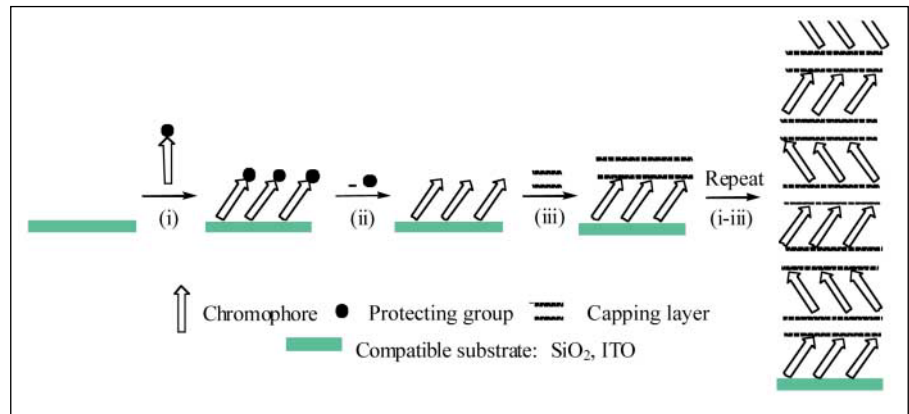


Self-Assembly of Organic/ Inorganic Superlattice Structures May Enable Novel Photonic Devices

Novel organic-based electro-optic (EO) components have the potential to greatly increase the rates of information transmission. The preparation of an organic EO superlattice consisting of layers of chromophore molecules separated by polysiloxane films was recently reported by M.E. van der Boom and T.J. Marks of Northwestern University and their colleagues both at Northwestern and the University of Arizona. The intrinsically acentric superlattice was prepared by a simple and efficient "one-pot" wet chemical self-assembly procedure and exhibited high structural regularity and excellent EO response properties. The researchers said that the material, synthetic method, and nanoscale control of the fabrication may contribute to a simplified method of macroscopic device fabrication.

As communicated in the January issue of *Chemistry of Materials*, the superlattice was prepared by allowing a layer of chromophore molecules to chemisorb onto a hydrophilic substrate, chemically de-protecting the chromophore film, and growing a thin polysiloxane layer ($-\text{SiO}_2-$) which is capable of covalently binding another layer of chromophore molecules. The researchers used the known chromophore 4-[[4-[N,N-(*tert*-butyldimethylsilyloxy)ethyl]amino]phenyl]azo]pyridine, which was modified with an *n*-propyl-3-trimethoxysilane functionality to allow strong covalent binding to silicon, glass, or indium tin oxide (ITO)-coated glass substrates. The chromophore layer was then treated with *n*-Bu₄NF to remove the *t*-butyldimethylsilyl protecting groups, resulting in a large density of reactive surface hydroxyl sites. The de-protected chromophores were treated with a hep-



Schematic representation of iterative self-assembly of acentric organic/inorganic superlattice structures. Reproduced with permission from *Chem. Mater.* **13** (2001) p. 16. Copyright 2001 American Chemical Society.

tane solution of octachlorotrisiloxane, which cross-linked and capped the chromophores with a robust polysiloxane film. The formation of this film enhances the stability and planarity of the structure. The hydrophilic polysiloxane layer was then exposed again to a chromophore solution, and the process was repeated until the desired number of layers had been deposited. The researchers reported the synthesis of superlattices having up to six bilayers. Each bilayer was determined to be ~ 20 Å thick. (See Figure.)

Characterization of the superlattice by synchrotron x-ray reflectivity and optical (UV-visible) spectroscopy showed that equal densities of chromophores are deposited in each layer and that the chromophore orientations are uniform. Second harmonic generation measurements revealed that the chromophores have a uniform polar alignment and structural regularity. The high structural regularity was further confirmed by atomic force microscopy on a six-bilayer assembly that indicated that the surface is smooth and featureless, with less than 8% roughness. The lattices were found to be thermally and photochemically robust and exhibited a very large EO response.

According to the researchers, this self-assembly approach is applicable to other chromophores and is more efficient than existing synthetic routes to EO materials. The fact that the entire preparation can be carried out in one reaction vessel makes this approach easily adaptable to automation. Furthermore, the layer-by-layer modularity of self-assembled superlattice building-block incorporation raises the intriguing question of whether other functional constituents (e.g., optical, elec-

tronic, magnetic, and mechanical) could be intercalated as part of the self-assembly process. The strong binding of the modified chromophores to silicon, glass, and ITO allows ready integration of these structurally tailored photonically/electronically functional materials into novel electro-optic devices.

GREGORY KHITROV

Potential Utility of Multiwalled Carbon Nanotube Field-Effect Transistors as Environmental Sensors Demonstrated

In the study of carbon nanotubes (NTs) as field-effect transistors (FETs), the silicon substrate usually also serves as the gate. However, with this method only weak field effects were observed in multiwalled nanotubes (MWNTs). Recently, collaborators at Universität Basel and École Polytechnique Fédérale de Lausanne in Switzerland have experimented with a new gating method, *electrochemical gating*, on a single MWNT. This method yields a much higher transconductance (gate-induced change on the electrical resistance) than the usual substrate back gating (BG) on MWNTs and demonstrates the extreme sensitivity of the MWNT FET to its surrounding environment—in this case, different electrolytes.

The researchers used single MWNTs with lithographically defined Au contacts evaporated over the NTs, fabricated on degenerately doped Si with a 400-nm-thick SiO₂ spacer layer. They positioned a micropipet over the device to deliver a LiClO₄ electrolyte droplet of a diameter ≤ 100 μm, thereby immersing the NT into the electrolyte. They used a Pt wire within the glass pipet as the gate contact, and

SBIR Update

MATECH Advanced Materials (Westlake Village, California) has been awarded a Phase I SBIR grant from the U.S. National Science Foundation to develop a new class of photocurable preceramic polymers to silicon nitride, an advanced ceramic material.

Powdermet, Inc. (Sun Valley, California) has been granted a six-month Phase I SBIR contract from the Department of Energy to further develop nanoengineered, oxide-dispersion-strengthened iron aluminate powders.

measured resistance of the NT devices at room temperature. An applied positive gate voltage U_g would polarize the NT-electrolyte interface by the attraction of cations. The gate capacitance C_g , formed by the double-layer capacitance, can be very large.

The researchers observed that while the initial gate-induced resistances $R(U_g)$ at $U_g = 0$ are comparable between liquid-ion gating and its BG counterpart, $R(U_g)$ has a maximum at $U_g = U_0$ in the electrolyte in the former, which is not observed in BG. This suggests that the NT has a *p*-type behavior for $U_g < U_0$ and *n*-type otherwise. The liquid-ion gating was also more effective than BG by a factor of more than 200. Time-independent measurements were carried out cyclically by sweeping U_g slowly (10 min/sweep); R change of about 20% with a small hysteresis was observed. Time-dependent measurements showed a much larger R change. In either case, U_0 was about 1 V in equilibrium.

According to the researchers, the MWNTs in air are hole-doped with a doping concentration of $\sim 10^{13} \text{ cm}^{-2}$ due to the adsorption of oxygen, leading to the Fermi energy E_F of about 0.3–0.5 eV. The electrolyte induces further doping, most likely due to adsorption of the (weakly) oxidizing species (in this case, the perchlorate ion ClO_4^-), leading to a charge transfer which partially oxidizes the NTs. The oxidation is weak in the sense that the NT carbon network is still preserved. The use of a stronger oxidizing electrolyte would shift the curve $R(U_g)$ farther to the right, while a reducing solvent would shift it to the left. The doping magnitude also depends on the electrolyte concentration. Polarizing the NT by an electrolyte allows E_F to move over a wide range, resulting in a large resistance change. NTs are possibly the most sensitive FETs for environmental application because the mobile NT carriers are in intimate contact with the environment—in this case, the electrolyte. In their report

published in the February 19 issue of *Applied Physics Letters*, the researchers also present a model to explain the physics of this experiment.

WIRAWAN PURWANTO

Naturally Occurring Vacancies Shuffle Low-Index Metal Surfaces

R. van Gastel, E. Somfai, S.B. van Albada, W. van Saarloos, and J.W.M. Frenken of Universiteit Leiden have reported in the February 19 issue of *Physical Review Letters* that atoms on the surface of low-index metal surfaces are in motion due to an ultralow density of surface vacancies that rapidly diffuse throughout the surface. Since no experimental techniques are available with both the spatial and the temporal resolution necessary to follow the diffusion of naturally occurring vacancies in a low-index metal surface, the researchers employed embedded indium “tracer” atoms on a copper surface to visualize the diffusive motion of surface atoms. They concluded

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that surface vacancies are responsible for the mobility of the indium, and that this metal surface is far from static, even at room temperature.

A single crystal of Cu (99.999% pure) was polished parallel to the (001) plane. It was cleaned by heating in Ar/H₂ to remove sulfur impurities, sputtering with 600-eV Ar ions in ultrahigh vacuum (UHV) with periodic exposure to a few Langmuir of O₂ to remove carbon, and annealing to 675 K. A 3% monolayer of indium was deposited on the Cu(001) surface from a Knudsen cell. The experiments were performed with a variable temperature scanning tunneling microscope (STM) in UHV. The diffusion of the indium atoms embedded in the copper terrace was followed by making a series of images of the same area on the copper surface to form an STM-movie of the motion (viewable at <http://lion.leidenuniv.nl/wwwhome/gastel/measurement.gif>).

The researchers discovered that the indium atoms move by long jumps of more than a single lattice spacing, separated by long time intervals, and that nearby indium atoms tend to jump at the

same time. The researchers said this strongly suggests that the diffusion of the indium is mediated by vacancies, which diffuse so rapidly that they remain undetectable by STM. The length of the long jump depends on the average number of times that a single vacancy changes places with the indium atom as the vacancy performs a biased random walk. The root-mean-square jump length of the indium atoms is 3.5 nearest-neighbor spacings, and it can be reproduced accurately in calculations if the chemical difference between indium and copper atoms is taken into account. Van Gestel favorably compares the continuous reshuffling of the surface to an atomic version of a slide puzzle.

ERIN S. CARTER

Nanoscale Patterning of Magnetic Recording Media Allows High-Density Data Storage

With the explosion of the Information Age, the demand for disk space keeps growing; however, magnetic-media manufacturers foresee the limits of the traditional scaling approach to achieving high-

er area densities where the signal-to-noise ratio is maintained while increasing bit density by reducing the grain size and preserving the number of grains per bit to several hundreds. In this approach, the grains will ultimately become small enough to become thermally unstable and undergo spontaneous reversals of their magnetization direction. One method for alleviating this effect is to create patterns of single-bit domains that have increased thermal stability due to the increased magnetic-switching volume. A group of researchers at the IBM Almaden Research Center in San Jose, California, reported systematic write-and-read experiments on magnetic media patterned at densities as high as 100 Gb/in².

As reported in the February 12 issue of *Applied Physics Letters*, the researchers used a focused Ga⁺ ion beam to cut 20-nm-wide trenches into 20-nm-thick perpendicular granular Co₇₀Cr₁₂Pt₁₈ recording media in order to create islands with lengths from 60 nm (100 Gb/in.²) to 230 nm (10 Gb/in.²). Using a static write-read tester, they have written square-wave bit patterns on these arrays of islands and found that

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read-back amplitudes depend strongly on the write phase, vanishing for writing out-of-phase on the single-domain islands as a result of the fact that bit transitions (domain walls) cannot be placed in the islands, and thus each island would have a 0.5 probability of being magnetized either up or down. The researchers also found evidence that for in-phase writing, there is a reduction of the read-back signal compared with the unpatterned media of identical linear density, which was linked to the reduction of magnetic material associated with patterning, although even the very smallest islands clearly exhibit a periodic signal. The work is still in its beginning stages, and it will continue focusing on improving the stability of the patterned island arrays.

CLAUDIU MUNTELE

Electrical Microdischarge Channel Integrated with Si p-n Diode Allows Efficient Generation of Visible/Near-IR Light

Efforts to generate visible or near-infrared radiation from silicon have a long history, but have been only moderately successful. External quantum efficiencies as high as ~1% are the most that could be obtained after extensive research. A research team from the Department of Electrical and Computer Engineering at the University of Illinois has taken a different approach to overcome the problem, integrating a reverse-biased silicon p-n junction with an electrical gas-discharge microchannel as reported in the February 5 issue of *Applied Physics Letters*. The gas discharge driven by a p-n junction offers the possibility of fabricating large arrays, and can be directly integrated with electronic and opto-electronic devices.

In designing these devices, C.J. Wagner, S.-J. Park, and J.G. Eden used commercially available diodes with the casings removed. After depositing a poly(methyl methacrylate) (PMMA) film around the perimeter of the exposed area for breakdown prevention, they drilled by ultrasonic milling a cylindrical channel through the ohmic contact and the p-n junction. The devices were then filled with the desired pressure of research-grade gas. For a Ne gas pressure of 700 Torr, the wavelength-integrated (300-800-nm) output power was ~48 μW for an operating current of 5.7 mA and a bias voltage of 134 V. Unlike previous hollow and planar cathode microdischarge devices fabricated in Si, no dielectric layer is required with this approach. The simplicity and robust structure of these hybrid semicon-

ductor/gas-discharge devices as well as their suitability for manufacture by conventional photolithographic and laser micromachining techniques make them attractive for arrays and on-chip atomic-frequency standards.

CLAUDIU MUNTELE

Single-Electron Inverter Achieves Voltage Gain of 2.6 at 25 mK

Theoretically, single-electron tunneling devices could be used for computation because they can be made very small and would consume little power. However,

few actual logic elements have been built and tested. C.P. Heij, P. Hadley, and J.E. Mooij from Delft University of Technology, The Netherlands, recently fabricated and experimentally tested a single-electron inverter.

As reported in the February 19 issue of *Applied Physics Letters*, the inverter consists of two identical single-electron transistors (SETs) in series, sharing a common input gate, bearing a strong resemblance to a standard complementary metal-oxide semiconductor (CMOS) inverter. Each SET contains a small aluminum island,

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capacitively coupled with the input voltage V_i through an 8-nm-thick Al_xO_y layer. Small tunnel junctions connect the transistors to power lead, output, and ground. A load capacitor connects the output to the ground to suppress charging effects. Two tuning gates, with voltages V_{g1} and V_{g2} , are used to tune the induced charges on the two islands.

The device was fabricated on a thermally oxidized silicon substrate using a high-resolution electron-beam pattern generator at 100 kV. A bottom layer of Al served as the lower electrodes of the gate capacitors and the load capacitor. An Al_xO_y dielectric layer was created upon these electrodes by oxidizing the sample in an O_2 plasma. A second (upper) layer of Al forms the aluminum islands and the leads; on this layer the four tunnel junctions were defined by shadow evaporation.

The inverter operates such that one SET is conducting while the other is in Coulomb blockade, depending upon the input voltage. Shifting the input voltage alters the induced charge on the SETs by a fraction of an electron and inverts the input.

Measurements were performed in a dilution refrigerator with a base temperature of 25 mK, while suppressing superconductivity using a 1 T magnetic field. The input-output behavior of this device varied greatly depending on the two gate voltages V_{g1} and V_{g2} . A maximum voltage gain of 2.6 was achieved at 25 mK, which remained larger than one up to about 140 mK, confirming that the device operated as designed. This is the highest temperature for which voltage gain in a SET has been achieved.

Inverters are building blocks for other digital logic elements, including NAND or NOR gates, SRAMS, and ring oscillators which should be producible from variations of or combinations of SET inverters. To date, however, there is no automatic method that would allow optimization of performance by adjusting gate voltages on-chip. The researchers state that "this is probably the largest problem inhibiting the further development of this sort of logic."

WIRAWAN PURWANTO

Electrophoretic Approach Results in 3D Assemblies of Gold Nanoparticles

A promising synthetic path for the preparation of three-dimensional (3D) films of gold nanoparticles has been described by a team of researchers at the Notre Dame Radiation Laboratory. In the February issue of *Nano Letters*, they report that highly porous nanostructured

films were assembled using an electrophoretic approach. The film thickness could be controlled by varying the concentration of gold colloids in solution and the applied voltage. The particles did not aggregate, as evidenced by the strong surface plasmon band.

The electrophoretic deposition method subjects colloidal solutions of tetraoctylammonium-bromide-capped gold nanoparticles of 5–10-nm diameter in toluene to a dc electric field (50–400 V). This results in a negative charge on the gold nanoparticles, which are then driven toward the positively charged electrode surface. In this study, the composite electrode consisted of an optically transparent electrode (conducting glass) onto which was cast a nanostructured TiO_2 film. The porous TiO_2 film is required for good deposition of the gold nanoparticles. The nanoparticles form a 3D array on the electrode surface without undergoing aggregation or inducing bulk film effects.

"We believe that the capping material acts as a spacer between the adjacent particles in the film," said senior research scientist Prashant V. Kamat, who conducted this study together with Nirmala Chandrasekharan, a postdoctoral re-

searcher at the Radiation Laboratory. "The films exhibit a strong surface plasmon band, which indicates that they retain their identity as individual nanoparticles." The thickness of the films can be controlled by adjusting the concentration of the colloidal solutions and the applied voltage.

The nanostructured films obtained by electrophoretic deposition are stable in atmosphere and highly porous, thus providing a large surface area for anchoring electroactive or photoactive molecules.

"To the best of our knowledge, this is the first report that highlights the feasibility of achieving relatively thick nanoporous gold films with minimal aggregation effects," said Kamat. "The ability to assemble gold nanoparticles as a 3D array of clusters opens new avenues for designing sensors and optoelectronic nanodevices. Nanostructured gold films of high surface area also have potential applications in catalysis and photoelectrochemistry."

CORA LIND

Self-Interstitial Clusters Diffuse Extremely Fast in Crystalline Silicon

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several small I_n clusters exhibit unexpected dynamic behavior and could dominate the precipitation of I 's under conditions of supersaturation. In the February 12 issue of *Physical Review Letters*, S.K. Estreicher and M. Gharaibeh of Texas Tech University, P.A. Fedders of Washington University, and Pablo Ordejón of Institut de Ciència de Materials de Barcelona report that *ab initio* molecular-dynamics (MD) simulations show that the di-interstitial (I_2) clusters and one particular tri-interstitial (I_3^a) cluster diffuse remarkably fast, too fast to be seen experimentally.

Ab initio MD simulations with pseudo-atomic basis sets (SIESTA) were performed in periodic supercells containing 64 (with four k -points), 128 (one k -point), and 216 (one k -point) host atoms. The basis sets varied from minimal (one set of s and p orbitals per Si atom) to double-zeta-plus polarization (two sets of s and p orbitals plus one set of d orbitals per Si atom). The electronic energy was obtained using density-functional theory within the local density approximation. The exchange-correlation potential was that of Ceperley-Adler as parameterized by S. Perdew and A. Zunger. Norm-conserving pseudopotentials in the Kleinman-Bylander form were used to remove the core electrons from the calculations. A time step of 2.0 fs was used in all the simulations.

After simulated quenching starting from many possible initial configurations, the researchers determined that only one configuration of I_2 and two configurations of I_3 are stable. Several structures for I_4 were also obtained. Constant-temperature MD simulations at 1000 K and 77 K show that I and I_4 behaved as expected, vibrating around their equilibrium sites. In the metastable I_3^b cluster, the three self-interstitials continuously exchange positions without motion of the center of mass of the defect. However, I_2 and I_3^a diffuse with remarkable ease. Both clusters are centered around a single bond-centered site and two (for I_2) or three (for I_3) I 's join forces to displace the same host atom, thus facilitating the exchange process and allowing fast diffusion.

DONALD F. CARTER

Aluminum Induces Crystallization in Amorphous Silicon at 150°C

Aluminum-induced crystallization (AIC) has been observed in amorphous silicon (α -Si:H) films. As reported in the February issue of *Electrochemical and Solid-State Letters*, researchers at the University of Arkansas deposited Al onto α -Si:H films and annealed them. Transmission electron microscopy (TEM) and x-ray diffraction (XRD) showed that crystallization occurred at 150°C and above. No further crystallization occurred after the Al was removed.

The α -Si:H films were deposited by ultrahigh-vacuum plasma-enhanced chemical vapor deposition (PECVD) onto carbon-coated nickel grids. A 50-nm-thick Al film was then deposited by vacuum evaporation. Next, the films were annealed at temperatures between 100°C and 250°C under 2 mTorr vacuum. The Al was removed by KOH etching.

TEM of a film annealed at 140°C for 20 min showed no large nucleation sites. The electron diffraction pattern (EDP) shows broad Si halos indicative of amorphous material. TEM of a film annealed at 150°C for 30 min, however, shows the film has completely crystallized into randomly oriented polycrystalline silicon, with grain sizes ranging from 0.2 to 0.5 μm . The EDP clearly shows the $\langle 111 \rangle$, $\langle 220 \rangle$, and $\langle 311 \rangle$ rings. At lower magnification, the micrograph shows a honeycomb-network morphology, which may indicate that the growth pattern of the polycrystalline silicon was dendritic. Similar features have previously been observed by other researchers.

For the XRD measurements, 400-nm-thick Al was deposited onto 500-nm thick PECVD α -Si:H. The area of the Si (111) peak was measured at different temperatures. At 140°C, there was no indication of crystallization. After 2–3 min at 150°C, the area of the peak began to increase. More than 40% of the film crystallized within 15 min. The Al was removed by etching and the XRD measurements were repeated, with temperatures up to 250°C. No increase in the (111) peak area was observed, implying that no crystallization occurred after the Al film was removed, even when annealed at 250°C for 20 min.

Since Al diffusion in α -Si:H at 150°C has been previously reported by several scientists, these researchers believe that the activation energy for crystallization was reduced by Al atoms in the α -Si:H. This agrees with previous work by other researchers showing that implanting P, B, or As in α -Si:H enhances the solid-phase crystallization.

ELIZABETH SHACK

High-Quality, Manganese-Doped ZnSe Nanocrystals Prepared by High-Temperature Organometallic Synthesis

A team of researchers has unveiled a method of preparing manganese-doped ZnSe nanocrystals that are not only superior to previously doped II–IV materials, but are also comparable in quality with the best-known undoped nanocrystals. In their work, published in the January issue of *Nano Letters*, D.J. Norris (NEC Research Institute), N. Yao (Princeton University), and F.T. Charnock and T.A. Kennedy of the U.S. Naval Research Laboratory have used an adapted version of the high-temperature, organometallic synthesis method developed by Hines and Guyot-Sionnest in 1998. Instead of the previously used organometallic source for Mn (diethylmanganese), the researchers used dimethylmanganese, whose lifetime is significantly longer.

To verify that Mn was actually embedded inside the ZnSe nanoparticles, instead of segregating to their surfaces as in the case of CdSe, the researchers applied optical, magnetic circular dichroism (MCD) and electron paramagnetic resonance (EPR) measurements. While photoluminescence and photoluminescence-excitation spectra showed successful doping, they could not guarantee that Mn was actually substituting for Zn in the nanocrystals. The confirmation for that came from the EPR results, which have shown values similar to those for Mn located at cubic lattice sites in bulk ZnSe. In addition to providing evidence for successful

doping, the MCD data also provided clues about the doping level in the samples prepared, with values within the limit of one manganese atom per crystal-lite or less, implying an atomic Mn:Zn ratio of 0.025–0.125%.

This simple method for preparing and testing high-quality ZnSe nanocrystals could provide a model for gaining a detailed understanding of dilute magnetic semiconductor nanocrystals and their potential applications such as trapped single-spin manipulation for the developing field of spintronics.

CLAUDIU MUNTELE

Reversible Thermal Denaturation of Immobilized Met-Hemoglobin Demonstrated

Enzymes, which have been extremely desirable catalysts for chemical reactions, are confined to use at room temperature because of their thermal instability. Immobilized met-hemoglobin (Fe(III) Hb), which showed peroxidase activity in the presence of hydrogen peroxide, is one such example. It starts to denature at 73°C with the loss of peroxidase activity and α -helical content. In the February issue of *Chemistry*

of *Materials*, professor C.V. Kumar and co-worker A. Chaudhari from the University of Connecticut report that Hb, immobilized at the galleries of α -zirconium carboxymethyl phosphonate (α -ZrCMP), did recover after heat denaturation.

The researchers used x-ray diffraction and spectral measurements of circular dichroism and Fourier transform infrared (FTIR) absorbance to verify the reversible thermal denaturation of immobilized Hb/ α -ZrCMP. The increased d spacings of the immobilized Hb on a series of galleries shrank upon heating; however, the d spacings of Hb/ α -ZrCMP recovered after cooling for an hour while the others did not, even after cooling for an extended period. Also, the native protein had characteristic bands in its circular dichroism spectra and IR absorption spectra. The characteristic bands of renatured Hb/ α -ZrCMP remained in position or nearly completely recovered after cooling. However, those characteristic bands either shifted or only partially recovered for other immobilized Hb after denaturation and cooling. The peroxidase activity of immobilized Hb/ α -ZrCMP after denaturation gradually recovered and reached

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100% recovery after an hour. Activities of free protein and immobilized Hb on other galleries recovered by at most 50%. The researchers believe that the combination of the three approaches demonstrate the first stoichiometrically recovered Hb/ α -ZrCMP. The researchers believe that the nature of the surface functions and the chemical reactivities of the support matrix played a very important role during this recovery process. The irreversibility of Hb/ α -ZrRP was due to the space orientation of the carbonyl group. The CH₂CH₂COOH group in Hb/ α -ZrCEP

(α -zirconium carboxymethylphosphonate) reacted with amines to form the amide that prevented the protein from recovering. But the CH₂COOH group in α -ZrCMP was inert to amines, and no amide formed. Thus, Hb/ α -ZrCMP could recover from its denaturation.

According to the researchers, "zirconium phosphonate support matrix with appropriate surface function may function as artificial chaperones for protein folding." In future studies, they plan to conduct molecular studies of these support surfaces for efficient refolding of proteins.

YING LI

Nanowires Fabricated by Step-Edge Decoration Process

Reginald Penner, a professor of chemistry at the University of California—Irvine, and graduate student researchers Michael P. Zach and Kwok Ng, have applied a method called step-edge decoration to build nanowires from molybdenum. The nanowires feature the conductivity, strength, and length necessary for use in microelectronic devices.

As reported in the December 15, 2000, issue of *Science*, the Penner group electrochemically deposited molybdenum dioxide onto a piece of graphite. Rudimentary wires began growing when their molecules linked onto step edges. After the brittle molybdenum dioxide wires were formed, they were heated in hydrogen gas at 350°C to remove the oxygen, leaving only the molybdenum metal.

The resulting pure molybdenum wires were smaller in diameter but also stronger, more conductive, and more flexible than those created in the first step of the process. The metal wires were then embedded in a polystyrene film and peeled off the graphite surface. The nanowires measured between 10 nm and 0.5 μ m in diameter and up to 100 μ m in length.

In developing a method to build long, uniform nanowires, Penner said that the step-edge decoration method used on graphite is proving to be more practical than using template synthesis, which is another fabrication method. When using templates, he said, a different one is needed for every diameter of wire, and thick templates required for the preparation of long nanowires are not readily available. The step-edge decoration process bypasses these obstacles. □

Correction

The figure in the February 2001 issue of *MRS Bulletin*, page 88, has been reproduced with permission from *Chemistry of Materials*; this is the web site version before publication of its modified version in the December 2000 issue.

Cost-Effective Portable Spin Coaters



KW-4A

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- Spin-up and flatten during Stage 2

Adjustable Speed

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- 2 to 18 seconds

Stage 2

- 1,000 to 8,000 rpm
- 3 to 60 seconds

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Features

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