

nanotube field-effect transistors (FETs). Their main approach involved converting *p*-type FETs in an array into *n*-type FETs by a local electrical manipulation under a vacuum.

As reported in the September issue of *Nano Letters*, Ali Javey, Hongjie Dai, and co-workers performed the fabrication of the *p*-type transistor device depositing single-wall nanotubes (SWNTs) between metal electrodes formed on the photolithographically patterned SiO₂ layer. Device fabrication involves the synthesis of SWNT arrays by chemical vapor deposition of methane on substrates pre-patterned with catalyst and bottom-*W*-gate arrays. Thus-obtained 4 × 4 mm² chips contain about 100 devices. The yield of the acceptable SWNT FETs was found to be in the range of 20–30%. The researchers achieved a *p*-type FET conversion into *n*-type by applying a high local gate voltage (−40 V) combined with a large source-drain (20 V) bias for a certain duration under vacuum (10^{−8} Torr). The yield of this technique results in ~50% *p*–*n* conversion. The researchers suggested a mechanism for this conversion based on reversible desorption of molecular oxygen from SWNTs, leading to significant *n*-channel conduction. The ability of local manipulation of SWNT FETs into *n*-type has enabled the researchers to obtain multiple *n*-FETs and *p*-FETs on a SWNT chip and construct complementary logic devices and ring oscillators.

The researchers concluded that simple computing operations are possible by using the high percentage of semiconducting SWNTs and the ability for local gating, manipulation, and doping of individual SWNT FETs.

ANDREI A. ELISEEV

AFM Enables Study of Biomolecules' Interaction with Minerals

Treavor Kendall, a graduate student in the mineral-microbe group in the Department of Geological Sciences at the Virginia Polytechnic Institute and State University, has demonstrated the use of an atomic force microscope (AFM) to study how biomolecules extract minerals. At the 12th Annual V.M. Goldschmidt Conference, an international geochemistry conference held August 18–23 in Davos, Switzerland, Kendall described his experiments on how the bacteria *Azotobacter vinelandii* acquire iron.

Kendall said that the bacteria release the organic molecules siderophores, which have an affinity for iron. While studies have shown how siderophores

interact with iron in water, Kendall's research explored how they acquire iron that is embedded in a mineral structure.

"This is important," said Kendall, "because minerals are a primary source of iron in the environment." He specifically looked at the affinity between azotobactin and the mineral goethite, an important iron oxide in soils worldwide, he said.

The research team covalently attached the molecule to the AFM tip using a common protein-coupling technique. The activated tip was then used to probe various minerals including goethite and diaspore, goethite's isostructural aluminum equivalent. The sensitivity of the AFM allowed the forces of interaction associated with the azotobactin and each mineral surface to be measured. A two- to threefold increase in the adhesion forces between the siderophore molecule and the iron-containing mineral over the forces measured for the aluminum-containing mineral was observed. According to the researchers, this large adhesion force between the siderophore and goethite could be attenuated upon the addition of small amounts of soluble iron, indicating the interaction captured in this measurement was specific between the azotobactin chelating groups and the iron in the surface. These force measurements demonstrating azotobactin's strong specific affinity for iron in a solid form suggests azotobactin may be directly coordinating with iron in the mineral surface groups, they said. Such a coordination could destabilize the Fe–O bonds in the mineral, driving dissolution and subsequent iron release.

This is a unique result, said Kendall, because larger siderophores such as azotobactin are often believed to acquire iron by acting as scavengers; that is, they steal iron from other, smaller, lower-affinity ligands in solution without interacting with the mineral surface. On the contrary, these results indicate that direct surface contact is a distinct possibility.

According to Kendall, siderophores are used in medicine to treat people who have too much iron in their blood. The siderophore locks up the iron so it is no longer toxic. The ability to measure iron affinity at the molecular level may allow researchers to refine siderophore medicinal use and detect iron concentrations in very small amounts by using them as a chemosensor.

Gradient Structures of Nanoparticles Prepared on Chemical Template

Scientists from North Carolina State University (NCSU) and the National Institute of Standards and Technology (NIST) have

created a material with a gradient of gold nanoparticles on a silica-covered silicon surface using a molecular template. The material provides evidence that nanoparticles can form a gradient of decreasing concentration along a surface. A description of the material appears in the July 23 issue of *Langmuir*.

"This material promises to be the first in a series with many applications in electronics, chemistry, and the life sciences," said Rajendra Bhat, a graduate student from NCSU and the lead author of the study. Bhat worked with Jan Genzer, a chemical engineering professor at NCSU, and Daniel Fischer, a physicist from NIST.

To build the material, the scientists first prepared a ~1-nm-thick layer of amine-terminated organosilanes on a rectangular surface of silicon (4.5 cm × 1.2 cm) with a 2-nm-thick native SiO_x layer. The head glues to the surface, while the amine-terminated tail sticks out, acting like a hook waiting for a gold nanoparticle to attach to it, said Genzer, leader of the NCSU team. The organosilane molecules, emitted vertically in the form of a vapor by a source close to one side of the surface, slowly fell on the surface with decreasing concentration as the distance from the source increased, thus creating a number-density gradient to serve as a molecular template.

The next step was to dip the material in a colloidal solution containing the gold nanoparticles. In the solution, the amine-terminated tails of the organosilane mole-

Corrections

Ihab F. El-Kady's name was omitted from a news article about a 3D photonic metallic crystal reported in the July 2002 issue of *MRS Bulletin*, page 488. El-Kady served as the lead of the research team from the Ames Laboratory at Iowa State University.

Brian D. Madsen's name was misspelled in the July 2002 issue of *MRS Bulletin*, page 490. He is part of the research team at Northwestern University who contributed to research on solid-oxide fuel cells, enabling hydrocarbon oxidation without coking.

A presentation at the Advanced Metallization Conference 2001 was reported incorrectly in the February 2002 issue of *MRS Bulletin*, page 138. The correct attribution is as follows: The last session of AMC2001 addressed atomic layer deposition (ALD), including an invited paper by K.E. Elers (ASM Microchemistry).

cles took on a positive charge, so that the negatively charged gold particles attached to the oppositely charged tails underneath.

To visualize the gradient of gold particles, Bhat and his colleagues used an atomic force microscope, and to look at the gradient of the organosilane molecules, the scientists used near-edge x-ray absorption fine structure (NEXAFS) spectroscopy.

"We needed to confirm that both the gold particles and the sticky groups followed the same underlying gradient template," Bhat said. "The results from both techniques were expected to coincide if the particles were attaching to the underlying layer of sticky molecules. Our results show exactly that."

According to Genzer, the distinguishing feature of this approach is that the particles follow a pre-designed chemical template provided by the organosilane sticky groups. "The ability to manipulate the underlying template allows us to prepare gradient structures of nanoparticles with varying characteristics," he said.

The main advantage of the gradient structure, the scientists said, is that large numbers of structures can be combined on a single substrate and used for high-throughput processing. It might, for example, save time for chemists testing clusters of nanoparticles used as catalysts.

Fischer said, "Clusters made of different numbers of nanoparticles could be put on a single surface, and scientists

could test this surface only once in a chemical reaction, instead of having to run each cluster separately through the reaction." The material could also be used as a sensor to detect species that have specific affinities for nanoparticles, or as a filter to select particles of given sizes. □

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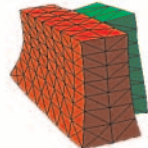
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