exponential decay, representing a liquid phase. At 330 K, the positional correlation function remained isotropic but the orientational one showed algebraic decay, a signature of the hexatic phase. At 290 K, the system became a two-dimensional hexagonal crystal, showing quasi-long-range positional order and long-range orientational order. The scaling of the correlation functions was consistent with KTHNY theory.

The melting transition was second order when the pores contained one layer of molecules and became weakly first order for pores containing two layers. The researchers attribute the change to interaction between defect configurations in the two layers.

Differential scanning calorimetry (DSC) measurements of CCl_4 and aniline in an activated carbon fiber with slit-shaped pores narrowly distributed around a mean size of 1.4 nm showed peaks near temperatures predicted in the simulations. Nonlinear dielectric effect (NDE) signals diverged with a scaling consistent with the theory.

Dielectric relaxation spectroscopy (DRS) of adsorbed aniline, a dipolar fluid, showed sharp changes, indicating phase transitions near the predicted temperatures. The orientational relaxation times of the adsorbed molecules were typical of a hexatic phase between 298 K and 324 K. Below that range, the time scales were typical of a crystal, and above it, they were typical of a liquid.

ELIZABETH A. SHACK

Direct Observation of Intercalated Cs in Zeolite $Si_{32}O_{64}$ Yields Example of Inorganic Electride

Understanding the properties of nanoscale arrays of metal atoms may allow scientists to manipulate these properties to produce nanomagnets, nanocatalysts, nanodevices, and composites with better optical properties than are currently possible. However, such applications require a detailed knowledge of the materials' atomic-level structure. Thomas Vogt, a physicist at Brookhaven National Laboratory, and scientists from Michigan State University led by physicist Valeri Petkov (now at Central Michigan University), have demonstrated that the atomic pair distribution function (PDF) technique allows them to decipher such fine-level nanostructures.

Their analysis of a material composed of cesium ions trapped inside nano-sized pores of the silicon oxide zeolite $Si_{32}O_{64}$ is described in the August 12 issue of *Physical Review Letters*. This material is also the first example of a room-temperature inorganic "electride," a stable separation of positively charged cations and electrons with properties determined by the topology of the pores in the host matrix.

In traditional crystallography, long-range order and symmetry, specifically the repeating three-dimensional (3D) patterns in the crystals, give rise to sharp Bragg peaks in the x-ray powder diffraction pattern, which are then used to determine the atomic structures. Materials constructed at the nanoscale, however, lack this long-range order and often accommodate a large number of defects and local disorder. The result, said Petkov, is that the diffraction patterns of nanocrystals are much more diffuse with few, if any, Bragg peaks.

To overcome this problem, the team of scientists employed the PDF technique, a nontraditional experimental approach, to read between the Bragg peaks of data produced by traditional x-ray powder diffraction experiments. With the PDF technique, the scientists revealed direct structural evidence that cesium is intercalated in the nano-sized pores of the silicon oxide zeolite in the form of positively charged cesium ions arranged in short-range-order zigzag chains. This verifies that $Cs_xSi_{32}O_{64}$ is a room-temperature stable inorganic electride, the scientists said.

"Electrides are novel materials that are just beginning to be studied," said Petkov. First results show that they could be used as reducing materials in chemical synthesis of other materials and that they have useful electronic properties such as low-energy electron emission.

Carbon-Nanotube Transistor Arrays Used for Fabrication of Multistage Complementary Logic Devices and Ring Oscillators

Carbon nanotubes are expected to be the most promising candidates for building blocks for the next generation of electronic devices, predominantly due to low surface scattering and nanoscale channel widths. A group of researchers at the Department of Chemistry and the Laboratory for Advanced Materials at Stanford University have demonstrated a fabrication route for multistage complementary NOR, OR, NAND, and AND logic gates and ring oscillators based on arrays of *p*- and *n*-type

https://doi.org/10.1557/mrs2002.239 Published online by Cambridge University Press

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 SiO_2 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 mm^2 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).

https://doi.org/10.1557/mrs2002.239 Published online by Cambridge University Press