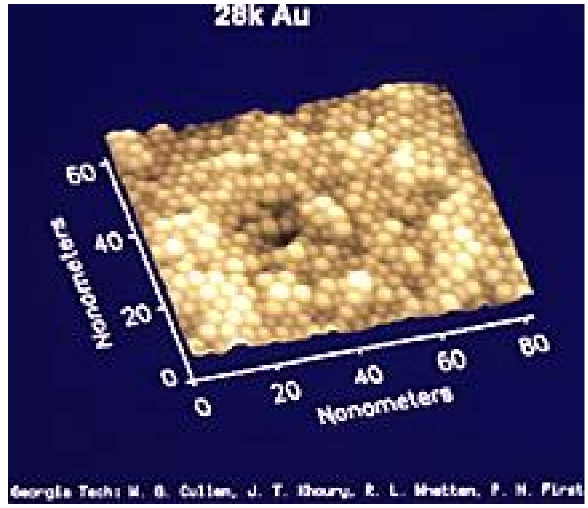
"The main fascination of very small metal crystals, and the foundation for their envisioned use in future electronics, arises from the fact that their conduction electrons are quantized both in their number — charge quantization — and in the states they can occupy — energy quantization," Whetten adds. "In crystals larger than a few nanometers, these effects can only be observed and used at very low temperatures, such as that of liquid helium, near absolute zero. The new series of nanocrystals are both sufficiently small that these effects are prominent even at ordinary temperatures, and large enough to have the robust crystalline properties of the bulk metal."

The electromagnetic and conduction properties of the clusters are extremely sensitive to charging, and somewhat less so to energy level. Whetten believes these states can be used in a proposed electronic circuitry known as "single-electronics," and will be tested for other applications in photoelectrochemistry and catalysis where their superior robustness may have advantages.

The new gold cluster materials are the first to exhibit the charge- quantization effect in a macroscopically obtained material, for which every cluster behaves identically. The first measurements were conducted in the laboratory of Dr. Phil First at Georgia Tech by observing the step-like changes in the current passing from a scanning tunneling microscope tip to a gold plate through a single gold cluster molecule as the voltage was increased.

The highly regular spacing between these steps, known as the "Coulomb staircase," showed that the molecules' gold core is charging like a small metal sphere in a series of discrete steps by adding or removing single electrons.

photo courtesy Robert Whetten



Each molecule in the new series, an array of which is shown here via scanning tunneling microscope (STM), has a compact, crystalline gold core. A shell of tightly packed hydrocarbon chains surrounds the core and is linked to it via sulfur atoms. [(200-dpi JPEG version - 150k)]

Subsequent electrochemical measurements on these clusters found an "ensemble Coulomb staircase" involving billions of identically behaving clusters, as reported by Whetten and collaborators at the University of North Carolina at Chapel Hill in the Journal of the American Chemical Society.

Research in the area of nanometer-scale molecular materials is highly interdisciplinary, requiring the skills of many diverse researchers and facilities. The molecular gold materials have been developed in Whetten's Georgia Tech laboratory, as guided also by the theoretical predictions and modeling of Landman's Center for Computational Materials Science.

They were characterized in the Georgia Tech Electron Microscopy Facility, directed by Dr. Z. L. Wang, in the X-ray facilities at Georgia Tech of Dr. Angus Wilkinson and the National Synchrotron Light Source by Dr. Peter W. Stephens of the State University of New York-Stony Brook. The research in Whetten's laboratory has been carried out by a team of graduate students including Marcos M. Alvarez, Joseph Khoury, Greg Schaaff, Marat Shafigullin, Brian Salisbury and Igor Vezmar.

The work was reported April 16 at the 213th National Meeting of the American Chemical Society in San Francisco.

Further information is available from Dr. Robert Whetten, School of Physics, Georgia Institute of Technology, Atlanta, GA 30332-0430. (Telephone: 404/894- 8255)
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ELECTRICAL & COMPUTER ENGINEERING

A Bright Future for Solar Energy

Georgia Tech is playing an important role in photovoltaics' status as a leading contender in the search for clean, renewable energy sources.

By Amanda Crowell

MIKE ROPP, A DOCTORAL STUDENT in Georgia Tech's School of Electrical and Computer Engineering (ECE), has just climbed nearly 150 feet of ladders to the barrel-vaulted roof of the Georgia Tech Aquatic Center. Wind whips menacingly over the sides and a stunning view of the Atlanta skyline lies to the south.

"Welcome to my laboratory," he quips, flashing a ready grin and spreading his arms expansively.

photo by Stanley Leary

Reseachers have reduced the time required to produce solar cells without losing efficiency. (200-dpi JPEG version - 362k)

And what a laboratory it is.

Spread over nearly three-quarters of an acre is what is believed to be the world's largest solar-powered energy system connected to a power grid and located on a single rooftop. The 342-kilowatt photovoltaic system — which converts sunlight into electricity — serves as both a research model and a supplementary power source for the Aquatic Center.

It is also one of many projects conducted under the Georgia Institute of Technology's University Center of Excellence for Photovoltaics Research and Education (UCEP), which is designed to help make photovoltaics (PV) a leading contender in the search for clean, renewable energy sources for the future.

Established in 1992 by the U.S. Department of Energy and supported by the DOE's Sandia National Laboratories, UCEP is one of only two national centers of excellence in PV research. (The second is at the University of Delaware.)

Researchers are charged with advancing PV research, producing cheaper and more efficient solar cells, and training the next generation of PV scientists — all with an eye toward giving the United States a competitive edge in photovoltaics.

"I think the main reason the DOE decided to make us a university center of excellence was there was no other university at the time, other than the University of Delaware, that could do research all the way from photovoltaic materials to materials characterization, modeling, process development, fabrication, testing and analysis of cells," says Dr. Ajeet Rohatgi, who directs UCEP and is a Regents' Professor and Georgia Power Distinguished Professor in ECE. "Large grid-connected PV systems on campus make us even more unusual. There are very few places that have everything going on in one place."

Dr. Joseph R. Romm, acting assistant secretary for the DOE's Office of Energy Efficiency and Renewable Energy, also notes that Georgia Tech "has an unusually strong interdisciplinary emphasis and a commitment to sustainable development."

"There's also a good healthy emphasis on education," he says. "All of that adds up to the perfect setting for a center of excellence."

Although proponents of photovoltaics say it's an ideal technology to supplement or replace traditional energy sources, PV power currently is less efficient (defined as the amount of energy a system produces divided by the energy that goes into it) and about four times more expensive. But 20 years ago, PV power was 50 times as expensive as traditional energy sources.

UCEP researchers have made major contributions to bringing down this cost by designing and testing new PV systems and developing cheaper, more efficient solar cell technologies.

Olympic Legacy

In the area of new PV systems, the Georgia Tech Aquatic Center is a standout example. Built to host swimming and diving events for the 1996 Summer Olympic and Paralympic Games, it is a lasting legacy for the campus and should provide significant, long-term data on how to build and maintain large-scale PV structures.

"The goal is to get a better understanding of how these systems work — their performance, their reliability and our modeling capability to predict their performance," says Rohatgi, who designed the $5.2 million system with Dr. Miroslav M. Begovic, also an ECE professor, and Richard Long, project support manager in Georgia Tech's Office of Facilities.

photo by Stanley Leary

The Georgia Tech Aquatic Center's roof holds a 342-kilowatt photovoltaic (PV) system, which will provide significant, long-term data on how to build and maintain large-scale PV structures. (200-dpi JPEG version - 362k)

Funding came from Georgia Tech, Georgia Power Company and the DOE.

"We realize that photovoltaics is a technically viable source for supplying future energy needs, and we wanted to help in the demonstration of that," explains Chuck Huling, who coordinates research for Georgia Power. "The Olympics provided a wonderful opportunity to demonstrate this renewable technology to a local, national and international audience."

During its first year, the system operated close to the efficiency level expected, although actual energy production was lower than predicted. Reasons included unexpected down time, periodic shutdowns for experiments and higher- than-usual temperatures during some months, which decreased the system's efficiency.

From July 1996 to June 1997, the system produced 333.3 megawatt hours of electricity, which is 81.5 percent of the 409 megawatt hours predicted and enough energy for about 28 average Georgia homes.

The rooftop system features a solar array made up of 2,856 photovoltaic modules, each with 72 multicrystalline silicon solar cells connected in series. A power conditioning system, or inverter, converts the array's direct current (DC) power to utility-compatible alternating current (AC) power, and a data acquisition system stores performance and meteorological information every 10 minutes.

Researchers also built a 4.5-kilowatt, AC array at the entrance to the Callaway Student Athletic Complex. It differs from the Aquatic Center system in that each module converts the solar-generated DC power to AC power itself, which reduces costs and simplifies installation.

"While UCEP has long been in the forefront of research in developing world-record efficient hardware, the PV systems will help us in becoming an authority in design and help assess the cost/benefit of the yet-to-be-built systems of the future," Begovic says.

New Processes and Materials

But for photovoltaics to truly compete with conventional energy sources, production costs must be reduced, so Georgia Tech researchers are exploring several innovative techniques.

One is rapid thermal processing (RTP), which researchers recently used to fabricate for the first time a silicon solar cell with the same 19 percent efficiency rating as cells produced by conventional furnace processing, but in half the time — 81/2 hours rather than 17.

Conventional solar cell production generally involves three trips into a high-temperature furnace, and each step lasts one to three hours. The cells also must be cleaned between each step. With RTP fabrication, the front and back of the cell are formed simultaneously by a rapid thermal diffusion process that takes three minutes, and an oxide is grown on the front of the cell by a five- minute rapid thermal oxidation (RTO) process.

Industrial manufacturers often delete the oxidation process, called passivation, to save money and increase output. Georgia Tech's RTO process offers a time-saving way to include this performance-enhancing step.

Once a solar cell is created, metal contacts are added to extract the electrical power from the cell. This step is the most time-consuming; in RTP fabrication, for example, it accounts for 80 percent of the production process. The common techniques of evaporation and photolithography give good resolution and conductivity, but Rohatgi says many commercial manufacturers have switched to a quicker method called screen printing, which produces less efficient cells.

In 1996, Georgia Tech researchers successfully integrated screen printing with RTP, slashing cell production time to 11/2 hours. Since then, they've raised cell efficiency from 14.7 percent to 16.3 percent and outlined modifications for future increases.

"If we can make the solar cells very fast compared to what's being done out in industry today, without sacrificing the cell performance, that will obviously reduce the use of chemicals, gases and manpower, and it will increase the production capacity and throughput," Rohatgi explains. "This should result in significant reduction in the cost of solar cell modules."

Researchers also are experimenting with a technique they call "Simultaneously Diffused, Textured, In-Situ Oxide AR-coated Solar Cell Process" or STAR. In this process, a single high- temperature furnace step can provide front and back surface diffusions simultaneously, in addition to front and back in-situ oxide surface passivation. The cell is textured and has an anti-reflection (AR) coating, to trap more light in the cell.

So far, researchers have created cells with 20.1 percent efficiency. And although the STAR process is not as fast as RTP cell fabrication, Rohatgi says STAR is compatible with high- throughput machinery commonly used by the solar industry today, while RTP currently isn't.

Another way to reduce the cost of photovoltaics is to make solar cells from less expensive materials. UCEP researchers are

Why Photovoltaics?

The bottom line for renewable energy is not that it's a matter of if. It's a matter of when.

When proponents of photovoltaics — the direct conversion of sunlight into electricity — argue their case, they note that two billion people in the world don't have access to electricity and that most conventional energy sources cause pollution, deplete natural resources or contribute to global warming.

Photovoltaics (PV), or solar power, offers a clean, renewable alternative. The U.S. Department of Energy is supporting extensive research in this area, including establishment of Georgia Tech's University Center of Excellence for Photovoltaics Research and Education (UCEP).

PV power operates on a simple principle: a cell is created from a semiconductor material like silicon. When sunlight hits the cell, photovoltage on an electric current is created, which flows through an external circuit and produces energy. Several cells can be wired together and encased in clear glass or plastic to form a panel or module. These can be connected into arrays — to collect and produce more power — then placed atop a building and either connected to an existing electrical system or linked to batteries.

The process is silent and self-contained, with no moving parts, no emissions and sunlight as energy source. Compared to burning coal, for example, DOE officials estimate that every gigawatt hour of PV-generated electricity prevents the emission of up to 1,000 tons of carbon dioxide.

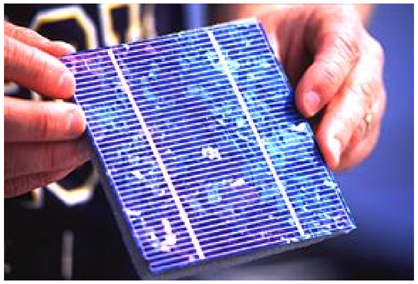
Solar power also is versatile enough to supply nearly any energy need, from working with several promising silicon materials, including float zone, Czchralski, cast multicrystalline, EFG sheet and dendritic web silicon, and currently hold the record for high-efficiency multicrystalline silicon cells — 18.6 percent.

Crystalline silicon is used in about 80 percent of the solar cell modules produced today, Rohatgi says. The other 20 percent are made from amorphous silicon and thin film materials like cadmium telluride.

Industry's Importance: Today and Tomorrow

Rohatgi attributes part of UCEP's success to close working relationships with more than two dozen U.S. solar manufacturers, including industry leaders like Solarex Corp., Siemens Solar Industries and ASE America Inc.

photo by Gary Meek



Research done at Georgia Tech could help lower the cost of producing photovoltaic arrays. (200-dpi JPEG version - 283k)

"To make our processing more manufacturable, we try to do applied research that can be easily transferred to industry," Rohatgi says. "That is part of the mandate from the DOE. Our job is not to just do blue-sky type research, [but to] focus on research that can lead to commercially viable solar cells."

So far, UCEP is having no trouble meeting that mandate. Researchers hold patents for seven production techniques and have applied for several others. They've published over 100 papers in peer-reviewed journals and both refereed and non-refereed conference proceedings. UCEP also includes an Educational Support Program (ESP) Laboratory, where solar cells are fabricated and/or tested for other universities, and lab space in both ECE and the Microelectronics Research Center.

Besides reducing solar costs and improving technologies, Rohatgi says future successes also will depend on transferring these new techniques from the laboratory to the production line.

"The next step would be to scale up some of the novel technologies we're developing to a larger scale — making larger-area cells, then transferring this know-how to industry," Rohatgi says. "Only then will industry get excited about it and be able to use it."

Further information is available from Dr. Ajeet Rohatgi, School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0250. (Telephone: 404/894-7692) (E-mail: ajeet.rohatgi@ee.gatech.edu) You can find the Georgia Tech Aquatic Center on the Web at http://www.ece.gatech.edu/users/2648/index.html.

lighting and small appliances for a single home to water-pumping systems for farms or industrial activities for whole villages.

Although PV power currently is less efficient and more expensive than conventional energy sources like coal, oil, natural gas and nuclear power, its advantages already make it the preferred choice in many everyday applications. Examples include calculators, U.S. Coast Guard navigational beacons, highway emergency telephones, traffic warning signs, satellites and remote cabins and farms.

It's also economically competitive in some parts of the United States now — including Hawaii, where electricity is very expensive; Massachusetts and New York, where energy costs are high and local governments often support solar power; and California and Arizona, which have large remote areas and much sunlight.

To help make photovoltaics more competitive, government, private industry and utility company partners have built or proposed dozens of projects, from large-scale power plants to programs that encourage home owners to install rooftop PV systems. Worldwide demand for solar power grew 290 percent from 1987 to 1995.

But for such advances to continue, sustained commitment is needed. Federal funding for renewable energy sources, high during the oil crisis of the 1970s, fell sharply in the early 1980s and only began rebounding in the past decade.

"We're at the point where we're ready to reap large returns on the investments that we've made over the years," says Dr. Joseph R. Romm, acting assistant secretary for the DOE's Office of Energy Efficiency and Renewable Energy. "You cannot profit optimally if you focus on lab work, then throw the results over the fence, assuming that the marketplace will pick them up. There needs to be a partnership with the private sector, and that's what we're doing at the DOE.

"The bottom line for renewable energy, really, is not that it's a matter of 'if,'" he adds. "It's a matter of when and who profits."

Research Horizons
Georgia Institute of Technology

UPDATE

Taking A Closer Look

Tech's electron microscope facility benefits research in nanotechnology, new materials and microelectronics.

By John Toon

IN A DARK, FIRST-FLOOR ROOM at Georgia Tech's School of Materials Science and Engineering, Dr. Z.L. Wang carefully adjusts the controls of a JEOL 4000EX transmission electron microscope. A black-and-white image appears on the monitor to his right, revealing a jumbled pattern of ridges and valleys that covers the surface of a tiny carbon nanosphere barely a quarter of a micron in diameter. The features are just 34 millionths of a meter — 0.34 nanometers — across.

photo by Stanley Leary

Equipment in the Electron Microscope Facility, used here by Dr. Z.L. Wang, will benefit research in nanotechnology, novel materials and structures, micro-electronics, new crystals, improved lubricants and living tissues. (200-dpi JPEG version - 355k)

This glimpse of the sphere's surface shows researchers that they are on the right track in their efforts to turn the tiny graphite balls into efficient solid lubricants for micromachines. It also gives them clues to the next series of experimental steps they should try.

Research into promising areas of nanotechnology, novel materials and structures, ever smaller microelectronics, new crystals, improved lubricants — and even living tissues — demands the use of electron microscopes able to see features a few hundred atoms in size. To make these costly tools available to researchers from many different disciplines, the Georgia Institute of Technology has formed the Electron Microscopy Facility.

The facility's three transmission electron microscopes and single scanning electron microscope have helped examine the molecular arrangement of gold nanocrystals, the charge distribution on a new type of P/N junction used in microelectronics, the growth processes in experimental quantum-dot semiconductors, lubricant layers for high-density disk drives and the configuration of a new phosphor material for computer displays.

In addition to showing the structure of materials on a very small scale, the equipment can also provide data on the chemical composition of these small objects, map electrical charges and measure magnetic domain.

"We want to play an important role in many research programs going on across Georgia Tech, and to promote projects across schools and across other divisions of campus," explains Wang, who is director of the Electron Microscope Facility and an associate professor in the School of Materials Science and Engineering. "We believe that a facility like this is essential to many exciting areas of research."

Wang sees the facility as a key part of a research process that begins with theory and simulation, proceeds to experimental fabrication, then relies on microscopy for feedback on the results. Rather than simply providing a microscopy service, he wants to help researchers design their projects to gain maximum benefit of the facility's equipment, which also includes sample preparation and digital image analysis equipment.

The cost of developing the Electron Microscopy Facility has been borne by the National Science Foundation, the State of Georgia through the Georgia Research Alliance, and Georgia Tech.

"We want to see this facility grow into one of the major microscopy facilities in the nation," Wang says. "This equipment is essential to many key areas of research, and most of the country's largest and best universities now have it."

The equipment includes:

- **Hitachi HF-2000 Field Emission Gun (FEG) Transmission Electron Microscope:** This instrument can perform high spatial-resolution chemical microanalysis, high-resolution lattice imaging, and high-coherent beam holographic imaging. It is equipped with a thin window energy dispersive X-ray spectrometer (EDS), which detects not only heavier elements, but also elements as light as carbon. It also has a Gatan parallel-detection electron energy-loss spectrometer, which can be used for quantitative chemical microanalysis of light elements as well as for studying atomic bonding in solid materials. A 180-degree rotational electrostatic biprism suitable for electron holography completes the package.

"The brightness of the highly coherent energy source of the Hitachi HF- 2000 allows high resolution lattice imaging at a point-to-point resolution better than 2.3 Angstroms, lattice resolution of one Angstrom, and chemical microanalysis at a spatial resolution of better than 20 Angstroms," Wang notes. "This is an ideal instrument for performing studies of nanostructured materials and interfaces in thin film and composite materials."

The holographic imaging is the only technique that can provide electron phase information, and is therefore suitable for quantitative mapping of electrostatic fields and magnetic fields in materials such as ferroelectric and magnetic recording materials.

To allow in-situ observation of structural evolution, specimens can be cooled to a temperature as low as -160 Celsius using a liquid nitrogen specimen holder, or heated to a temperature of up to 1,300 Celsius using a heated holder. "This capability is vitally important to predicting the lifetime and reliability of advanced materials," Wang notes.

- **Hitachi S800 Field Emission Gun Scanning Electron Microscope:** This equipment can image materials at a resolution of better than 30 Angstroms, and perform chemical microanalysis from bulk specimens.

- **JEOL 4000EX High Resolution Transmission Electron Microscope:** This device routinely provides point-to-point image resolution of 1.8 Angstroms and is best suited for recording high-resolution images of thin foil specimens.

- **JEOL 100CX II Transmission Electron Microscope:** This instrument is

How Does A Transmission Electron Microscope Work?

Transmission electron microscopes use high electric voltages — as much as 400,000 volts — to accelerate a beam of electrons within a vacuum chamber. The beam is then aimed at a thin slice of the material under study. After the powerful beam of electrons passes through the sample, it is focused and projected onto either a monitor or photographic film to provide an image of the structure.

Transmission electron microscopes can provide magnification as much as 1.5 million times. Since the electron beam must pass through it, preparation of the sample is critical.

primarily used for undergraduate and graduate education, though it also has conventional research uses.

Further information is available from Dr. Z.L Wang, School of Materials Science and Engineering, Georgia Institute of Technology, Atlanta, GA 30332- 0245. (Telephone: 404/ 894-8008) (E-mail: zhong.wang@mse.gatech.edu).

Research Horizons

Georgia Institute of Technology

RESEARCH NOTES

CEOs and the 21st Century

Changes ahead mean new practices must be adopted.

Smart manufacturing CEOs will avoid letting the 21st century just "happen" to them — they are preparing their companies in advance, says Dr. Ned Ellington of the Georgia Institute of Technology's Economic Development Institute (EDI).

To help companies prepare, EDI developed a list of the top ten things CEOs are doing to prepare for the next century. The list, (see below) was developed from a survey of manufacturers; EDI's experience with its nationally known industrial extension efforts; and research done in the National Institute of Standards and

How CEOs Are Approaching the 21st Century

- ✓ Aggressively and continually managing change
- ✓ Finding marketing and manufacturing niches
- ✓ Adopting information technology to reduce time to market
- ✓ Getting lean on manufacturing production
- ✓ Continuing the focus on quality
- ✓ Using all employees to drive continuous improvement
- ✓ Effectively managing energy purchase and use
- ✓ Incorporating environmental

Technology's Manufacturing Extension Partnership (MEP).

"Manufacturing companies that have been successful in the 1980s and 1990s must aggressively manage change if they wish to be leaders in the 21st century," says Ellington, a senior researcher on loan to NIST's MEP to lead its strategic planning effort.

An explosion of information technology, increasing openness of global markets, changing markets and the growing importance of energy and environmental concerns are a few of the many factors that will continue to challenge manufacturing companies. Managers will have to re-examine all their practices if they want to compete successfully.

"This will make manufacturing in the next century not only incredibly dynamic and challenging, but also very profitable to the winners!"

management into production

- Managing the "secondary" business — making money from indirect processes

- Integrating multiple management systems

Source: Georgia Tech's Economic Development Institute

Materials Science and Technology Research

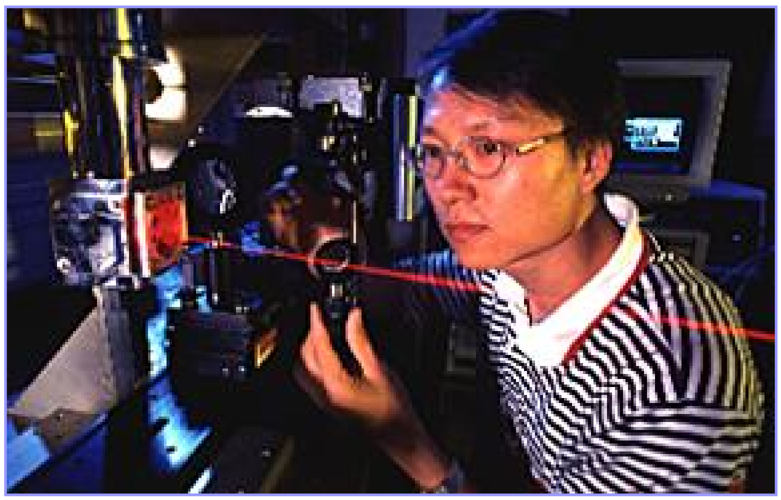
GTRI programs, ranging from polymers to materials analysis, are among the U.S.'s most advanced.

Major activities include:

- Phosphor Research — The Phosphor Technology Center of Excellence, a research consortium including four additional universities, the David Sarnoff Research Center and the American Display Consortium, develops new phosphor materials and better techniques for thin film deposition of color phosphors to aid in the development of improved flat panel displays.

The Georgia Tech Research Institute's Materials Science and Technology Program performs a broad range of research for sponsors in industry and government.

Georgia Tech photo



A GTRI researcher performs spectroscopic studies on new phosphors for advanced flat panel displays.

- **Polymers** — Research focuses on developing non-ozone depleting technologies and researching solid waste recycling technology.

- **High Temperature Materials** — Materials synthesis and processing, coatings and films, and materials characterization are explored via chemical vapor deposition and ceramic matrix composite technology.

- **Metallurgy** — Work focuses on several topics, such as the fabrication of metal wires and welding steel alloys and lightweight aluminum-scandium alloys for transportation. A variety of metal processing concerns are addressed.

- **Catalysis** — GTRI offers one of the nation's leading research and development programs in the field of molecular sieves, zeolites and clay catalysts. The program also is active in catalysis and adsorption studies.

- **Sensors** — Research focuses on developing thin-film sensors to monitor the presence and concentration of materials on different surfaces. Researchers also are producing improved planar optical waveguides for environmental sensors.

- **Materials Analysis** — The Materials Analysis Center conducts specialized analysis and characterization of materials and material processes for Georgia industry. It also conducts independent research and development in partnership with industry and government.

Further information is available from Dr. Henry Paris, Electro-Optics, Environment and Materials Laboratory, Georgia Tech Research Institute, Georgia Institute of Technology, Atlanta, GA 30332-0826. (Telephone: 404/894-3688)
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World Wide Web Worries

Users support privacy of information, voluntary spam control.

Users of the World Wide Web support government efforts aimed at protecting the privacy of confidential information, but believe the problem of unsolicited electronic mail — known as "spam" — can be solved by voluntary efforts similar to those used by traditional marketers.

These conclusions result from the analysis of comments made by more than 19,970 Web users responding to an on-line survey conducted in April and May 1997 by researchers in Georgia Tech's Graphics, Visualization and Usability (GVU) Center.

While few respondents said they liked to receive unsolicited e-mail, the survey found little support for laws against it. The solution favored by 38 percent of respondents was creation of an "opt-out" list of persons who do not want to receive the mailings. This would be similar to the process now used by telephone and direct mail marketers to avoid contacting persons who have indicated they do not wish to receive solicitations.

Just 8 percent of the respondents supported legislation to ban the unsolicited e-mail, while 14 percent suggested some type of "impact fee" be levied on those sending the spam.

While the respondents looked to non-government remedies for junk e-mail, they agreed that government legislation should protect the privacy of information on the Internet, says Colleen Kehoe, one of the researchers who conducted the 7th GVU World Wide Web Survey.

"When you give people a general concern about protecting their confidential information, which is an unknown risk that people can't assess, they choose government protection," she says. "When you talk about the specific issue of unsolicited e-mail, people know what that is and they can assess how much of a problem it is."

The survey also found a growing number of users who admitted to falsifying information provided at Web sites, Kehoe notes.

"People say they falsify information because they don't trust the entity collecting it and they are not provided with a statement explaining how the information is going to be used," she explains.

Among the survey respondents, only 60 percent said they had never provided false information while registering at a Web site — meaning 40 percent had given false information on at least one occasion. Nearly 15 percent of the users admitted to providing false information at least a quarter of the time while registering.

Though lacking the validity of a true scientifically-selected random survey, the GVU survey of Web users has provided an interesting and widely- respected "snapshot" of who's using the giant computer network. Data was first gathered on-line in January 1994 when the project was begun by researcher Jim Pitkow.

The results of this and earlier Web surveys may be purchased from Georgia Tech's Office of Technology Licensing (404/894- 6900) and are available at http://www.gvu.gatech.edu/user_surveys/survey-1997-04/.

Commercial Acoustics

GTRI researchers have expertise, equipment to study diverse, varied sounds.

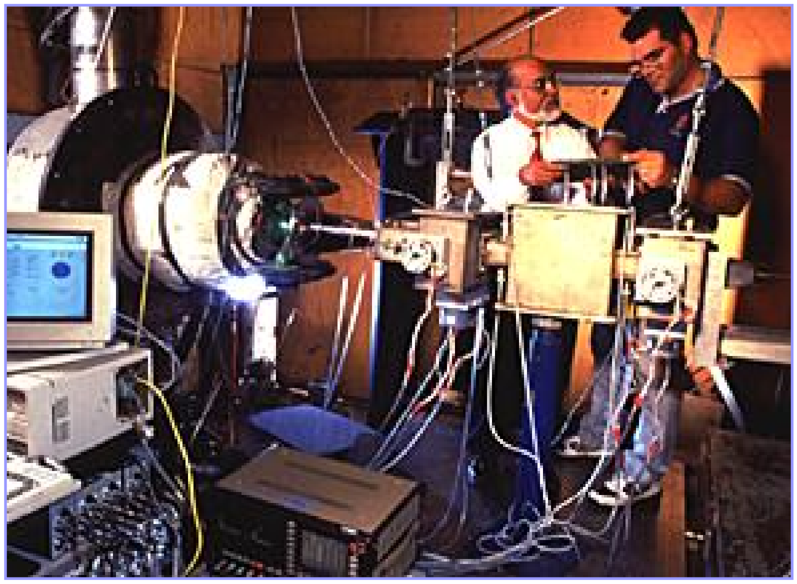
The Georgia Tech Research Institute (GTRI) conducts commercial acoustics research that draws on the international expertise of its staff, state-of-the-art facilities and instrumentation, and advanced signal processing techniques.

Whether studying the sounds produced by automobiles and jet engines, the noises generated by hair dryers and refrigerators, or the way in which people react to them, GTRI offers experience, innovative ideas and cutting-edge test facilities.

Among GTRI's specialties are:

- aerospace acoustics
- active cancellation
- field measurements
- automobile noise control
- acoustic liners
- industrial noise control
- noise simulation.

Georgia Tech photo



GTRI researchers have developed a unique facility to measure sound absorption properties.

Researchers also perform work in underwater acoustics and psychoacoustics, atmospheric acoustics and radio acoustic sensing. They look at optical and biomedical applications, as well, and teach short courses in noise measurement methodologies and noise control.

Facilities include two wind tunnels, several anechoic chambers, a large vacuum chamber, an electrically driven tiltrotor, a sonic boom simulator, and test facilities for high-temperature jet flow, high-temperature acoustic liner flow and flow visualization.

Further information is available from Dr. Krishan Ahuja, Aerospace and Transportation Laboratory, Georgia Tech Research Institute, Georgia Institute of Technology, Atlanta, GA 30332-0844. (Telephone: 770/528-7054) (E-mail: krishan.ahuja@gtri.gatech.edu)

Renowned Researchers

Tech scientists and engineers honored in recent awards.

Dr. Michael Lacey is one of two researchers awarded the 1996 Prix Salem. Lacey, a professor in the School of Mathematics, and Dr. Christoph Thiele of the University of Kiel, Germany, were recognized for their exceptional work on Calderon's bilinear Hilbert transform and the development of a new method of phase space analysis. Their method brings to the study of functions a sensitivity to their spatial and oscillatory behavior.

The Salem prize has been awarded since 1968 to young mathematicians performing exceptional work in areas of interest to the late Raphael Salem, who studied and applied the Fourier series. The Prix Salem selection committee was made up of six top mathematicians from France and the United States.

Dr. W. Steven Johnson is a 1997 recipient of the American Society for Testing and Materials' Award of Merit, and also was named a Fellow of the organization. Johnson, a professor in the School of Materials Science and Engineering, has a joint appointment in the School of Mechanical Engineering, and was recently named director of Georgia Tech's Composites Education and Research Center.

Dr. Raymond Vito, professor in the School of Mechanical Engineering, has been named a Fellow of the American Society of Mechanical Engineers.

Dr. David McDowell, a Regents' professor in the School of Mechanical Engineering, received the Nadai Award from the materials division of the American Society of Mechanical Engineers. The award is ASME's highest honor given for materials research. He was recognized for "outstanding contributions to the experimental study and development of constitutive equations for the rate and temperature-dependent inelastic flow and damage to solids, including cyclic and large strain phenomena, and to the basic understanding and modeling of combined stress state fatigue and fracture processes." McDowell has a joint appointment in the School of Materials Science and Engineering, is director of the Mechanical Properties Research Laboratory, and serves as chairperson of Georgia Tech's Materials Council. He will deliver the Nadai Lecture at the ASME Winter meeting in Dallas in November.

Georgia Tech recently became the only institution to employ three winners of the Henry R. Lissner Award, the most prestigious bioengineering award presented by the American Society of Mechanical Engineers. **Dr. Ajit Yoganathan** has been named the 1997 award winner, continuing a tradition begun by **Dr. Robert Nerem**, director of the Parker H. Petit Institute for Bioengineering and Bioscience, who was selected in 1989; and **Dr. Don Giddens**, professor in the Petit Institute, who was honored in 1993 while dean of engineering at Johns Hopkins University.

Yoganathan is associate director of the Petit Institute, director of the Bioengineering Center and Regents professor in the School of Chemical Engineering. His research addresses cardiovascular fluid mechanics, cardiovascular devices and biomedical engineering. He has conducted pioneering fundamental research on the fluid mechanics of heart valves.

— Articles by Amanda Crowell, Lea McLees, Amy Stone, John Toon