SMALL SCIENCE WITH BIG PROMISE

— NANOTECHNOLOGY RESEARCH AT NJIT

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U.S. TANKS AND OTHER MILITARY VEHICLES may soon be painted with "Smart Coatings™" — which will allow such vehicles to modify their color, chameleon-like, on the battlefield, creating instant desert or jungle patterns and rendering them virtually undetectable. And if the coatings are scratched or nicked, they will detect the defects and heal themselves automatically.

It smacks of science fiction, but it's not. Researchers at NJIT in collaboration with a team at Picatinny Arsenal in New Jersey are now working on the coatings for the U.S. Army. "The key to the development of these coatings is nanotechnology," says research team leader Daniel Watts, executive director of NJIT's York Center for Environmental Engineering and Science. At Picatinny Arsenal, three NJIT graduates are also helping to lead the Smart Coatings effort — Laura Battista '96, MS '97, Nelson Colon '89 and James L. Zunino III '02, MBA '03.

This project is just one example of NJIT's nanotechnology research initiatives, an area of investigation identified as a priority in the university's strategic plan. In addition to the coatings for the Army, NJIT researchers are also using nanotechnology to develop other types of films, better electronic circuitry, fuel cells, more efficient batteries, faster computers, and ultra-sensitive switches and sensing devices.

The recognition accorded to the efforts under way at NJIT in the nanotechnology field continues to increase as well. Recently, online *Nano World News* called special attention to the paper subsequently presented at the 2005 Nanotechnology Conference and Trade Show in May by NJIT investigators Rajesh Dave, Abhijit Gokhale, Boris Khusid and Robert Pfeffer: "Formation of Polymer Nano-particles in Supercritical Fluid Jets."

A trillion-dollar market

What is nanotechnology? It takes its name from the nanometer — one-billionth of a meter — about 80,000 times smaller than the diameter of a human hair. By manipulating substances from one to several hundred nanometers thick, scientists and engineers can take advantage of magnetic, electronic or optical properties not present on a larger scale. This technology is the single fastest-growing research area in the nation. The National Science Foundation estimates that in the next 10 to 15 years the nanotech market will annually exceed $1 trillion. Last year, the federal government spent more than $800 million on nanotechnology.

Already, nanotechnology has produced stain- and wrinkle-resistant clothing, glare-reducing coatings for eyeglasses, better sports equipment, improved cosmetics and sunscreens, and stronger automotive parts. But these products are exceptions, not the rule. For the most part, nanotechnology is still a scientific frontier — though one with very definite promise.

Take, for instance, the Smart Coatings project. NJIT intends to have an improved prototype ready by year's end, building on the version already attracting Department of Defense interest. But it will take another five years, says Watts, before the technology can be tested in the field on combat vehicles. The disciplines represented on Watts' team indicate the complexity of this effort. A partial listing of the team's expertise includes chemistry,

Members of the team developing nanotechnology-based Smart Coatings for camouflage and other applications: NJIT's Daniel Watts (left) with Nelson Colon '89 and Laura Battista '96, MS '97, who work at Picatinny Arsenal

chemical engineering, physics, electrical and computer engineering, and materials science — all of which contribute to developing the coatings.

In addition to changing a vehicle's appearance, the project involves embedding a coating with nanosensors that will allow the coating to sense and trigger repairs without human intervention. The coatings are intended not just for tanks but for an array of military vehicles — trucks, helicopters and other weapons systems. The ultimate challenge, Watts says, is getting the coatings to work under combat conditions. That's much harder than developing a prototype of a coating in the lab. Nevertheless, Watts is optimistic. "Coatings with the characteristics we envision sound like something out of Star Wars, but we believe it can be done."

Too small to break

Other NJIT researchers are having great success with a nanotechnology known as carbon nanotubes — nanoscopic layers of carbon rolled like a sheet of paper. Carbon nanotubes, discovered in 1991, are made from carbon atoms that are connected — single-file — in a tube. The tubes, which are typically closed at either end by hemispherical structures, have unique electronic and mechanical properties. Such properties may allow the tubes to play a crucial role in the drive towards miniaturization of products at the nanometer scale.

There's a hitch, however, with carbon nanotubes. Made from graphite or graphite-like sheets, they are chemically inert. They don't easily react chemically and are insoluble in common solvents like

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water and alcohol. But Zafar Iqbal, research professor of chemistry, and Somenath Mitra, professor of chemistry, have discovered a method that changes the chemical characteristics of the tubes.

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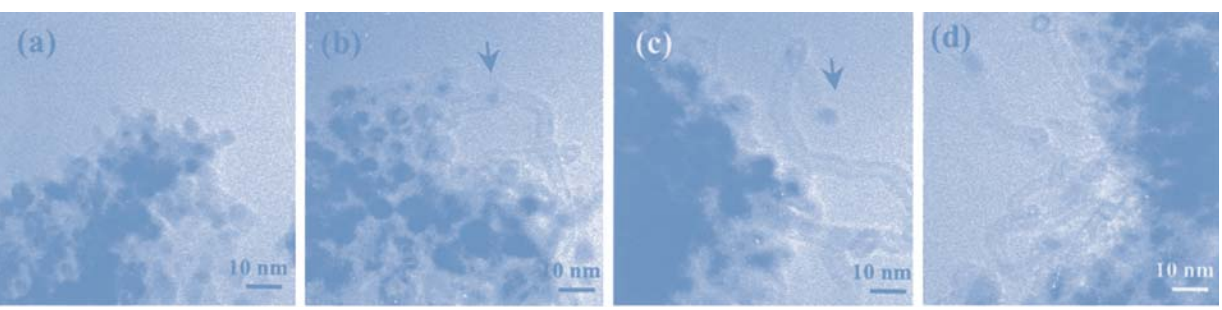
They use microwaves to heat the carbon nanotubes in combination with other chemicals to 250 degrees Celsius. After just a few minutes in the oven, the tubes become chemically reactive and soluble; they will dissolve in water and in common solvents. This solubility and chemical reactivity "open the doors to various applications," says Mitra of the breakthrough for which a patent application has been filed. Once modified, the tubes can be used to make thin films, paints, composites, transistors, and more.

Some components of advanced aircraft and the Space Shuttle, says Mitra, are made from carbon composites. But in five or ten years, those composites may be replaced with much stronger materials based on carbon nanotubes. Carbon nanotubes, Mitra explains, possess a miraculous quality: "A hundred times stronger than steel, they are too small to break."

"We believe that we are really pioneers in the field for having developed this microwave method," Mitra adds. Recently, Iqbal and Mitra presented their data at the annual conference of the American Chemical Society in San Diego and published their results in the journal *Carbon*. "The beauty is that our method is green, clean and inexpensive. Whereas it takes other researchers hours and even days to get carbon nanotubes to react, it takes us just three to ten minutes."

Iqbal is investigating several other applications for carbon nanotubes. One project he and Mitra are working on involves building a sensing system for airborne organics. For another, he is depositing carbon nanotubes on micro-sized chips of flexible carbon and combining them with enzymes to create electrodes for biofuel cells. The fuel cells could be implanted in the body to power medical devices such as pacemakers.

Iqbal also combines carbon nanotubes with catalytic metals to fabricate electrodes for another type of miniature fuel cell that could one day power smart coatings, laptop computers and other electronic devices. A longer-term project involves storing hydrogen in a conducting polymer and carbon-nanotube membrane for use in fuel cells to power



A STUDY IN STRENGTH

NJIT's Zafar Iqbal partnered with Professor Renu Sharma of Arizona State University to describe the real-time growth of carbon nanotubes in the environmental chamber of a transmission electron microscope. The study provided the first direct nanoscale view of the nanotube growth process, in which a subtle interplay between the dark catalyst particles and the growing tubes can be seen. Published in *Applied Physics Letters* in 2004, the study is an important advance in synthesis and growth of carbon nanotubes, which are emerging as the basis of new superstrength materials.

automobiles. These projects, Iqbal says, will take between five and fifteen years to produce marketable products. A big challenge is making the carbon nanotubes cheaply enough through mass production. Nonetheless, in his eyes, carbon nanotubes hold the most immediate promise of commercial success among the subsets of nanotechnology research. Carbon nanotubes are, he says with a smile, "the darlings of nanotechnology."

Optical interconnects

Leonid Tsybeskov, associate professor of electrical and computer engineering, is using nanotechnology to increase computer-processing speed. The interconnects inside a computer that link transistors are subject to delays, says Tsybeskov. With a $500,000 grant from Intel, he is researching three-dimensional silicon-germanium nanostructures that can be used as light emitters and integrated optical interconnects, both chip-to-chip interconnects and board-to-board interconnects.

Tsybeskov creates silicon germanium nano-clusters, which he derives from alternating and latticed layers of silicon and germanium. "The layers are strain free, and most importantly, defect free," Tsybeskov says. "The nano-clusters can be used as very efficient light emitters, similar to a semiconductor laser. This is why Intel supports my research," he adds. "Silicon-germanium is compatible with current silicon technology and can be used to make integrated emitters on a chip. That means optical interconnects can be used in your computer system."

Tsybeskov, who has also partnered with the National Research Council of Canada, says the new interconnects will take at least ten years to develop. "That Intel is paying for my research means it's very serious in terms of science, and we're making huge progress."

But while the science is very sound, Tsybeskov cautions that it will not be easy to shepherd the fundamental innovations promised by nanotechnology into the production stage. Not only are there years of research involved, but any resulting device or product must be compatible with readily available manufacturing or fabrication processes and be economical for a company to make. That may be the biggest hurdle faced by Tsybeskov and his colleagues working in this area — turning basic nanoscience breakthroughs into true nanotechnology. ■

ALSO ON THE NANOTECHNOLOGY FRONTIER AT NJIT:

- John Federici, professor of physics, is using terahertz spectroscopy to characterize and understand the electronic properties of carbon nanotubes. The goal of his research is to expand knowledge about nanotubes basic to their practical use, including sensing and switching applications.
- Haim Grebel, professor of electrical and computer engineering, heads a team of researchers who have grown carbon nanotubes in the tiny spaces between the silica spheres that comprise synthetic opals, creating a material with specific optical properties. The resulting material promises to be a superior medium for optical switching at relatively low levels of laser intensity.
- Boris Khusid, associate professor of mechanical engineering, is collaborating with Sandia National Laboratories on simulations of microscale and nanoscale manipulation of biomolecules, such as DNA. The goal of these simulations is to facilitate development of microdevices to detect harmful biological or chemical agents in air and water. Other potential applications include tiny separation devices for a wide variety of systems for environmental monitoring and health care.
- Robert Pfeffer, distinguished professor of chemical engineering, is investigating ways to process nanoparticles to produce nanomixtures and nanocomposites with tailored properties. This work, which has received funding from the National Science Foundation, is potentially very significant for many industries, including the pharmaceutical, chemical, agricultural and ceramics industries.
- Kamalesh Sirkar, distinguished professor of chemical engineering and foundation professor of membrane separations, is developing an environmentally-friendly technique for making nanoporous membranes that have extensive applications in separating liquid solutions. Examples of such solutions include proteins in fermentation broths and larger organic molecules in organic solvents. To this end, he is working with Marino Xanthos, professor of chemical engineering, on a project funded by the National Science Foundation. The two researchers are developing a technique for making nanoporous membranes without using solvents that contaminate the air and produce contaminated wastewater.