constructs. The purpose of these devices is to achieve a variety of structural configurations on the nanometer scale, thus paving the way for nanorobotics. By inserting DNA "set" strands that select the state of the device and "fuel" strands that remove the set strands to return the device to an unspecified state, into individual molecule pairs, the scientists fabricated a sequence-dependent rotary DNA device that operates in a four-step cycle.

In the January 3 issue of *Nature*, the scientists reported that they used paranemic crossover (PX) DNA, a four-strand molecule in which two double helices are joined by the crossing over of strands everywhere that the strands come together. The scientists produced a half-turn rotation by converting them into JX_2 molecule pairs that lack two of the crossovers present in the PX structure. "Set" strands refer to the strands that position the state of the device in the PX conformation. The "fuel" strand refers to the strand that is complementary to the entire length of the set strand and will pair with it.

The scientists alternated additions and removals of fuel and set strands, holding the solution at 20°C for 60 min through each stage of the four-step cycle. Nondenaturing gel electrophoresis and atomic force microscopy verified the formation and interconversion of the PX DNA and its topoisomer JX_2 DNA. The researchers report motions up to 35 nm.

Sacrificial Bonds in Collagen Contribute to Bone Strength

With the use of atomic force microscopy (AFM), scientists at the University of California—Santa Barbara have revealed that sacrificial bonds in collagen may be partially responsible for the toughness of bone. Collagen is a protein that serves as a structural component of a variety of tissues including bone, tendon, and skin.

Using a purified cow tendon as a sample, the scientists stressed the collagen, discovering that the protein contains sacrificial bonds that rupture when stretched, then reform.

Graduate student James B. Thompson said, "These sacrificial bonds provide a mechanism for dissipating mechanical energy in collagen molecules. The time scale required for sacrificial bonds to reform in collagen correlates to the time needed for bone to recover from microscopic indentations."

Besides stretching the collagen from bones (AFM pulling using force probes with spring constants of 50 pN nm^{-1}), the scientists made small indentations in the femur of a rat (AFM indentation with spring constants of ~50 N m^{-1}), discovering that the bone returns to its original shape in ~30 s. They needed a stiffer force probe to indent a bone than to stretch a collagen molecule.

As reported in the December 13 issue of *Nature*, the researchers noted that the sacrificial bonds found within or between collagen molecules in their samples were similar to those found in abalone shell. Thompson said it is too early to tell what impact this study will have on human health and how the study might affect technology or medicine.

Carbon Nanotube Electrodes May Increase Storage of Li-Ion Batteries

Researchers at the University of North Carolina—Chapel Hill have shown that carbon nanotubes can contain roughly twice the energy density of graphite. They suggest the possibility that more energy could be stored in batteries using carbon nanotubes than with conventional graphite electrodes.

Currently, graphite and carbonaceous materials are used as one of the two working electrodes in rechargeable Li-ion batteries. The energy capacity of the battery is partly limited by the amount of Li that can be stored per unit weight of carbon by the intercalation reaction. For graphite, the limit is LiC_6.

Associate professor Otto Z. Zhou said, "In our experiments, we used both electrochemistry and solid-state nuclear magnetic resonance (NMR) measurements, which show similar results. With graphite, we can store, reversibly, one charged lithium ion for every six carbon atoms in graphite, but we found that with nanotubes, we can store one charged lithium ion for every three carbons, also reversibly."

As reported in the January 7 issue of *Physical Review Letters*, the researchers chemically etched the single-walled nanotubes (SWNTs) into much shorter cylinders. In this process, the ends of the nanotubes were opened, and the inner core spaces were exposed. The research team performed electrochemical and solid-state ^{13}C NMR experiments on both the control (purified SWNTs with closed ends) and etched SWNTs with open ends. The results showed that the reversible Li storage capacity increased from LiC_6 in the closed-end SWNTs to LiC_3 in the open-end SWNTs.

Zhou said, "We believe this is due to Li diffusion into the inner core spaces of the nanotubes."

Zhou said that many technical issues must still be resolved, such as large irreversible capacity, high intercalation voltage, and life time.

Nanotube "Peapods" Exhibit Tunable Electronic Properties

A team of researchers from the University of Illinois at Urbana-Champaign (UI) and the University of Pennsylvania have demonstrated that the encapsulation of C_{60} molecules in a single-walled carbon nanotube is a viable route to controlling the motion of electrons in carbon nanotubes. The samples were produced using molecular self-assembly techniques by materials science professor David Luzzi and his research group.

To explore the properties of these nanostructures—dubbed "nanoscopic peapods"—Ali Yazdani, a professor of physics at UI, and Daniel Hornbaker, a UI graduate student, used a low-temperature scanning tunneling microscope (STM), obtaining high-resolution images. As reported on the *Science Express* Web site on January 3 and the February 1 issue of *Science*, the researchers were able to image the physical structure of individual "peapods" and map the motion of electrons inside them. The researchers found that the encapsulated fullerenes modify the electronic properties of the nanotube without affecting its atomic structure.

The researchers said that the encapsulation process can in principal deform the nanotubes' structure, which is very unfavorable. Therefore, the majority of the peapods were made of nanotubes in which there was enough room to fit the C_{60} molecules inside. The strong electronic interaction between the C_{60} molecules inside and the nanotubes' electronic states was unexpected, they said.

"In contrast to unfilled nanotubes, peapods exhibit additional electronic features that are strongly dependent on the location along the tube," Yazdani said. "By mapping electron waves of different energies inside these nanoscale structures, we can begin to unravel the complex interaction in these systems and better understand their electronic properties."

Using the STM to manipulate the encapsulated molecules, the researchers compared the measurements performed on the same section of nanotube with and without the encapsulated molecules. Using tunneling spectroscopy, the researchers mapped how electronic states were distributed in energy (density of electronic states). They performed these measurements on the filled and unfilled section of a nanotube in order to compare how the electronic states of a nanotube were modified by the presence of the molecules inside. The measurements directly

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mapped the electronic wave function at a given energy. They accounted for their measurement with a detailed model of the electronic states of the nanotube peapods, which was constructed by considering how arrays of C_{60} molecules interacted with the one-dimensional electronic states of the nanotube.

"These calculations showed us how the electronic states of this composite system derive its character from both electronic states of the nanotube and the C_{60} molecules," said Yazdani.

The researchers speculate that the lessons learned in unraveling the properties of this complex nanostructure also may apply elsewhere.

Luzzi said, "When we first created peapods, it provided the first glimpse of a toolbox of nanomaterials that could provide the same excellent mechanical strength and thermal conductivity of nanotubes but would have other tunable properties—optical, electrical, or catalytic—to provide the diverse functionality needed for integrated and complex nanodevices. This work confirms that these materials are not peas in a pod but actually peapods, a completely new material."

News of MRS Members/Materials Researchers

Rudolph Buchheit, associate professor at the Fontana Corrosion Center at The Ohio State University, has received the **H.H. Uhlig Award** on April 7 from NACE International in recognition of his enthusiastic teaching of corrosion at all levels, involvement of undergraduate and high school students in research activities, and continued promotion of the highest quality of corrosion research and education.

Robert A. Condrate Sr., emeritus professor of spectroscopy at Alfred University, has been made a **Fellow of the Canadian Ceramic Society** recognizing his contributions to the Society in ways that help it meet its mission of advancement of knowledge in ceramic and glass sciences and manufacturing.

Cees Dekker (Delft Technical University) has received the **Julius Springer Prize for Applied Physics 2002** for the discovery of the electronic properties of carbon nanotubes and for pioneering work on their application in single-molecule electronic devices. The prize has been awarded since 1998 by the editors of the Springer journals *Applied Physics A (Materials Science & Processing)* and *Applied Physics B (Lasers and Optics)*.

J. Murray Gibson (Argonne National Laboratory) has been appointed **Associate Laboratory Director for the Advanced Photon Source (APS)**, effective October 22, 2001. Gibson has been the director of the Materials Science Division at ANL since 1998, where he has strengthened existing programs, and worked to add new areas. In particular, Gibson oversaw ANL's early efforts in nanosciences and fostered the development of the x-ray nanoprobe.

Lene Hau (Harvard University) has received a **2001 MacArthur Fellowship** from the MacArthur Foundation in recognition of her insights of the fundamental interactions of light and matter.

Mietek Jaroniec (Kent State University) received the **2001 Activated Carbon Hall-of-Fame award** for his innovative, patented "New Porous Carbons."

Steffen Kaldor (IBM T.J. Watson Research Center) received the **American Vacuum Society (AVS) 2001 Graduate Research Award** at the Fall 2001 meeting in San Francisco. The award recognizes his graduate research on the analysis of bending shapes in Si and its application to both strain measurements in thin films and microelectromechanical systems. Kaldor served as president of the MRS University Chapter at Columbia University and writes research news for *MRS Bulletin*. He recently joined IBM as an engineer/scientist in the Advanced Semiconductor Technology Center, where he will work in thin-film-process development for microelectronics.

Lisa C. Klein, a professor of ceramic and materials engineering in the School of Engineering at Rutgers University, has been selected as a **Fellow in the New York Academy of Sciences** for her breakthrough contributions to engineering, particularly in the area of sol-gel science, a low-temperature process for making ceramic coatings.

Linn W. Hobbs Awarded Honorary Officer, Order of the British Empire

Linn W. Hobbs (left) of the Massachusetts Institute of Technology receives his honorary OBE from British Ambassador Sir Christopher Meyer.

Materials science professor **Linn W. Hobbs** of the Massachusetts Institute of Technology has been awarded an honorary OBE (Officer, Order of the British Empire). The honor was presented by British Ambassador Sir Christopher Meyer in a ceremony at the British Embassy in Washington, DC on November 14. Hobbs was awarded the honor in recognition of his services to British-American relations in education through his work on the Marshall Scholarships.

The Marshall Scholarships, established by an Act of the British Parliament in 1953, bring the "best and brightest" of young U.S. graduates to the United Kingdom for degree studies in any subject at the institution of their choice. The scholarship now brings up to 40 students annually for two years of postgraduate study or a second undergraduate degree. Noted past Marshall Scholars include U.S. Supreme Court Justice Stephen Breyer and Duke University president (formerly president of Wellesley) Nannerl Keohane.

Hobbs, an internationally distinguished scientist, has taught at MIT since 1981. He is a past associate chair of the MIT faculty. He is a past councillor of the Materials Research Society; past president of the Microscopy Society of America, and is a Fellow of the American Ceramics Society. He has been a Research Fellow of Wolfson College, Oxford; a visiting professor at Balliol College, Oxford; and has worked at the UK Atomic Energy Research Establishment at Harwell.

Hobbs joined the Boston selection committee for the Marshall Scholarships in 1985 and has served as its chair since 1989. He was a 1966 Marshall Scholar. Hobbs holds a BSc degree in materials science from Northwestern University (and was the university's first Marshall Scholar) and a DPhil degree in Materials from Oxford. He is a past president of the Oxford and Cambridge Society of New England.

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