and AlB_2-type superlattices after adding oleic acid…and into $NaZn_{13}$- or cuboctahedral AB_{13}-type BNSLs after the addition of dodecylamine or TOPO [tri-*n*-octylphosphine oxide], respectively."

The researchers said that entropic (i.e., space-filling or packing-density factors), as well as van der Waals, steric, and dipolar forces also stabilized the BNSL structures.

Integrated Optical Ring Resonator Demonstrated as a High-Sensitivity Biosensor

Over the last decade, optical biosensors have become increasingly indispensable tools in the life sciences, particularly in the area of drug research. These sensors need to be simple, reliable, and able to detect and identify extremely low concentrations of biological molecules. In an article in the December 15 issue of *Optics Letters* (p. 3344), Alex Ksendzov and Ying Lin of the Jet Propulsion Laboratory (JPL) in Pasadena, Calif., report the demonstration of a new optical biosensor based on a ring resonator that is able to detect concentrations of a test protein as low as 0.1 nM.

State-of-the-art optical biosensors are based on "whispering gallery" modes, which guide light along the surface of a spherical microstructure. The term is derived from the Whispering Gallery of St. Paul's Cathedral in London, where the curvature of the dome allows a whisperer near one wall to be heard by a listener near the opposite wall. Proteins binding to the surface of the device alter the index of refraction experienced by the light, and thus change the resonant frequency of the optical mode. However, these modes are numerous and closely spaced in frequency, which complicates the data collection and analysis for small signals.

Instead, the research team's biosensor is based on a 1.8-μm-thick Si_xN_y/SiO_2 waveguide bent into a "racetrack" ring resonator with a 13-mm circumference. This device has simple optical modes that are easily identified by transmission resonances. To demonstrate the resonator's sensitivity, the researchers coated its surface with biotin, which has a specific and extremely high affinity for the glycoprotein avidin, and then flowed 3 nM, 0.6 nM, and 0.3 nM concentrations of avidin past the device. By varying the temperature and thus the length of the resonator, the team could locate the transmission resonance frequency. As avidin from the flow accumulated on the resonator surface, the resonance frequency shifted in time, with a rate that was proportional to the protein concentration. Given background drifts, the team estimated that this shift would be measurable for avidin concentrations as low as 0.1 nM (6.8 ng/ml). This is many orders of magnitude more sensitive than most optical biosensors and may be further enhanced as the team implements plans to improve the quality of the biotin coating and the temperature control and monitoring. Integrated ring resonators carrying a variety of protein-binding coatings may ultimately become the basis for large biosensor arrays for use in pharmaceutical biomolecule identification.

COLIN MCCORMICK

Electronic Carriers Cross Si-Bound Alkyl Monolayers in Two Ways

In order to uncover whether organic molecules can be used to pass electrical current, researchers first need to understand how electrons pass through molecules. "To answer this question," said David Cahen of the Department of Materials and Interfaces at the Weizmann Institute of Science in Israel, "we need to design, build, and use a system that is sufficiently well controlled so that we can be sure that we are measuring what we think we are measuring." Cahen, collaborating with an international group of researchers, has built such a system and has shown that electrons pass through the system by two different mechanisms, switching from one to the other depending on how much voltage is applied and on the length of the molecules.

As reported in the December 31, 2005, issue of *Physical Review Letters* (DOI: 10.1103/PhysRevLett.95.266807; #266807) the researchers—Cahen, T. Boecking of the University of New South Wales in Australia, C.K. Chan of Princeton University, and colleagues—studied a system of Si-C linked alkyl monolayers sandwiched between a metal (Hg) and semiconductor (*n*-Si). They discovered that at low forward-bias voltages, the electrons behave quasi-classically, and the temperature-dependence of the current suggests that current is limited by thermionic emission over a barrier in the semiconductor. At higher forward-bias voltages, the electrons behave as waves, and the dependence of the current on the length of the molecules suggests that current is limited by tunneling through the molecules. The researchers said that the longer the molecules, the lower the voltage at which the molecules start to control the current (see Figure 1).

Control samples of monolayers on silicon were characterized using both photoemission and other spectroscopies as well as advancing water contact angle (CA). Only samples with CA >110° on Si were used for electrical measurements. With these results and current–voltage measurements, the electron transport processes could be described quantitatively, said the researchers.

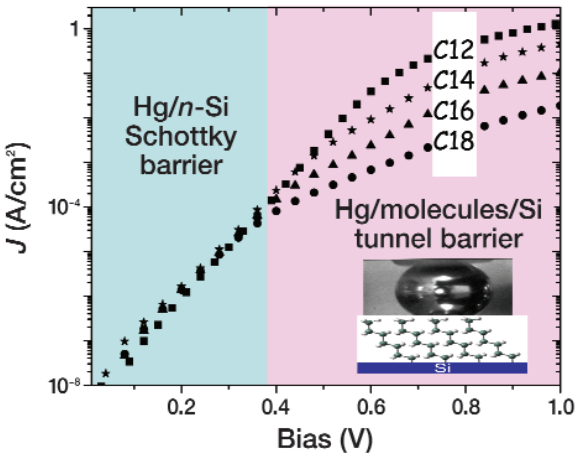

Figure 1. Experimental n-*Si-*$(CH_2)_{n-1}CH_3$*/Hg J–V curves.*

The researchers said, "Our results agree with theoretical predictions for semiconductor/insulator/conductor solar cells that had not been seen till now, because no suitable insulator was found."

Cahen added, "Agreement between experiment and theory breaks down, though, for the temperature-dependence of the current–voltage characteristics, where the signature of the presence of molecules (rather than of, say, an oxide) is seen."

Cellular Uptake of Functionalized Carbon Nanotubes Shown to be Energy-Dependent

Recent research has shown that single-walled carbon nanotube (SWNTs) can transport peptides, proteins, and nucleic acids into living cells. The biocompatibility and nontoxicity of SWNTs, together with their near-IR absorptivity, make them a promising new class of biotransporters for drug and radiation therapies. Recent studies conflict on the mechanism that regulates the cellular internalization of SWNTs. One suggests an energy-independent mechanism involving insertion and diffusion of the SWNTs through the cell membrane, while another suggests endocytosis,

https://doi.org/10.1557/mrs2006.34 Published online by Cambridge University Press

a general entry mechanism that is energy-dependent. Recently, however, N.W.S. Kam, Z. Liu, and H. Dai from the Department of Chemistry at Stanford University have demonstrated the SWNT cellular entry mechanism to be endocytosis.

As reported in a recent issue of *Angewandte Chemie International Edition* (DOI: 10.1002/anie.200503389), Dai and co-researchers undertook a systematic investigation of the cellular uptake mechanism of SWNTs. The researchers used sonication to obtain short (~50–200 nm) individual SWNTs and small SWNT bundles, which they characterized by atomic force microscopy. Non-oxidized SWNTs were used for complexation with nucleotides and acid-oxidized SWNTs for complexation with proteins. The researchers incubated the functionalized SWNTs with mammalian cells in solution at 37ºC and observed cellular uptake of the nanotubes with confocal fluorescence microscopy and flow cell cytometry.

Cellular uptake of SWNTs was reduced substantially when incubation was performed at 4ºC or under adenosine-triphosphate-depleted conditions, which indicated to the researchers that endocytosis is the internalization mechanism. Endocytosis encompasses several specific pathways, the most common of which takes place mainly through clathrin-coated pits in the cell membrane. Incubations performed under conditions known to disrupt the formation of clathrin-coated vescicles in cell membranes were found to drastically reduce cellular internalization of SWNTs. However, cells pretreated to disrupt an alternative caveolae endocytosis pathway, which involves membrane domains enriched with the protein cavelin, did not result in diminished SWNT cellular uptake.

These results suggested to the researchers that the specific mechanism for cellular uptake of short, dispersed, functionalized SWNTs is clathrin-dependent endocytosis. The researchers said, "Establishment of the entry mechanism is of fundamental importance and will facilitate future developments of carbon nanotube transporters for biological delivery applications."

STEVEN TROHALAKI

Xenon Flash Lamp Annealing Shown to be Effective for Processing Ultrathin HfO2 Films for Advanced CMOS Gate Dielectrics

To maintain the current pace of innovation in the silicon-based microelectronics industry, new materials with superior properties must be identified and integrated for next-generation devices. An excellent example is the search for alternative high-dielectric-constant (high-κ) materials to replace silicon dioxide (SiO_2) as the gate dielectric in advanced complementary metal oxide semiconductor (CMOS) devices. Since candidate high-κ materials lack the thermal stability of SiO_2 at temperatures used in CMOS processing steps, alternative annealing techniques are being explored. S. Kamiyama, T. Miura, and Y. Nara of Semiconductor Leading Edge Technologies Inc. in Tsukuba, Japan, have determined that xenon flash lamp annealing (FLA) may be used to reduce the thermal budget during CMOS processing because of the short anneal times (<1 ms). They based their conclusions on their study of the effect of xenon FLA on the structural and electrical characteristics of hafnium dioxide (HfO_2), a promising high-κ material.

As reported in the December 2005 issue of *Electrochemical and Solid-State Letters*

Single-Particle Microbatteries Exhibit Behavior Similar to Commercial Batteries

To further develop microsensor technology, reliable aqueous micropower sources such as microbatteries are needed. These microbatteries should demonstrate behavior comparable to those made by commercial manufacturers to be successful in applications ranging from bioengineering to defense. As reported in the December 2005 issue of *Electrochemical and Solid-State Letters* (p. A622), A. Palencsár and D.A. Scherson of Case Western Reserve University have developed a method for assembling and characterizing Zn-MnO_2 and Ni metal hydride—the two most common commercially used aqueous systems for alkaline batteries—using single microparticles of these materials. The results of this research suggest the microbatteries show voltage–time profiles similar to those of commercially available batteries involving the same chemistries.

For both the Zn-MnO_2 and Ni-MH systems, microparticles of the active materials were brought in contact with individual current collectors (typically gold microdisk electrodes or tungsten spears) and immersed in 9 M solutions of KOH. Assemblies of both microbattery systems are shown in Figure 1. The performance of these micropower sources was assessed in a fashion typical for commercial devices, that is, by measuring voltage versus time under constant charge or discharge currents, also referred to as the C-rate, where 1 C is defined as the current required for the nominal capacity of a battery to be consumed in one hour. The voltage versus time (or discharge) curve for a Zn-MnO_2 microbattery, incorporating a ~150-μm-diameter particle of Zn and a ~30-μm-diameter particle of MnO_2 and recorded at a rate of 2 C, is nearly identical to that of a commercial AA battery discharged at C/330. The Ni-MH model microbattery also displayed a behavior similar to conventional batteries. As in commercial devices, said the researchers, the microbattery cathode material, MnO_2 or Ni oxide, respectively, limited the capacity.

ADITI RISBUD

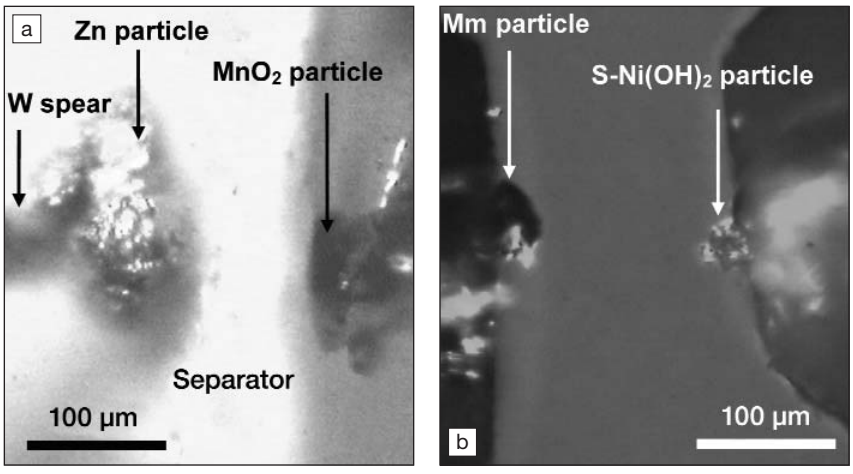

Figure 1. Micrographs of (a) assembled Zn-MnO_2 and (b) Ni-MH microbatteries. The separator in (b) was not included for clarity. Reprinted with permission from Electrochemical and Solid-State Letters ***8*** *(12) (2005) p. A622. © 2005 The Electrochemical Society.*

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