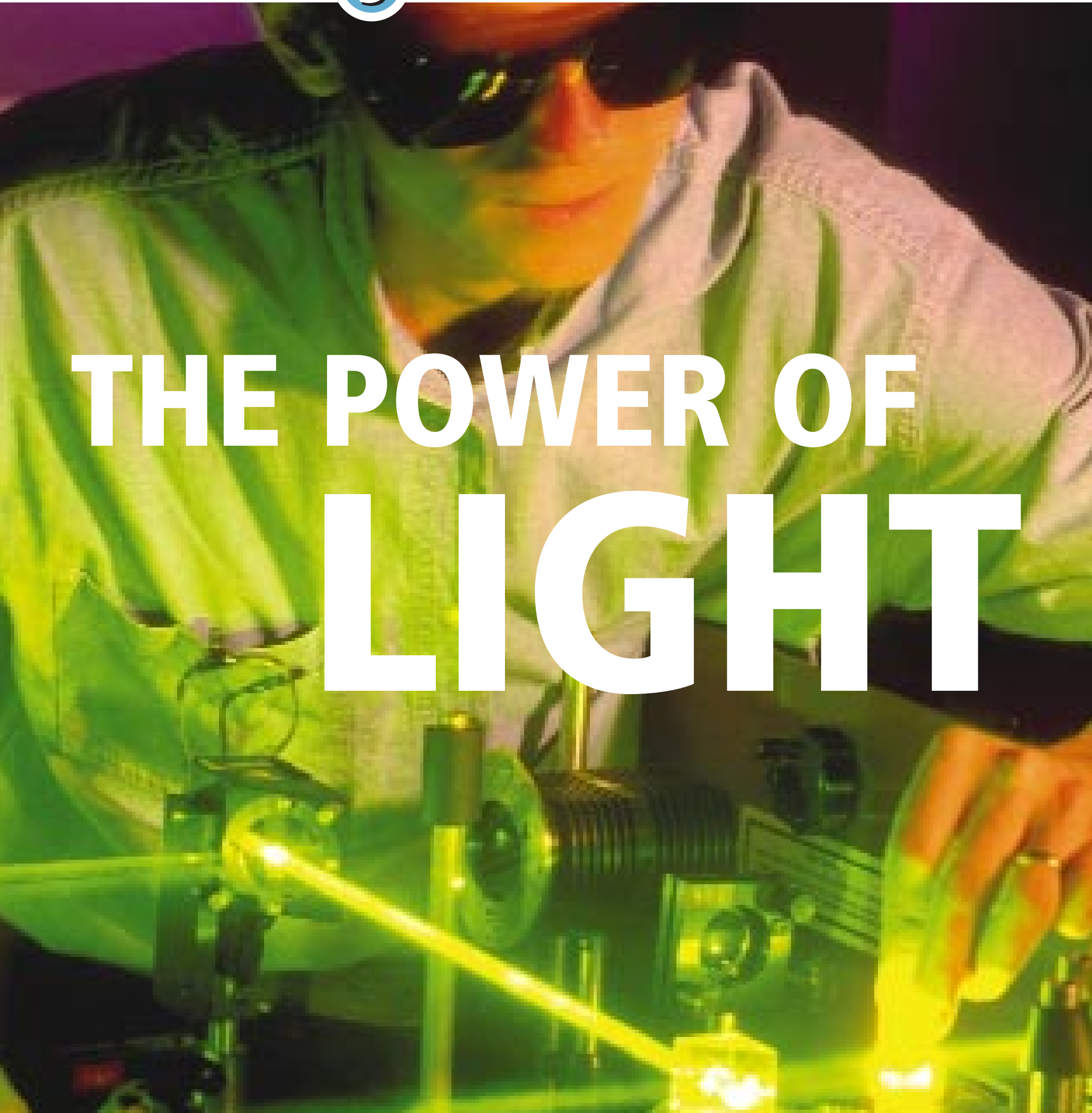
THE POWER OF LIGHT



School of Engineering and Applied Sciences

University at Buffalo *The State University of New York*

www.eng.buffalo.edu

Mark H. Karwan
Professor and Dean

I am pleased to share with you our third publication in a six-issue series explaining our school's research focus areas as they relate to our strategic objective of performing high-quality research while preparing future researchers for industrial, academic, and government positions.

In this issue, we focus on relatively new and exciting areas of photonics, microelectronics, and nanotechnology. Major areas addressed within these topics by our faculty include sensing, nanoparticle development, and microelectronic fabrication.

We've also included additional major items of great import to our school—outstanding educational programs for our students, data on our recent research funding success, and information about our just-concluded successful comprehensive campaign, which included a large software gift from EDS.

Clearly, our collective accomplishments are contributing to advances in applied science and technology.

Please enjoy this issue.

Igniting Ideas Series available at: www.eng.buffalo.edu/IgnitingIdeas

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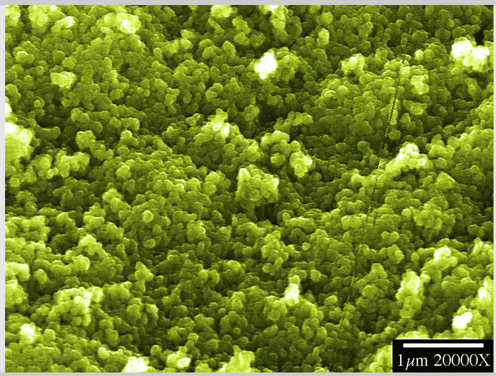
The Fuel Cell Challenge

Carl Lund, professor and chair of chemical engineering, and his research team are investigating ways to develop improved catalytic materials. In one current project, for example, they are examining the water-gas shift reaction for the production of hydrogen. This reaction is becoming critically important in the drive to develop fuel cells and move to a hydrogen economy, as called for by President Bush in his most recent State of the Union address. In the team's latest efforts, they have been examining the effect of adding copper to nanoparticles of iron oxide. They are also conducting a program in heterogeneous catalysis that explores the surface reactivity of nanoparticles of catalytic materials. The catalytic activity of many materials changes dramatically as the size is varied in the range of ca. 1 to 10 nm.

One of the central goals of Lund's work is to determine how the size, structure, and composition of nanoparticles affect their catalytic activity and selectivity. A closely related goal is to learn how they can control these same properties as they synthesize catalytic materials.

This work is supported in part by the National Science Foundation and the U.S. Department of Energy.



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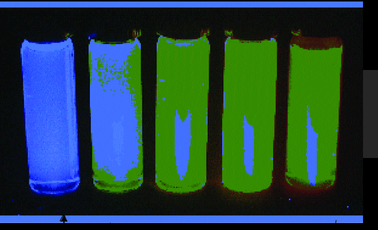
Shedding light ON NEW MATERIALS AND TECHNOLOGIES

ILPB is a central coalescing point at UB for laser, photonic, and biophotonic research



The UB Institute for Lasers, Photonics, and Biophotonics (ILPB) combines an outstanding group of engineering and science faculty with world-class facilities to perform research with a common focus on light. ILPB is dedicated to:

- Conducting R&D of new materials and technologies
- Providing education and industrial training for a skilled workforce (see piece on IGERT in this issue)
- Marketing a world-class facility for consulting and testing

At ILPB, faculty from engineering, chemistry, physics, biology, and medicine team up to address research opportunities in nanophotonics/nanoelectronics, spintronics/spin photonics, nonlinear optics, and biophotonics. Following are a few examples of cutting-edge research and accompanying results.

Combining the expertise of Albert Titus, assistant professor of electrical engineering, in analog VLSI design and Alexander Cartwright, associate professor of electrical engineering, in photonic devices with that of Frank V. Bright, UB Distinguished Professor and A. Conger Goodyear Chair, in understanding fundamentals of molecular-based chemistry has led to the successful development of a suite of small, low-power biosensor prototypes.

A novel approach by the three researchers brings together Bright's work in chemically responsive xerogels and Titus's work with smart pixel detector technology to produce complementary metal oxide semiconductor (CMOS)–based detectors and data processing circuitry on a single integrated circuit. Cartwright makes his contribution through the development of new, addressable LED structures for improved optical excitation methods. Their initial device can detect and quantify the concentration of gaseous and dissolved oxygen. This success is the beginning of what is expected to become widely used biochemical detectors that are portable (about the size of a small cell phone) and require very little power.

Cartwright is also conducting research with Paras Prasad, SUNY Distinguished Professor of chemistry, electrical engineering, medicine, and physics. Together they are developing binary and ternary semiconductor nanoparticles with tunable opto-electronic properties. The benefits of semiconductor lasers and detectors, and high-speed digital integrated circuits are derived from the unique physical properties of compound semiconductors. Low-dimensional compound semiconductors are even more interesting because of size-dependent magnetic, optical, and electrical properties with respect to charge confinement; therefore, this research area has become the focus of many investigations seeking to produce semiconductor quantum dots, nanoparticles with the lowest possible polydispersity. Colloidal chemistry is a promising route to produce compound semiconductor nanoparticles of nearly uniform size. Cartwright and Prasad have successfully developed a process for the synthesis of GaP and InP semiconductor nanoparticles. Examples of the resulting emission are shown in the figure above.

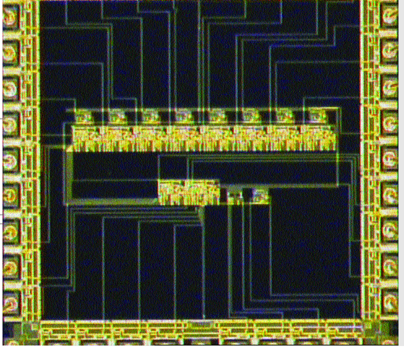
Funding sources for associated faculty include Corning, GE, Intel, Kodak, Motorola, Raytheon, Siemens, Xerox, the U.S. Air Force Office of Scientific Research, the U.S. Army Research Office, the Department of Energy, the National Aeronautics and Space Administration, the National Institutes of Health, the National Science Foundation, and the Office of Naval Research.

To date, the collective effort of ILPB faculty has:

- Attracted nearly $30 million in federal, state, and industrial support in the institute's short existence
- Won and implemented a National Science Foundation–Integrative Graduate Education Research Traineeship (IGERT) grant for Biophotonics: Materials and Applications
- Spun off three companies

More than 25 professors, many of whom are SEAS faculty, participate in the institute's research program. Paras N. Prasad, executive director, heads the institute. SEAS faculty members Alexander Cartwright, director of the lasers and photonics division, and Mark Swihart, deputy director of the materials division, assist in the institute's administration.

A Multidisciplinary Approach to Circuits



Albert Titus, assistant professor of electrical engineering, and the students in his Analog Very Large Scale Integration (AVLSI) Laboratory are involved in a range of research projects, the common theme of which is the design, analysis, fabrication, and testing of analog and mixed-signal silicon integrated circuits (ICs) for specialized signal processing and sensing.

Students have an opportunity to design ICs and test them using state-of-the-art data acquisition equipment in the lab. Because the ICs are part of a larger system, students must combine knowledge of CMOS circuit design with additional knowledge in sensing, visual processing, and neural networks—a truly multidisciplinary approach to the research.

One project focuses on AVLSI systems to perform neuromorphic processing. A unique approach implements an integrated artificial visual system formed from components that work together seamlessly. The entire system operates as a functional unit; however, it is designed as modular pieces, with each piece created individually, since the complexity of the visual system requires that it be modeled in manageable pieces. Ultimately, the visual system combines low-level processing functions performed by the retina and high-level functions, such as object recognition and classification.

Significant results to date include:

- Development of a silicon retina chip based on the octopus
- Development of a circuit for computing values for Kohonen Self-Organizing Maps on a chip
- Development of a method for determining depth using relative velocity information (on a chip)
- Demonstration of hierarchical classification that is possible using the analog outputs from an adaptive resonance theory (ART2) algorithm
- Development of an AVLSI approach for modeling rod and cone visual pathways to the brain

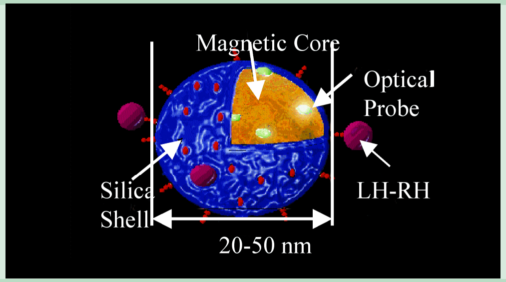
This research is funded in part by Titus's NSF Career Award.

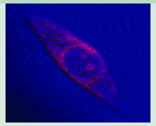
IGERT presents new learning opportunities

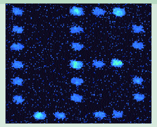
Alexander Cartwright, associate professor of electrical engineering and PI, is "Dr. Light" for student participants in UB's Integrative Graduate Education Research Traineeship (IGERT) grant for Biophotonics: Materials and Applications from the National Science Foundation.

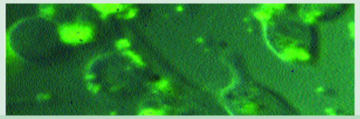
Midway through the grant's five-year duration, the multidisciplinary fellowship program, led by Cartwright with the active participation of an outstanding faculty, trains graduate students from engineering, chemistry, physics, biology, and medicine across the spectrum of such research topics as bio-inspired and hybrid materials, nanotechnology, bioimaging, diagnostics and therapeutics, biomaterials and spectroscopic characterization, biosensors, and device fabrication and characterization.

What makes these students special is not only the topics they study, but also the way in which they gain their knowledge and experience. All participating students take courses outside of their core disciplines and are co-advised by a professor not in their specific department. Thus, these students graduate with doctoral degrees comprising a fundamentally sound education, as well as multidisciplinary research skills to take on the biophotonics challenges of today and tomorrow.









Photos: From works of Prasad, Bergey, and Bright

Summer with UB's REU

The UB Research Experience for Undergraduates (REU) on Nanostructured Semiconductors, sponsored by the National Science Foundation, provides students with a summer of learning opportunities in this cutting-edge technology, including laboratory experience and professional ethics seminars under the tutelage of outstanding faculty. And when they're not in the classroom or lab, the students have some free time to participate in social activities and Western New York sightseeing.

The UB program is administered through the UB Institute of Lasers, Photonics, and Biophotonics and coordinated by Mark T. Swihart, assistant professor of chemical engineering.

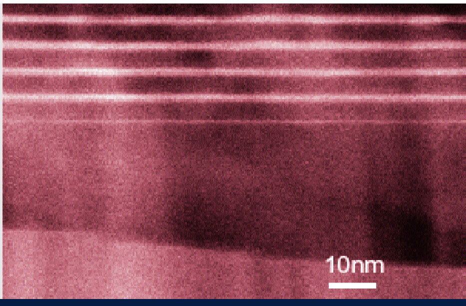
This year, students are from UB, SUNY/Binghamton, Carnegie Mellon, Harvard, MIT, Virginia Tech, Washington University, and Youngstown State.

Photonic Devices

Improving light-based electronic devices like lasers, light-emitting diodes (LEDs), photodetectors, and modulators is the goal of Alexander Cartwright, associate professor of electrical engineering.

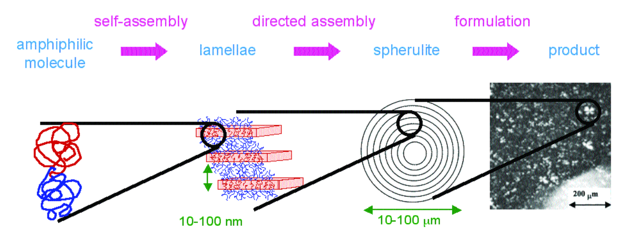
One of his research projects focuses on the development and improvement of optoelectronic devices from heterostructures of III-N (AlxGa1-xN, InxGa1-xN, GaN) wide bandgap semiconductor materials. Here, he and his team provide valuable experimental data, design criteria, and theoretical considerations for the design of devices for applications in such areas as display technology, printer technology, medical technology, high-density optical storage, and UV communications. This work focuses on the coupling of fundamental experimental research and theoretical research for the development of design criteria for lasers, photodetectors, and modulators from these III-N materials. The modeling, design, fabrication, and characterization process is iterative, allowing improvements to be incorporated at each new design phase.

In this work, the team has focused on the use of ultrafast laser systems (< 1 picosecond pulses) to study electron transport and recombination dynamics. Knowledge of these fundamental parameters makes possible the design of more efficient devices.



Nanoscale Organization via Self-Assembly

Paschalis Alexandridis, professor of chemical engineering, and his research team are working to capitalize on the ability of amphiphilic, dual-nature molecules to organize themselves into complex assemblies with structures from the nanoscale to the macroscale.



Self-assembly, an energy-efficient process that occurs spontaneously, can lead to products that are functional, responsive, and high value-added. All living creatures bear manifestations of self-assembly (e.g., cell membranes, collagen), and numerous technical processes take advantage of properties afforded by the self-assembly of surfactants, polymers, and/or colloidal particles. Properties imparted by self-assembly include compartmentalization, compatibilization, network formation, and surface modification.

The development of self-assembly as a useful approach to the synthesis and manufacturing of complex systems and materials is identified as a "Grand Challenge" for chemists and chemical engineers, according to the 2003 National Research Council report *Beyond the Molecular Frontier*. Alexandridis's research program—which has resulted in more than 100 publications and two patents over the past 10 years—is tackling this grand challenge.

Self-assembly takes place spontaneously when the "right" components are at the "right" conditions … but what are the "right" components and the "right" conditions? Alexandridis utilizes commercially available amphiphilic molecules and develops formulations with desirable structure-property relations that are tailored for specific applications—pharmaceutics and personal care products, where the ingredients allowed are tightly regulated, or coatings and inks, where environmental considerations restrict the kinds of solvents used.

What if the conditions change so they are no longer "right"? Alexandridis is investigating ways to arrest the self-assembled structure and determining the kinetics of structure formation and dissolution. This is relevant to the synthesis of nanomaterials, where the self-assembled structure serves as a template; however, the synthesis conditions and/or by-products disturb the self-assembly. It is also relevant to the shelf-life of products that incorporate self-assembled components.

How can we "help" self-assembly? Alexandridis explores external fields—both flow and electric—to orient self-assembled structures over macroscopic-length scales, and to collect and organize nanoparticles in a hierarchical manner. The combination of self- and directed assembly has great potential in such nanotechnology applications as sensing, actuation, and synthesis of nanocomposite and/or biomimetic materials.

Alexandridis's research is supported by the National Science Foundation and has also attracted funding from such major corporations as Dow Chemical, Bausch & Lomb, and Xerox. Local companies like FlexOvit USA and Quebecor World Buffalo have also utilized the expertise of Alexandridis's laboratory on issues of product quality and product design.

am·phi·phil·ic, adjective: of, relating to, or being a compound (as a surfactant) consisting of molecules having a polar water-soluble group attached to a water-insoluble hydrocarbon chain; also: being a molecule of such a compound

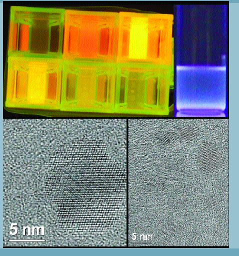
Next Issue: Computing and IT

Nanoparticles and the Future of Lighting

The lighting systems in use today—especially ordinary, everyday light bulbs—may not be as common in the future, if a team of chemical engineers led by Mark T. Swihart, assistant professor of chemical engineering, has its way. Today's incandescent light bulbs have good color and poor efficiency, while fluorescent tubes have better efficiency and poorer color. Take a break, light bulbs: Solid state lighting based on silicon nanoparticles, with potential applications in such devices as ceiling squares, promises to offer both better color and higher efficiency than traditional lighting systems.

These luminescent nanoparticles have exciting potential applications in bioimaging as well. In biomedicine, fluorescent organic dyes are currently used as diagnostic tools. The dyes go to sites of interest and serve as beacons to enable clinicians and technicians to make diagnoses. Unfortunately, even though the dyes bleach quickly and stop fluorescing after unreasonably short periods of time, this technology is the best we have. In contrast, Swihart and SEAS researchers envision replacing these organic dyes with semiconductor nanoparticles whose fluorescence is stable considerably longer.

Swihart's team is preparing silicon nanoparticles to emit light under varying controlled conditions. Changing particle size and preparing particles in different ways can manipulate particle electronic properties to produce different colors.



Silicon nanoparticles (less than 5 nm in diameter) with bright visible photoluminescence have been prepared by a new combined vapor-phase and solution-phase process, using only inexpensive commodity chemicals. The wavelength of maximum photoluminescence intensity can be controlled by controlling processing conditions and methods, over a range that includes the entire visible spectrum. The particle surfaces can even be treated with organic chemicals or polymers to control their chemistry. Using these approaches, stable dispersions of silicon nanoparticles have been prepared in both polar and nonpolar solvents. These surface treatments can also stabilize the photoluminescence spectrum. The functionalized nanoparticles can then be attached to surfaces, biomolecules, or other sites, or incorporated into conducting polymer matrices. Two areas where this technology is expected to have applications are lighting systems and bioimaging.

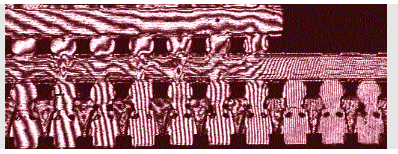
Swihart and his team interface with his colleagues in chemical and electrical engineering and the UB Institute for Lasers, Photonics, and Biophotonics to extend their technology to other systems and to pursue device fabrication. Aspects of this research are supported by the National Science Foundation, a company, and internal university funds.

Nanoscale Electronics Reliability Issues

Some of the world's most advanced research in electronic-packaging reliability is taking place in the Electronic Packaging Laboratory at UB (www.packaging.buffalo.edu).

Researchers are addressing critical board-level problems to make packages smaller and more reliable. They also are working to break industry-wide bottlenecks that are impeding development of revolutionary systems and products, such as lead-free packages, nanoscale computers, and implantable bio-electronic devices.

Cemal Basaran, lab director and associate professor of civil, structural, and environmental engineering, and lab codirector Alexander Cartwright, associate professor of electrical engineering, have developed a methodology for measuring the stress and strain on ball-grid array packages under near-exact operating conditions and with displacement resolution down to 27 nanometers. Moreover, they have developed a system for real-time, computer-simulated testing of electronic packages that makes expensive prototyping obsolete.



"With the model, we can design a complete system without doing more than one prototype," Basaran says. "This results in savings from development costs, product testing, and time to market—down from three years, to one to six months." The model also can be used to measure vibration damage on packages caused during shipping.

From this research, Basaran and Cartwright have recommendations on shape, placement, and bonding of ball-grid arrays that companies can implement. And they have recommendations for a ball arrangement that absorbs displacement of solder material due to stress and strain.

"When you shrink in size, the ways in which the laws of science manifest themselves change and you need new theories at the nanoscale," explains Cartwright. "The question we're working on is, How do you get smaller, cheaper, and more reliable bonds?"

The team's methods and results are generating interest throughout the electronics industry. Intel is currently using the research in the next-generation packaging for its Pentium processor; other groups include Micron, the U.S. Navy, the U.S. Department of Defense, the National Science Foundation, and New York State.

"Nanoelectronics is the future," Basaran says. "Once we have reliable packages at the nanoscale we can do many things."

Breakthroughs in Nanotechnology and Storage

The *Forbes/Wolfe Nanotech Report* heralded the work of Harsh Deep Chopra, associate professor of mechanical and aerospace engineering, and Susan Hua, director of UB's Bio-Micro-Electro-Mechanical-Systems Facility and research associate professor of mechanical and aerospace engineering, as one of the top five nanotechnology breakthroughs of 2002. In addition, *Industry Week* selected Chopra and Hua as one of the 21 top research and development teams of 2002.

A simpler and more reliable manufacturing method has allowed the two UB materials researchers to produce nanoscale magnetic sensors that could increase the storage capacity of hard disk drives by a factor of 1,000.

The new sensors are up to 100 times more sensitive than any current alternative technology, according to researchers Chopra and Hua.

The breakthrough could impact significantly the multibillion-dollar storage industry. The National Science Foundation (NSF) supports their work.

As reported in *Physical Review B*, Hua and Chopra's latest experiments with nanoscale sensors produce, at room temperature, unusually large electrical resistance changes in the presence of small magnetic fields.

"We first saw a large effect of over 3,000 percent resistance change in small magnetic fields," Chopra explains. "These latest results show that what we reported at the time was just the tip of the iceberg, pointing to beautiful science that remains to be discovered."

The largest signal they have seen is 33 times larger than the effect they reported earlier, which corresponds to a 100,000 percent change in resistance, the researchers say.

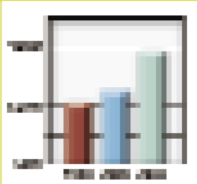
As stored "bits" of data get smaller, their magnetic fields get weaker, which makes individual bits harder to detect and "read." Packing more bits onto the surface of a disk, therefore, requires reliable sensors that are smaller, yet more sensitive to the bits' magnetic field.

Hua and Chopra's nanoscale sensors seem to be ideally suited to the task. The sensors produce much more distinct and reliable signals than current technologies do, which would enable the bit size to be dramatically reduced.

Chopra and Hua's sensors have another advantage over other experimental techniques: Because of the sensors' high sensitivity at room temperature, they could be adapted more easily to work with existing hard disk drive technologies used in the $25 billion data storage industry. Chopra predicts that their sensors would permit disk capacities on the order of terabits (trillions of bits) per square inch.

Research Growth

The School of Engineering and Applied Sciences is pleased with its faculty's research accomplishments, which have resulted in increasing research expenditures. Pictured are plots of expenditures from 1998, 2000, and 2002 as reported to ASEE.



In fiscal year 2001, the school was ranked sixth in the nation among engineering schools for receiving National Science Foundation Engineering Directorate funding. An $11 million grant from the NSF George E. Brown Jr. Network for Earthquake Engineering Simulation bolstered this standing. At the time, it was the largest single-facility grant ever made by the Engineering Directorate.

Generation to Generation Update

September 2003 marked the end of the university's comprehensive capital campaign, "Generation to Generation," and the school's participation in it.

The campaign was historic for the school in many ways. Important milestones included:

- **First-ever comprehensive campaign for the school**
- **First million-dollar gifts received by the school**
- **The school was the recipient of the university's largest gift ever**
- **First-ever use of faculty/staff solicitation to kick off the drive**

The school exceeded its goal of $18 million with receipts totaling $19 million. Then there was a surprise: At the end of the campaign, the school received a much-appreciated major software system gift from EDS valued at more than $50 million to push the total far above the set goal and put UB comfortably over the top for the university-wide goal.

We wish to acknowledge James McLernon (B.S. IE '51), campaign chair, and Charles Fogel and Howard Strauss, founding faculty, professors emeriti, and honorary campaign chairs, for their leadership and encouragement throughout the campaign. We also wish to acknowledge Dennis Malone, SUNY Distinguished Service Professor of electrical engineering, who chaired the faculty/staff portion of the campaign.

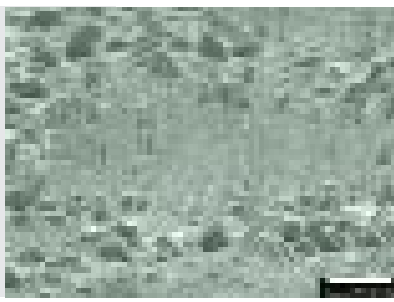
And our thanks go to the many generous donors for each of their contributions that helped make this first campaign such a resounding success.

Making Cheaper, Smaller, and Better-Performing Metal Films

Microelectronic fabrication is allowing Wayne Anderson, professor of electrical engineering, and his research team to improve performance as well as reduce size and cost of thin and thick metal films for electronic components and solar cells.

Anderson's team is involved in a diverse array of research projects. One resistor project helped a company develop a very thin metal film with near-zero change in resistance with temperature. The team's work on solar cells via improved amorphous silicon and nanocrystalline silicon thin films is geared toward a lower-cost product. Another project aimed at lower cost is the group's work of applying thin film transistors on glass and plastic for flat panel displays.

A new area of inquiry for the team is the fabrication of nanowires (shown below) and MEMS magnetic actuators, a natural outgrowth of their research showing the feasibility of connecting miniature devices via silicon—in some cases by a single crystal. Anderson is teaming with colleague and PI Robert Wetherhold, professor of mechanical and aerospace engineering, to fabricate magnetic thin films using sputtering; next, they will attempt multiple layers, and then devices.



The evident commercial application of Anderson's thin film capacitors and resistors research has resulted in patents and licensing of his designs.

Outside of his own lab, Anderson is also helping develop the next generation of scientists/engineers by coordinating—and for some students, mentoring—the university's NASA Space Grant program. In existence since the early 1990s and conducted in conjunction with Cornell University, the UB program has provided space-related laboratory experience for more than 50 students interested in this research.