First, the investigators patterned fuel channels of 80–90 μm depth by photolithography and wet etching a highly doped Si wafer. An *n*-type Si wafer was chosen because of its higher wet-etching rate with low resistivity to ensure it worked as a current collector. A 100 nm copper layer was sputtered on the Si wafer to supply current from a potentiostat. On the opposite side, anodization of the Si wafer in a 46% HF-ethanol solution using a current density of 100 mA/cm^2 resulted in a porous Si layer that grew up to the base of the fuel channels at a rate of 45 nm/s. These were the optimal conditions found for formation of a uniform porous Si layer. Anodizing typically lasted for 5–6 min, as observed experimentally. A catalyst layer was later deposited on the porous Si layer by using a plating bath of 1.0 M H_2SO_4 + 10 mM H_2PtCl_6 + 5 mM K_2RuCl_5 + 50 mM HF at 293 K. The hydrofluoric acid added to the bath removed any silica present at any stage and resulted in electroless deposition of Ru and Pt. Thus, combining the HF addition to the bath with the use of a pulse plating technique assured the deposition of catalyst metal ions inside the pores of the catalyst layer. Otherwise, it was not possible to obtain coverage inside the pores since the catalyst metal ions were not able to reach the pores by electrodeposition means exclusively. The pulse plating technique utilized consisted of applying a current of 5 mA/cm^2 at a frequency of 1 Hz for 0.2 s followed by a halt of 0.8 s. This cycle was repeated for 5 min, obtaining coverage toward the porous Si layer to a depth of 10 μm. The Si wafer was then immersed in a 40% $FeCl_2$ solution at 313 K for 3–5 min to remove the copper layer. Two Si wafers thus processed were hot pressed with their catalyst sides facing top and bottom of a Nafion 112 piece, which worked as a polymer electrolyte membrane, using Nafion 5% solution as an adhesive. Hot pressing was accomplished at 0.05 MPa and 443 K for 30 min. The total thickness of the miniature fuel cell thus assembled was 250 μm.

Testing the full assembly with hydrogen gas gave a peak power of 1.5 mW/cm^2 at 353 K, and the porous Si layer indeed functioned as a current collector, reported the researchers. They said that the parabolic shape of the polarization curves show that the controlling mechanism is the catalyst performance. Power-generation capabilities of this miniature fuel cell are better than those of similar structure not using activated carbon as a catalyst layer, they said.

SIARI SOSA

Electrochemical Polishing Technique Yields Apparatus for Manipulation of Micro- to Nanometer-Sized Magnetic Beads

To date, the application of miniature electromagnets for molecular and cellular manipulation has been limited by weak magnetic field gradients and resultant weak magnetic forces that are produced by these devices. A further complication is resistive heating of the electromagnet that may damage living cells and lead to expansion of the material used for the electromagnet core. This thermally induced expansion diminishes the ability to control the level of applied force. For example, precisely controlled forces in excess of 100 pN are required to produce nanometer-range displacements of a 4.5-μm diameter magnetic microbead and the adhesion receptor on a living cell. B.D. Matthews of Harvard Medical School, D.A. LaVan of Yale University, and their colleagues have fabricated a temperature-controlled electromagnetic microneedle (EMN) capable of forces >50 nN with minimal heating.

As described in the October 4 issue of *Applied Physics Letters* (p. 2968), Matthews and co-workers have developed a novel electropolishing technique to create micromagnetic pole tips for controlled manipulation, probing, and positioning of magnetic particles. Their apparatus consists of multiple loops of insulated electromagnetic wire coiled around a permalloy magnetic core (1 mm diameter). Copper wire (50 μm diameter, 44 gauge) was wound around the magnetic core. Typical electromagnets in this study had 2000 turns of wire, a resistance of 16 Ohms, an inductance of 1.4 mH, and a capacitance of less than 2 pF. The core and electromagnet wires were housed within a temperature-regulated water flow chamber. Two 1-mm diameter plastic shields were fitted over the ends of the core, with an exposed section of the wire between them. The exposed end of the rod was initially electropolished in an 8:7:5 phosphoric acid, sulfuric acid, and water solution with an applied potential of 6 V. After the core diameter was reduced by 50%, the plastic shield was removed from the distal end of the rod and electropolishing continued at a 4 V applied potential until the distal end broke off. The final tip geometry was determined by the initial surface area exposed between the two plastic sleeves. Optical micrographs show that the technique is reproducible.

The researchers concluded that the magnitude of the magnetic field gradient generated by the EMN is primarily a function of the needle tip. EMNs with large tip radii (20 μm) are capable of interacting with multiple beads, they said. Electropolishing to smaller radii (0.1–6 μm) allows selective capturing of single magnetic beads. The researchers demonstrated removal of a single 4.5 μm superparamagnetic bead from a group of similar ones, less than 10 μm from each other. It is then possible, they said, to relocate the bead by moving the needle and simply shutting off the current. The researchers demonstrated that 50 nN forces could be applied to 4.5 μm diameter beads using an EMN with a pole tip radius of 20 μm, while more than 1 nN could be applied to 250 nm diameter beads using an EMN with a pole tip radius of 100 nm.

JEREMIAH T. ABIADE

Bacteria Use "Molecular Lasso" to Cop Copper

The bacteria that destroy about one-third of the potent greenhouse gas methane before it can reach the atmosphere produce a small organic compound and release it into the surrounding environment, where it "lassos" atoms of copper. The bacteria then reabsorb the compound and use the copper as a weapon against methane, from which they extract energy. The crystal structure of the compound, called methanobactin, is reported in the September 10 issue of *Science* (p. 1612). The research was led by H.J. Kim, who did much of the work as a graduate student at the University of Kansas and is now a postdoctoral associate at the University of Minnesota College of Biological Sciences. Methanobactin may have antibacterial properties, and its ability to absorb copper may find application in the semiconductor industry, which needs copper-free water.

The methanobactin molecule is a tiny, pyramid-shaped compound with a cleft that holds a single atom of copper in place. The researchers identified the components as a tetrapeptide, a tripeptide, and several moieties, including two 4-thionyl-5-hydroxy-imidazole chromophores that coordinate the copper, a pyrrolidine that confers a bend in the overall chain, and an amino-terminal isopropylester group. The copper coordination environment, found at the base of the pyramid structure, includes a dual N- and S-donating system derived from the thionyl imidazolate moieties.

The bacteria that make methanobactin are common. "These bacteria are often found in rice paddies and wetlands," said Kim. "Methane is produced in the bottom muck and diffuses into the water, where these bacteria live. The bacteria sequester the methane and turn it into methyl alcohol."

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The bacteria churn out methanobactin molecules in large numbers and send them into the environment to fetch copper. When the compound returns with copper, it is thought that the copper is incorporated into molecules of a key enzyme that converts methane to methyl alcohol. Due to its high reactivity, copper would be an appropriate atom to metabolize methane. Their reactivity also makes copper atoms toxic to the bacteria. Thus, methanobactin serves to keep copper under control and protect the bacterial cells from it, said the researchers.

One piece of the story still to be learned is how the methanobactin is retrieved by bacterial cells, Kim said. The cells apparently latch onto copper-bearing methanobactin molecules, but what happens next is unknown. Methanobactin has no tether to its mother cell. Therefore, when bacterial cells release their methanobactin molecules, they probably never see them again; instead, they take delivery of copper from methanobactin released by other cells of the same species, the researchers said

"Synthesized compounds analogous to some parts of the methanobactin molecule have been shown to be antibacterial," said Kim.

SnO_2 Nanoribbons Channel Light at the Nanoscale

In photonics technology, the use of electrons moving through semiconductors as information carriers is replaced with the movement of photons. For the promise of photonics to be delivered, however, scientists need to manipulate and route photons with the same dexterity as they do electrons. Peidong Yang's research team at Lawrence Berkeley National Laboratory and the University of California at Berkeley have demonstrated that semiconductor nanoribbons can serve as waveguides for channeling and directing the movement of light through circuitry.

"Not only have we shown that semiconductor nanoribbons can be used as low-loss and highly flexible, optical waveguides, we've also shown that they have the potential to be integrated within other active optical components to make photonic circuits," said Yang.

"Chemically synthesized nanowires and nanoribbons have several features that make them good photonic building blocks," Yang said. "They offer inherent one-dimensionality, a diversity of optical and electrical properties, good size control, low surface roughness, and, in principle, the ability to operate above and below light diffraction limits."

As reported in the August 27 issue of *Science* (p. 1269), Yang and his colleagues synthesized their nanoribbon waveguides from tin oxide. The single-crystalline nanoribbons measured ~1500 μm in length and featured a variety of widths and thicknesses. Yang said ribbons measuring 100–400 nm in width and thickness proved to be ideal for guiding visible and ultraviolet light.

"To steer visible and ultraviolet light within dielectric waveguides such as the tin oxide crystals we were synthesizing, we needed to make sure that a sufficient portion of the light's electromagnetic field was confined within the nanostructures so there would be minimal optical transmission loss," Yang said. "Considering the dielectric constant of the tin oxide, it follows that the diameter of 100 to 400 nanometers would be ideal for waveguiding light that measures from 300 to 800 nanometers in wavelengths." In their tests, Yang and his colleagues attached nanowire light sources and optical detectors to opposite ends of their tin oxide nanoribbons, then demonstrated that light could be propagated and modulated through subwavelength optical cavities within the nanoribbons. The nanoribbons were long and strong enough to be pushed, bent, and shaped with the use of a commercial micromanipulator under an optical microscope. Freestanding ribbons were also extremely flexible and could be curved through tight S-turns and twisted into a variety of shapes, which Yang said is "remarkable for a crystal that is brittle in its bulk form."

According to the researchers, while the nanoribbon waveguides can be coupled together to create optical networks that could serve as the basis of miniaturized photonic circuitry, the ribbons need to be in close proximity, preferably in direct physical contact, to enable an efficient transfer of light between them (see Figure 1).

Yang said, "We tested various coupling geometries and found that a staggered side-by-side arrangement, in which two ribbons interact over a distance of several micrometers, outperforms direct end-to-end coupling."

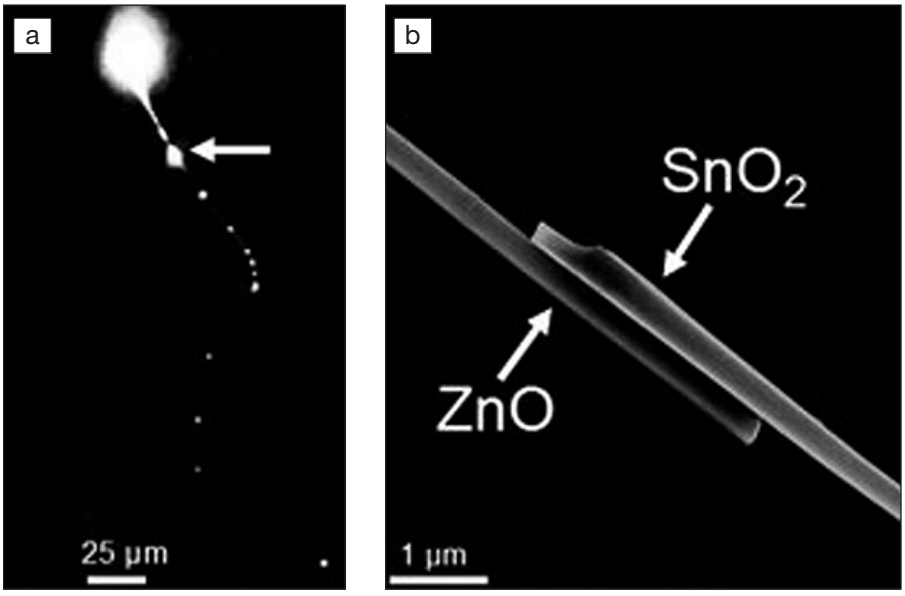

Figure 1. (a) A zinc-oxide nanowire laser is pumped with light, which is channeled into a tin-oxide nanoribbon at a junction between the two materials and guided through the rest of the ribbon's length; (b) an electron microscope image of the junction between wire and ribbon.

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