

RESULTS

RESEARCH AND GRADUATE STUDIES AT NORTH CAROLINA STATE UNIVERSITY

BIG BUILDING PLANS FOR SMALL SCIENCE

The surge of nanotechnology research at NC State is resulting in rapid deployment of new laboratories, classrooms and offices to help researchers stay competitive in one of the most challenging and futuristic areas of modern science. The University has recently broken ground on two large buildings on its Centennial Campus, most of which will be devoted to nanotechnology. Both buildings are designed to house the specialized nanoscience instruments that allow manipulation of single atoms.



New building on Centennial Campus for Chemical Engineering and Materials Science Departments •

Partners Building III, an 80,000-square-foot facility expected to open in early 2005, will provide updated laboratories for nano physics, chemistry, and theory groups, including the planned Center for Nanotechnology Innovation, in the College of Physical and Mathematical Sciences. Sharing the building will be College of Agriculture and Life Sciences researchers in genomics and metabolic engineering. Under construction nearby, a new College of Engineering building will add 90,000 square feet of labs, offices and classrooms by the summer of 2004 to consolidate the chemical engineering and materials science departments, both major players on NC State's

nanotechnology team. The new buildings will add to a growing cluster of facilities on Centennial Campus devoted to advanced materials research and education, including the College of Textiles complex, the Materials Research Center, and the Engineering Graduate Research Center complex, which houses several university-industry-government materials-related research centers.

The programs moving to the two new buildings were first in line not only because of their need for more technology-capable space, but also because of the large amount of grant funding they attract. Partners Building III is being built with borrowed funds to be repaid partially with indirect cost receipts (also known as facilities and administrative funds) from research grants.

In addition to the two new academic and research buildings, construction is proceeding on a new energy plant to provide steam and chilled water to more efficiently heat and cool these and other new buildings on Centennial Campus. Funds for the engineering building and energy plant were made possible by North Carolina voters, who passed a \$3.1 billion higher education construction bond referendum in 2000. ■

Partners Building III will house the Center for Nanotechnology Innovation. •



N A N O T E C H N O L O G Y



RESEARCH ADMINISTRATION

GILLIGAN TAKES RESEARCH HELM

When Dr. John Gilligan became vice chancellor for research and graduate studies, he knew he had his work cut out for him. The growing recession was making the state's budget crisis worse, and NC State research gains seemed at risk. RESULTS asked Gilligan to comment after six months in the vice chancellorship.

R: Dr. Gilligan, are you having any fun yet?

Gilligan: Absolutely. These past six months, I've discovered so many exciting things happening on campus. Major boosts in faculty and facilities strength over the past several years in computer networking, genomics, bioinformatics, advanced materials, and environmental technologies have positioned us well for the next big things—wireless communications, proteomics, nanotechnology, and biomedical engineering—not to mention new technologies for homeland security. You can see the impact in every area, from agriculture and computer technology, to human health and space flight.

R: Any surprises so far?

Gilligan: Not too many. After 20 years on the faculty at NC State and six years as associate dean for research in the College of Engineering, I know it's always been a tough world out there for universities where money is concerned. This year is particularly tough, but I'm gratified that the state cuts were not as bad as we feared. So far, we've been able to cooperate with the State so the cuts don't throw us into a downward spiral. Investment in new ideas has a multiplier effect on the future of not only the higher education system, but also economic development. Fortunately, our legislators understood that.

R: How did the legislature's actions help?

Gilligan: For this year, at least, we've been allowed to keep the facilities and administrative [F&A] portion of our grant funds so we can leverage other support for new research programs and reinvest in new facilities and equipment. Likewise, support for enrollment increases and graduate research assistant tuition were left intact. We're not out of the woods yet, but these three things are the real seed corn for the academic research enterprise. Support for research enhances our educational programs for the future, and in fact, at the graduate level, research *is* education. If we grind the seed corn, what will we harvest in the years to come?

R: What are your major goals as vice chancellor?

Gilligan: First, I want to dramatically increase federal research funding to enable us to attack more complex problems and to support more graduate students. And second, I want to make it as easy as possible for faculty and students to do basic discovery without undue administrative burden.

"AT THE GRADUATE LEVEL, RESEARCH IS EDUCATION."

R: How will you go about increasing federal funding?

Gilligan: We already see gradual increases each year. But in order to have a dramatic increase, we need to go after more of the big opportunities in our areas of strength. Nanotechnology is a good example. There are hundreds of millions of federal dollars available, and we're so good in chemistry, physics, biomaterials, chemical engineering, textiles, and electronic materials, that nanotechnology is a natural for us. We need to initiate working groups in each our major multidisciplinary thrust areas to further increase interactions among faculty and develop ideas for new research centers that showcase our strengths in bigger ways.

R: How can you facilitate the discovery process?

Gilligan: A big potential hassle for our laboratory researchers is the increasingly restrictive federal regulatory climate we are facing as part of the fallout from the War on Terrorism. Congress is attaching more strings to funding, requiring more extensive reporting on who's using what in our labs, and restricting opportunities for graduate students who are not U.S. citizens. Our staff is taking a systems approach to reducing the regulatory compliance load on our researchers, including interpreting the regulations and communicating with faculty, developing software solutions and centralized reporting support, and making sure our international students are treated fairly. That's just one example.

R: You've been a big supporter of graduate education. Why is supporting more graduate students so important?

Gilligan: A research university has a special mission to train the brightest people we have for leadership positions, whether it's in technology, industry, politics, education, or any other field. Our graduate students are not only laboratory assistants. They are also innovators, collaborators, and teachers while they are here. Our success is measured in the number and quality of graduate students who fulfill their goals and advance their fields. This is the way our country builds and sustains its intellectual strength. ■

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CHEMICAL ENGINEERING STAYING AHEAD OF THE OSTEOPOROSIS CURVE



Dr. Richard Spontak advises graduate student Elizabeth Wilder •



Spontak's discovery was the November cover story in *Advanced Materials* •

Could osteoporosis be reversed by using a biocomposite material as a framework for bone tissue regeneration? Discoveries made recently through quantitative 3-D supramolecular imaging, a tool adapted by NC State's Dr. Richard J. Spontak, make it a very real possibility.

Spontak, a professor of chemical engineering as well as materials science and engineering, announced the imaging technique early last year

as a method to create three-dimensional images for scientific visualization, study, and measurement of nanostructured polymers at the nanometer level. Recently, he and his collaborators used the technique to identify quantitative similarities between synthetic polymers and bone tissue.

To reveal these similarities, Spontak and an international, multidisciplinary research team used quantitative 3-D imaging techniques to compare the structural patterns of two kinds of polymer systems with samples of trabecular bone—the porous bone found in the spine and articulating joints. The investigators focused on the unique characteristics shared by these manufactured and naturally-occurring “bicontinuous morphologies”—described as asymmetrical, irregularly channeled spatial structures resembling the inside of a sponge. What intrigued Spontak and his colleagues was the discovery that structural characteristics of sponge-like synthetic polymers and trabecular bone are strikingly similar, despite substantial differences in origin and scale.

“With this knowledge, we can start to think of designing the polymer equivalent of bone at nanoscale dimensions,” Spontak said. “The polymer could be used to initiate finer, but similar structure off existing bone. Because the polymer is more highly interconnected at smaller scales and could serve as a template for stronger structural materials, it could help

people who need bone grafts, as well as people who suffer from osteoporosis.”

The understanding of the nanoscale molecular structure that led to this discovery is related directly to the development of quantitative 3-D imaging methods. When the method was announced, it was valued primarily as a tool for research scientists, and its potential for application was not fully realized. Scientists no longer had to rely on mathematical models that only approximate the potentially complex nature of nanostructured polymers. With 3-D imaging, investigators are able to “see” inside and quantify these nanostructures for the first time, much as an MRI allows physicians to see inside their patients in three-dimensions. This makes the technique ideally suited for studying the design or “evolution” of nanostructures, as well as defect formation.

“Learning more about the structure, connectivity, and material properties of nanostructured polymers is important,” Spontak said, “but the possibility of extending that knowledge to other systems in ways not apparent at the time of discovery is truly exciting.” This imaging technique and the accompanying methods of analysis allow in-depth study of any nanostructured polymer at length scales greater than about one nanometer (or about one thousandth of the width of a human hair). They also provide a direct approach for developing relationships between structure and properties of interest in commercial applications.

“All research knowledge is valuable,” Spontak says, “even if it can't be used immediately. I'm confident that people will come to appreciate the utility and potential of this technique more and more, especially in light of the growing importance of nanotechnology in today's society.” ■

COULD OSTEOPOROSIS BE REVERSED
BY USING A BIOCOMPOSITE MATERIAL
AS A FRAMEWORK FOR BONE
TISSUE REGENERATION?



NANOTRIBOLOGY

A PREDICTION OF FRICTION

As engineers, chemists and physicists race to design the nanomachines predicted to revolutionize everything from manufacturing to health care, other scientists are worrying about the friction—not to mention adhesion, indentation, dissipation, corrosion, and even downright self-destruction.

Dr. Jacqueline Krim, an NC State professor of physics in the College of Physical and Mathematical Sciences, is one of a new breed of scientists called *nanotribologists* who know that friction at the nanoscale is no small matter. Recent progress in nanotribology has demonstrated that the laws of macroscale friction simply don't apply to atomic scale devices, and that the problems friction can generate are overwhelming in machine components with such astoundingly small dimensions.

“The technology has crashed head-on with fundamental physics and chemistry,” says Krim. “At the atomic scale, friction has very little to do with surface roughness. Some dry surfaces slide against each other easier than wet ones. And contrary to what we know about industrial scale machines, gravity (related to volume or weight) is a negligible contributor to friction when opposing objects are only a few atoms or molecules thick.”

Nanotribology [from the Greek *tribo*, to rub] is such a new science that Krim herself coined the term in 1986 while working at Northeastern University. A number of textbooks mention her pioneering work. She works today in the Nanoscale Tribology Laboratory on NC State's Centennial Campus with six graduate research assistants and two post-doctoral associates. With annual funding from the National Science Foundation, the Department of Energy, and the U.S. Air Force in the half-million-dollar range, she runs one of the world's top research groups studying the fundamental origins of friction.

Krim's goal is to develop a lubricant that can be used at extreme temperatures without vaporizing or freezing, reducing both heat generation and wear. Either heat or wear could inflict mortal wounds on nanomachines, where melting or shearing off a surface layer of atoms could render a device useless.

To meet their research goal, Krim's group must first understand *why* a lubricant lubricates a particular surface. Their most recent discovery, now awaiting publication, occurred on a project sponsored by the Air Force. Researchers at Wright Patterson Air Force Base were searching for jet engine materials and lubricants that could withstand higher temperature stress, reducing the need for heavy, energy-guzzling engine cooling systems.

In response, Krim set out to compare how fast the lubricant particles begin to bind or stick to the materials they are supposed to lubricate. She was

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www.physics.ncsu.edu:8380/nanotribology/

astonished by the discovery that a difference in how the lubricant's molecules flexed and slipped *after* they stuck was what made the difference in effectiveness. "Nothing is totally flat at the molecular scale, and microscopic irregularities of surfaces touch and push into one another as materials slide. If the lubricant begins to stick to one surface, but the molecular bonds have just the most miniscule amount of flex, sometimes that's all that's needed to slide the contact points of the two surfaces past each other." (See illustration below.) Using a quartz microbalance, she and her students observed that in this case, only a picosecond of slip—one millionth of a millionth of a second—was the critical factor.

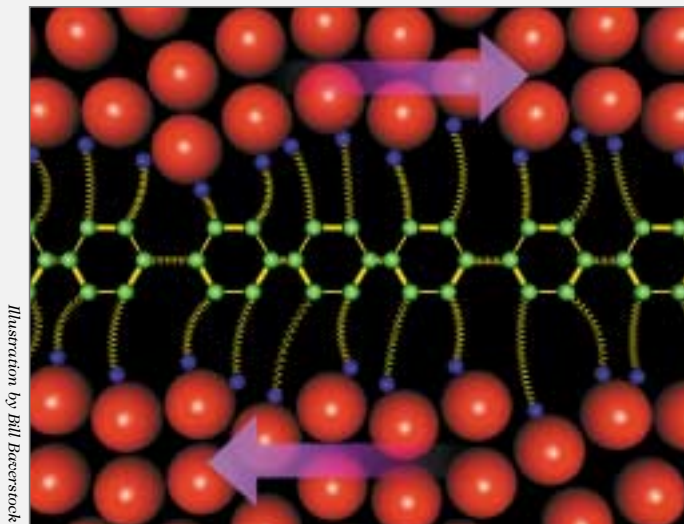
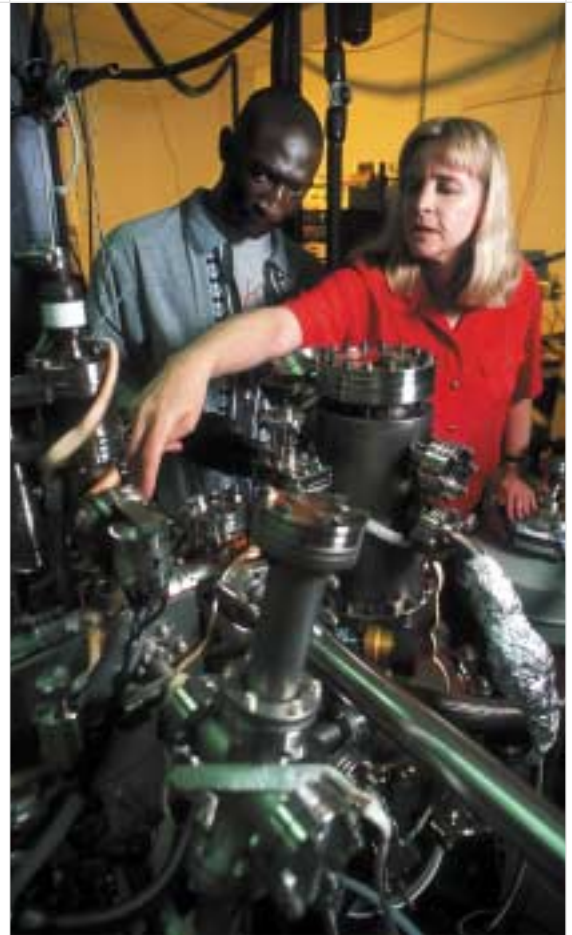


Illustration by Bill Beversstock

As surfaces (red) slide past each other, the lubricant's molecular bonds (yellow) flex, accommodating surface roughness. ●

Armed with this unforeseen result, Krim is advising Air Force researchers about possible parameters for design of new lubricants and materials that allow the flexible bonding. "It can save the Air Force both time and money to have this experiment done at a university," she says. "An even greater advantage to them may be that now any of my graduate students could step into a job in the Wright Patterson research lab fully trained to work on this problem."



Grad students Robert Trubie (above left) and Cherno Jaye (above) assist Dr. Jackie Krim in lab. ●

Krim says her discovery will be just as important for nanomachines as for jet engine parts. "Scientists working on nanoscale devices must understand friction at the atomic scale or their devices won't survive the heat they generate." For now, she's one of perhaps a hundred nanotribologists in the world. But she predicts that as the need to conserve both energy and raw materials becomes more urgent, nanotechnologists' rush to understand basic frictional processes can be expected only to accelerate. ■

EITHER HEAT OR WEAR COULD INFLICT MORTAL WOUNDS ON NANOMACHINES, WHERE MELTING OR SHEARING OFF A SURFACE LAYER OF ATOMS COULD RENDER A DEVICE USELESS.



PARTNERSHIP

TAPPING NATION'S TOP NANOSCIENCE RESOURCES

The power of the world's fastest supercomputers and most intense neutron beam will soon be added to NC State's nanoscience equipment list. Both are being built at Oak Ridge National Laboratory (ORNL) in Tennessee, a U. S. Department of Energy (DOE) laboratory now managed in part by NC State.

In April 1, 2000, seven universities and the Battelle Memorial Institute were selected by DOE to manage and operate ORNL, where a 300-million-dollar modernization program will add a dozen new buildings over the next five years. Among them are the Spallation Neutron Source—the nation's biggest science project ever—the Center for Nanophase Materials Sciences, and the Center for Computational Sciences with its ten-teraflop supercomputer, nicknamed "Cheetah."

ORNL is a multipurpose research laboratory with 4,500 employees and a research budget of about \$700 million per year. It began as a Manhattan Project lab during World War II, and had the world's first nuclear reactor. Today, ORNL is DOE's largest multipurpose energy science laboratory, and the national leader in neutron science, materials research, and high-performance computing.

ORNL director Dr. Bill Madia is especially proud of the lab's pioneering work in nanoscience, declaring: "Nanoscience is the heart of rock and roll if you're a scientist." Madia is eagerly anticipating the 2006 completion of the Spallation Neutron Source (SNS), now under construction at a cost of \$1.4 billion. The SNS will generate the world's most intense pulsed beam of neutrons, with concentrations at least ten times greater than at any other facility in the world. Scientists use neutron beams to see how atoms are structured in nano- and bio-materials.

The "new" ORNL plans to make interactions with universities its highest priority, including: joint university/ORNL faculty positions, joint seminars and workshops, joint research proposals, summer programs

for students and faculty, and joint think tanks. ORNL is looking to team up with more university experimental programs to complement its analytical programs.



ORNL's "Cheetah" super computer -
Photo courtesy of ORNL. Reevce •

In fact, both ORNL and NC State believe that the partnership will make it easier to attract prominent scientists from other prestigious research institutions. They are betting that offering the best of both university and national laboratory world will be a draw in certain cases. Joint research institutes have already been suggested in areas of strength such as advanced materials and nanoscale science, advanced computational science, complex biological systems, proteomics and structural biology, neutron science, bioinformatics, genomics, environmental science and technology, and homeland security.

NC State's chancellor, vice chancellor for research, and several research faculty serve on key steering and review committees at all levels at ORNL. Dr. Ray Fornes, associate dean for research in the College of Physical and Mathematical Sciences, acts as a direct liaison with ORNL's deputy director for science and technology, facilitating new research relationships between faculty and ORNL scientists. "Our faculty now have easy access to the expertise of Oak Ridge's world-class scientists, which is so important in this highly technical arena," Fornes points out. "Together, we can be a powerhouse of nanoscience capability for research funded through the National Nanotechnology Initiative."

Beyond all that, it is difficult to even try to estimate the value of ORNL's resources as a training ground for graduate students and post-doctoral research associates. "It can be pretty irresistible to young scientists," says Fornes, "to learn they might be able to do their dissertation research at a national laboratory of this caliber." ■

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MATERIALS SCIENCE

ORNL MICROSCOPES LEND FOCUS TO SEMICONDUCTOR SOLUTION

While the supercomputer beckons to other faculty at NC State, it is ORNL's powerful microscopes that appeal to Dr. Gerd Duscher, an assistant professor of materials science and engineering at NC State.

Duscher was the first to sign up for a joint faculty appointment with ORNL, and now splits his time between teaching and research in NC State's materials science department and ORNL's Solid State Division. "Oak Ridge has two of the three highest resolution microscopes in the world," says Duscher. "We can look directly at interfaces between atoms."

Employing a technique called "z-contrast imaging," Duscher and graduate student Sergei Lopatin are using ORNL's scanning tunneling electron microscope (STEM) and electron energy loss spectroscopy (EELS) to look at the atomic interfaces between materials. The research centers on determining how two different materials order themselves and bond when they come together. The goal

is to maximize conductivity, generating the least heat and greatest speed.

Duscher was the first to use the STEM-EELS combination to simulate and interpret chemical bonding. He hopes to eliminate experimental trial and error by understanding the principles behind bonding and electronic states at these interfaces. With this understanding, scientists could develop new materials and understand old ones better, with the ultimate benefit of making semiconductors faster, cheaper and with higher power. ■

"JUST THINK, SAYS DUSCHER. "IF CELL PHONES HAD THE POWER TO CONNECT WITH SATELLITES INSTEAD OF TOWERS, THERE WOULD BE NO ROAMING, AND WE COULD ALL STOP ASKING 'CAN YOU HEAR ME NOW?'"

PHYSICS

BERNHOLC A MAJOR PLAYER AT ORNL

Drexel Professor of Physics Dr. Jerzy Bernholc is one of the largest users of supercomputing time in the U.S. He travels from Raleigh two or three days a month to Oak Ridge, Tennessee, as a "visiting distinguished scientist" within the ORNL Computational Science Directorate. He consults with ORNL management, helps write collaborative proposals, uses the supercomputer for his own research, and serves on the advisory committee for ORNL's new Center for Nanophase Materials Sciences.

The new center—now on a construction fast-track—will be a user facility for ORNL's universities partners and visiting distinguished scientists. When completed this year, the 80,000-square-foot facility will have nanofabrication systems for synthesis of materials in ways that previously were not available anywhere—let alone affordable for NC State.

Working at the Center, Bernholc will use ORNL's new supercomputer for simulations investigating novel nanoscale materials for nano-electronics and sensors, magnetic memory, super strong materials, and nanoscale switches. He uses simulations to understand the properties of materials before they are built or to explain experimental results. Bernholc is world renowned for his 1999 publication in the journal *Physics Today*, in which he described how the properties of new and artificially structured materials could be predicted and explained entirely by computations, using atomic numbers as the only input.

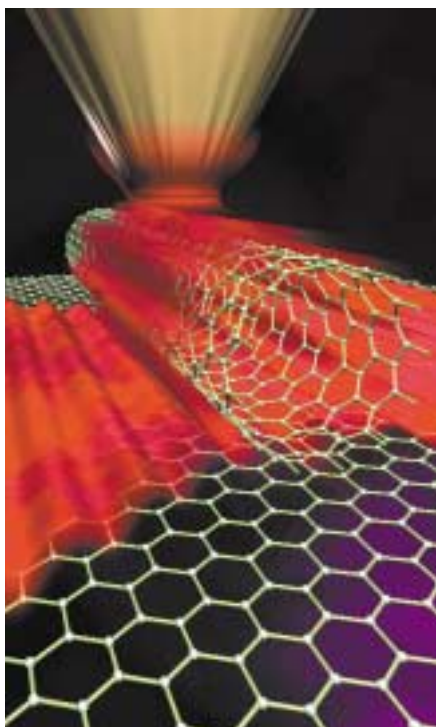
Born in Poland, Bernholc has been on the faculty at NC State for 16 years, and is the founding director of NC State's newly forming Center for High Performance Simulations. ■



Dr. Jerzy Bernholc •

PHYSICS

DUDE, YOU'RE GETTING TEN TERAFLOPS!



Computer simulation of nano-rheostat made by rotating a carbon nanotube on a sheet of graphite •

nemo.physics.ncsu.edu/~nardelli/

Dr. Marco Buongiorno-Nardelli leans over his computer in Cox Hall, scanning the results flashing across the screen from a state away. He's exploring the feasibility of using carbon nanotubes in nanoscale electronic devices, and is using the Oak Ridge supercomputer to run his own suite of codes simulating electron transport in nanotubes. Although carbon nanotubes are very small objects on the human scale, simulation of their behavior is possible only on a very large-capacity supercomputer.

The biggest supercomputer in the Research Triangle area, located at MCNC, has one-teraflop capacity, handling one trillion floating point calculations per second. But the reigning supercomputer at ORNL is an IBM Power 4, nicknamed "Cheetah," which has six teraflops of computing power. ORNL has recently acquired a test Cray X1 system, which could be expanded and made even faster in the next few years, bringing ORNL's capacity to ten teraflops—Christmas for a certain young theoretical physicist.

Buongiorno-Nardelli came to the U.S. from Italy as a post-doc in 1995. He became an assistant professor in the College of Physical and Mathematical Sciences at NC State in 2001, having already begun his interaction with ORNL the year before. He now holds one of the two new positions shared between NC State and ORNL.

With a young family, Buongiorno-Nardelli was concerned about working for organizations in two different states. But a new high-speed fiber-optic link 10,000 times faster than today's fastest networks has been set up to connect ORNL, the "Atlanta gigapop," and the Research Triangle. "Now, there is no difference between my sitting in a control room in Oak Ridge and my lab in Raleigh," says Buongiorno-Nardelli. He splits his time by teaching one semester at NC State, then spending a week a month at Oak Ridge in the following semester, and more time there in summer. "There is no substitute for the face-to-face interaction with the scientists at Oak Ridge," he maintains, "so I visit as often as I can."

Using the ORNL supercomputer, Buongiorno-Nardelli predicted that it would be possible to build a nano-rheostat, similar to a dimmer light switch. In such a device, a carbon nanotube—a cylinder resembling rolled-up chicken wire because its carbon atoms are arranged in a hexagonal configuration—is placed on a sheet of graphite whose carbon atoms also have a hexagonal arrangement (see illustration on top left).

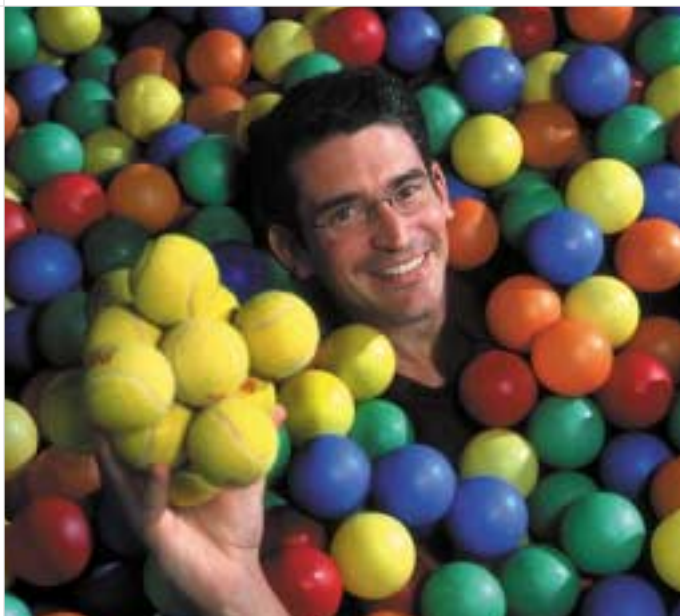
Computational simulations verified that the interface between a carbon nanotube and graphite gives tunable resistance. "If you place the carbon cylinder on the graphite sheet so that the carbon atoms of both are aligned, a current will flow at the interface," Buongiorno-Nardelli says. "As you rotate the carbon cylinder on the graphite sheet, changing the angle between the atoms in the system, you get increased electrical resistance and reduced current flow. As the atoms become aligned, you get low resistance and high current flow." His theoretical predictions agreed with experimental results at the University of North Carolina at Chapel Hill, and were published in *Science* magazine in 2000.

Buongiorno-Nardelli and his NC State colleagues are also computationally modeling a proposed molecular memory cell that would allow laptop computer batteries to last 100 times longer than today's batteries. "We're not actually making things," explains Buongiorno-Nardelli. "We're simulating nanoscopic pieces for experimentalists to use in fabricating devices. This is such a great opportunity to be a part of the interplay between theory and experiment." ■



Dr. Marco Buongiorno-Nardelli •

"THE PREDICTION SIDE IS MORE EXCITING TO ME THAN THE EXPLANATION SIDE," SAYS BUONGIORNO-NARDELLI. "IT'S MORE FUN TO PREDICT SOMETHING AND SEE IF IT WORKS."



CHEMISTRY

FROM MOLECULAR MYSTERY TO MASTERPIECE

"Here's the mystery," ruminates associate professor of chemistry Dr. James D. Martin. "What's the structure of something that's not supposed to have structure?"

Liquids and glass have long been understood by scientists to be amorphous, meaning without structure. Basic chemistry textbooks frequently present cartoon representations showing liquids to be much like gases—a collection of randomly moving atoms or molecules. But Martin has discovered a few things about the nature of liquids and glasses at the atomic and molecular levels that suggest the need to revise many of those books. Martin's breakthrough, featured in a September 2002 issue of the journal *Nature*, could lead to the development of totally new materials with valuable optical and electronic properties for computing and communications technologies, where the ability to direct movement of light and/or current through matter is critical.

WHAT'S THE STRUCTURE OF SOMETHING THAT'S NOT SUPPOSED TO HAVE STRUCTURE?

Like many discoveries, Martin's was an unforeseen result of other basic research. Several years ago, he noticed that as he designed and synthesized crystals, he also produced a lot of liquid and glassy blobs. He originally dismissed the blobs as trash, but became curious about them because they appeared so frequently. His curiosity led him into the study of the molecular structure of liquids and glasses, an area not well understood by science.

Did the blobs have a common structure? An analogy occurred to him one day as he watched his children "swim" through big playpens filled with plastic balls. "No matter how kids moved around in the playpen, the balls always touched each other in about the same way," Martin says.

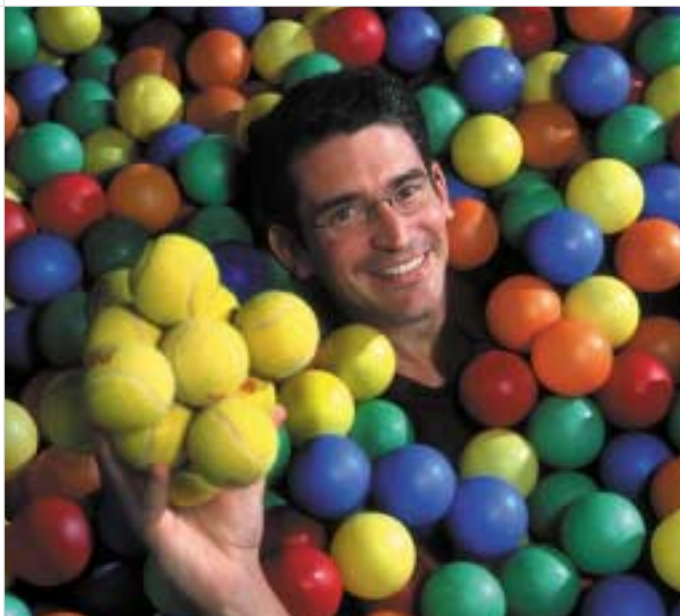
"And the arrangement of the balls looked very much like my tennis ball models of the molecules in crystals."

Martin deduced that if similar bonding interactions hold molecules in liquids, glasses and crystals, then it should be possible to engineer the structure in liquids and glasses just as it's possible to engineer the structure of crystals. And he was right. "If you understand the network's structure and the chemical bonds within the structure, you can manipulate the structure," he explains. "And if you change the structure, you change the properties."

In the lab, Martin and graduate student Steve Goettler have proven this by introducing molecules of a different substance into glasses and liquids, thereby changing the original properties. The foreign molecules were engineered at the atomic level to fit within the liquid's structure and interact with the liquid's own molecules. The presence of these foreign molecules changes the liquid's characteristics, such as the melting point, viscosity, and manner in which light travels through the material. Control of these properties is important in mechanical applications such as lubrication and liquid crystal displays.

"Just as a symphony is much more than a collection of random notes," says Martin, "the atoms and molecules in a liquid are quite organized—more like those in a crystal than a gas." With this new understanding of the structural organization in amorphous materials comes the ability to engineer specific atomic and molecular arrangements. In essence, Martin and his colleagues have discovered chemical principles that allow them to "write new symphonic masterpieces" opening a new area of scientific research—amorphous materials engineering. ■

LIKE MANY DISCOVERIES, MARTIN'S WAS AN UNFORESEEN RESULT OF OTHER BASIC RESEARCH.



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SPIN-OFF GEARS UP TO START PRODUCTION



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Dr. Kevin Linthicum •

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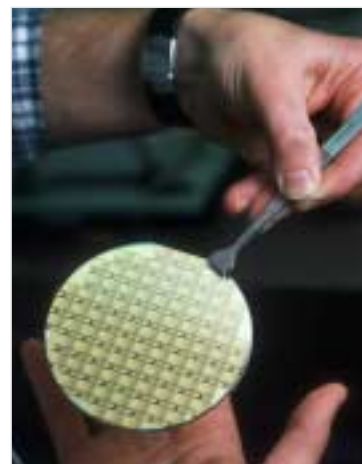
An idea hatched in an NC State lab is enabling Raleigh's Nitronex Corporation to become a worldwide leader in the development of gallium nitride semiconductors, expected to become the basis for the next generation of mobile wireless technology. In anticipation of expanding production, Nitronex is preparing a new 69,000-square-foot facility in Research Triangle Park. It's part of a stunning growth spurt for the four-year-old university spin-off.

Founded in 1999 by four NC State graduate students, Nitronex now boasts 60 employees. It was the first company to graduate from the business incubator on NC State's Centennial Campus, and secured its initial \$530,000 investment from the university's venture capital fund. Since then, Nitronex has raised over \$34 million in venture capital.

Nitronex's competitive advantage lies in its ability to use standard silicon wafers as a substrate for gallium nitride crystal growth. In tandem with related materials, gallium nitride is used to fabricate high-powered, high voltage, and extremely efficient semiconductors with greater wireless bandwidth. The company and its investors are betting that it will soon become a fundamental building block of the cellular phone industry.

"Poor performance of silicon transistors in existing base stations is the biggest limitation to power and microwave performance, and gallium nitride is much more capable than the current technologies based on silicon or gallium arsenide," says Kevin Linthicum, chief technology officer. "The next wave of wireless communications devices will require gallium nitride because of its power, linearity, efficiency and associated cost savings." He predicts that when gallium nitride is brought to the billion-dollar wireless base station market, it could supplant the current silicon-based technology altogether.

Linthicum and his three co-founders, Mark Johnson, Warren Weeks and Thomas Gehrke, met in graduate school. All were research assistants working in the laboratories of Dr. Bob Davis, Kobe Steel Distinguished University Professor of Materials Science, and Dr. Jan Schetzina, professor and director of NC State's Solid State Physics Laboratory. Davis had already found that a lateral epitaxial overgrowth (LEO) process could reduce defects in gallium nitride. "But it was the students who 'turned the problem upside down' and came up with an idea to eliminate part of the LEO process and the resulting defects in the semiconductor that slow electrons," Davis remembers. "Those were exciting days in my lab after that 'aha' moment. They were beginning to realize they had the potential to eliminate a whole host of problems for the industry."



Gallium nitride semiconductors on silicon wafer •

Linthicum says the team is still strong, but the challenges they face now are much tougher. "When you have a fast growing company like this, you have to think about not just materials, but market niches, new products, timing, economics, and employee personalities." The exact timing of Nitronex' move to its new site in Research Triangle Park isn't set, but Linthicum anticipates moving all operations as soon as the company reaches its capacity at its Raleigh facility. The company is preparing for a third round of venture capital, with eventual expectations of an IPO. "To grow at the rate we need to grow, we're going to need some pretty large capital infusions over the next few years," says Linthicum. "Rivals are coming on strong, but I believe we have the drive, focus, investor backing, and the team talent needed to bring gallium nitride to the wireless market first." ■

"THOSE WERE EXCITING DAYS IN MY LAB AFTER THAT 'AHA' MOMENT."

— DR. BOB DAVIS

BIOMEDICAL ENGINEERING NANOTECH KEY TO BIOMED ENGINEERING INITIATIVE



Dr. Troy Nagle (l.) with electronic nose sensor array testbed; artificial retina chip (below) •



In an innovative move to link world class engineering, life science, and medical schools, NC State and the University of North Carolina at Chapel Hill (UNC-CH) are laying the groundwork for a single joint department in biomedical engineering, merging existing departments on each of the two campuses. This first-ever shared department within the UNC System will combine existing education programs in biomedical science with engineering from nano to macro scales.



Research associate Jason Fiering develops flexible biosensors for study of heart disease in Biomedical Microsensors Lab •

The department will serve as an interface between medical applications and the new technologies emerging in basic scientific and engineering fields. "Nanotechnology is a key area for future emphasis in biomedical engineering research, and will be an important part of our academic curricula," says Dr. Troy Nagle, interim head of the existing department at NC State. "In the next few years, all of our biomedical engineering students will need to understand the fundamentals of nanotechnology as advances in electronics, optics, materials, and miniaturization accelerate development of more sophisticated devices for diagnosis and therapy."

"Cooperation between the major research universities can leverage scarce resources and avoid duplication of efforts," says Nagle, who holds doctorates in both medicine and engineering. "But more importantly, it will allow our students to take advantage of active research and education accomplishments on both campuses, and to benefit from faculty collaborations involving

instrumentation for diagnosis, therapy, rehabilitation, and cell and tissue engineering."

Nagle explains that nanotechnology is changing the way we design and build medical devices. Just as nanotechnology is being used to make biosensors more specific, sensitive, and reliable, it is also improving the durability and biocompatibility of artificial joints and other orthopedic implants. New nanoscale structures will precisely control the time release of pharmaceuticals, and biomedical engineers are exploiting nanotechnology to interface electronic devices to living cells. Researchers are even inserting nanoscale sensors and actuators into living cells to monitor and control their behavior.



Artificial knee implant (l.); presurgical practice models of dog legs (r.) •

"Our goal is to develop nationally recognized research and academic programs that will support the growing biomedical industry in North Carolina and the nation," says Nagle. The U.S. medical technology industry boasts 6,000 companies, \$78 billion in production, \$17 billion in exports, and a \$7 billion trade surplus. The Bureau of Labor Statistics predicts that the 300,000 U.S. jobs in the industry will increase by 31.4% through 2010. R&D expenditures in the sector are 13% of sales-over four times the U.S. industrial average. North Carolina is ranked eighth nationally in medical technology businesses, providing a positive outlook for graduates of the new department. ■

Biomedical engineering will be the focus of the next issue of RESULTS.

"ALL BIOMEDICAL ENGINEERING STUDENTS WILL NEED TO UNDERSTAND THE FUNDAMENTALS OF NANOTECHNOLOGY AS ADVANCES... ACCELERATE DEVELOPMENT OF MORE SOPHISTICATED DEVICES FOR DIAGNOSIS AND THERAPY."

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FACULTY
**BRENNER HONORED
WITH FEYNMAN PRIZE**



Dr. Donald Brenner

Dr. Donald W. Brenner, associate professor of materials science and engineering at NC State, has received the prestigious 2002 Foresight Institute Feynman Prize for his pioneering research in theoretical nanotechnology.

The Foresight Institute, a nonprofit educational organization formed to prepare society for the impact of molecular nanotechnology, awards two \$5,000 Feynman prizes each year: one each for theoretical and experimental advances in nanotechnology. The prizes are named for Nobel laureate physicist Dr. Richard P. Feynman, who predicted the possibilities of molecular-scale engineering in his famous 1959 speech entitled "There's Plenty of Room at the Bottom."

Brenner's award recognizes advances he made at the Naval Research Laboratory (NRL) and at NC State in molecular machine systems modeling and the design and analysis of components likely to be important to the future of molecular manufacturing. He developed the first mathematical expression that allowed chemistry to be modeled on an equal footing for molecular and solid systems, and that was computationally efficient enough to be used in large-scale molecular simulations. The publication of Brenner's initial breakthrough is on the list of NRL's most cited publications, and the mathematical expression is used in universities, government, and industrial labs worldwide.

Brenner was recruited in 1994 from the NRL to NC State's College of Engineering, where he and his collaborators have recently published an improved version that better describes properties such as bulk elastic constants. His current simulation work supports experimental efforts at several research institutions. Since joining NC State, Brenner has received two awards for outstanding teaching, and has developed new technologies for materials education. ■

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