given the other experimental variables employed. By staining the bacteria with a fluorescent dye, the researchers were able to monitor the manipulation of the bacteria with a fluorescence microscope.

By controlling the current in each wire of the matrix, versatile manipulation of the bacteria could be achieved. For example, the researchers transported multiple groups of bacteria independently along different paths and oriented individual bacterium. The assembled magnetic nanostructures, which were exposed when the researchers lysed the cells and removed the cellular membranes and other debris, were viewed with scanning electron microscopy. Examples of the nanoassemblies include a long chain of spherical nanomagnets and a ring of magnetic nanoparticles, resembling a pearl necklace, formed by trapping two bacteria.

The researchers said, "Using an electric field for manipulation, [our] method… can be extended to assemble other types of biogenic nanoparticles, for example, silver or gold nanocrystals in bacteria, or cadmium sulfide nanocrystals in yeast." They said that biomineralization and micromanipulation can be combined to grow and assemble nanoparticles into customized structures.

STEVEN TROHALAKI

Organic–Inorganic Hybrid Electrolyte Membrane Achieves Thermal Stability above 100°C

Proton conductors are attractive materials because of their application in fuel cells, proton sensors, and ion-exchange membranes. However, currently available materials suffer from a decrease in conductivity at temperatures above 80°C and are unstable above 100°C. A group of researchers in Japan from the Himeji Institute of Technology, the New Glass Forum Osaka Research Laboratory, the Kobe University of Mercantile Marine, the National Institute of Advanced Industrial Science and Technology, and Kyoto University has developed an organic–inorganic hybrid ionic conductive material with chemical resistance and thermal stability above 100°C.

As reported in the March issue of the *Journal of the American Ceramic Society* (p. 504), T. Yazawa of the Himeji Institute of Technology and co-workers fabricated a porous glass by phase separation and later modified its surface by attaching thiol groups. The modification was performed by the reaction of the glass with (3-mercaptopropyl)trimethoxysilane. The thiol groups were later oxidized in concentrated HNO_3 to obtain sulfonic acid groups, which are effective donors of protons. The pore size and pore volume of the samples were measured by nitrogen absorption isotherms; the researchers also studied their surface acidity and conductivity.

The conversion of the thiol groups on the surface upon oxidation to sulfonic acid produced an increase in the surface acidity. The intrinsic acidity constant pK_a

Circular Photonic Crystals Allow Formation of an Isotropic Photonic Bandgap

One of the main advantages of photonic crystals is their ability to inhibit spontaneous emission of light. An isotropic photonic bandgap has been previously proposed to suppress spontaneous emission in all directions. To date, two vehicles used to obtain an isotropic bandgap are quasi-crystals and amorphous (i.e., disordered) photonic materials. In the May 15 issue of *Optics Letters* (p. 1084), N. Horiuchi of RIKEN, T. Nozokido of Tohoku University, and their colleagues have reported that circular photonic crystals (CPC) are yet another route to the formation of an isotropic photonic gap. Disordered materials are inherently difficult to design for specific bandgaps due to their random nature. The advantage of the CPC over disordered materials is that the CPC has a very structured design that allows *a priori* determination of the bandgap.

The CPC was fabricated by carefully arranging 30 mm alumina rods (with a refractive index of 3.1) in concentric circles, similar to microstructured optical fiber. The number of circles was varied between 10 and 108. While no translational symmetry exists in such a structure, triangular and square-like lattices appeared within different regions of the structure. In order to minimize this, a random phase shift from 0 to $\pi/3$ of the sixfold symmetry for each circle was employed, as shown in the Figure. In this way, the distance between rods within a concentric circle is constant. Despite the phase shift, the nearest-neighbor distance also remains unchanged.

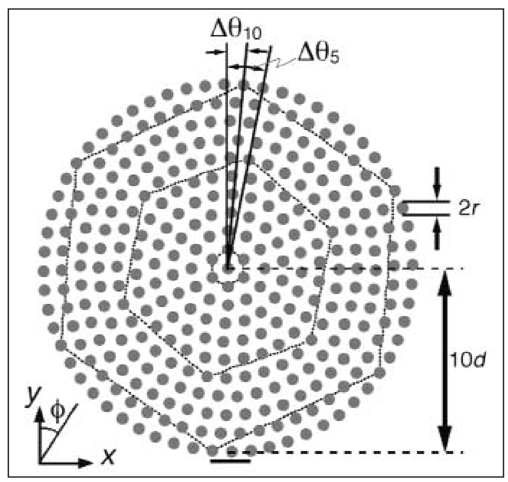

Figure. A circular photonic crystal composed of 10 concentric circles with a small phase shift (Δθ) to reduce the appearance of ordered regions. The bar at the bottom indicates the position of the probe antenna, d *is the radial distance, and* r *is the radius of the rods. The angle of the incidence of the millimeter wave* ϕ *is zero when parallel to the* y *axis.*

The transmission of a millimeter wave into the CPC was measured by irradiating the CPC with a transverse magnetic-polarized wave incident from a direction orthogonal to the longitudinal axis of the rods. The signal strength inside the CPC was measured by placing a probe antenna within it. Multiple measurements were made, and the resulting transmission spectra showed a bandgap between 9.1 GHz and 14.0 GHz. Theoretical calculations were in close agreement with the experimental findings. Angle-resolved measurements showed no significant change in the bandgap, indicating an isotropic photonic bandgap. It was found that an exterior part of CPC with a large number of concentric circles (108) yielded a 1 GHz shift upwards in the lower band edge, but the bandgap was otherwise unaffected.

The researchers said that the isotropic bandgap is found not only at the axis of the concentric circles, but throughout the structure. This suggests, they said, that the isotropic photonic bandgap is the result of the short-range order of the CPC. The research team said that a practical application of this technology, beyond that of suppressing spontaneous emission, is the ability to create two-dimensional waveguides by line defects with arbitrary bend, since the technology is not restricted to the photonic crystal lattice.

JEFFREY DIMAIO

https://doi.org/10.1557/mrs2004.111 Published online by Cambridge University Press

of the sample surface increased from a value between –5.6 and –3 to a pK_a of –1.2. The pore volume decreased after surface modification from 0.143 cm^3/g to 0.083 cm^3/g, indicating that the sulfonic groups covered the pore surface of the sample. The conductivity of the samples was measured at 95% and 100% relative humidity at temperatures ranging from 40°C to 120°C. The maximum value of conductivity was 4.2×10^{-2} S/cm at 120°C and 100% relative humidity. Under these conditions and after being in contact with methanol, the sample did not suffer any degradation. The research team reports that these results show the good mechanical and thermal stability of the material, making it a good candidate for electrolyte membranes in the direct methanol fuel cell.

This ionic conductive material overcomes the limitations in operating temperature and water swelling of currently used proton conductive membranes such as Nafion. The researchers said that the thermal stability of their material originates from the thermal stability of porous glass and the covalent bond formed between the organic molecules and the glass surface.

"By this process, we can obtain well-designed organic–inorganic nano hybrid materials," Yazawa said.

MARIA CORTALEZZI

Garnet/SOI Magneto-Optical Devices Fabricated by Direct Wafer Bonding

Silicon-on-insulator (SOI) is an attractive substrate for dense integrated optical circuits because of its high index contrast, which allows small, high-performance components such as waveguides, bends, splitters, and modulators. In addition, SOI substrates allow seamless integration with electronics for on-chip optical devices. Current integration schemes for garnet–semiconductor devices are insufficient due to the difficulty of alignment with active devices on the semiconductor substrate or small nonreciprocal phase shifts, requiring long device lengths. In the May 1 issue of *Optics Letters* (p. 941), R.L. Espinola of Columbia University, H. Dötsch of the University of Osnabrück, and their colleagues have reported an integrated magneto-optical (MO) device design consisting of a garnet film directly bonded to SOI waveguides. Theoretical predictions indicate their design can achieve a threefold enhancement of the nonreciprocal phase shift over previous designs.

Optical isolators or circulators are important components for photonic integrated circuits. To date, neither has been developed in SOI or any integrated materials platform. Optical isolator research generally focuses on the MO effect in a magnetic garnet film. A promising concept depends on the nonreciprocal phase shift—the difference between the forward and backward propagation constants. To measure the nonreciprocal phase shift, the researchers fabricated thin Si waveguides onto an SOI wafer with e-beam lithography, thermal evaporation, and reactive ion etching. Bismuth-lutetium-neodymium-substituted iron garnet (BiLuNd-IG) was deposited epitaxially on gadolinium gallium garnet, and then bonded to Si waveguides by using a direct wafer-bonding technique. The BiLuNd-IG layer showed an optical loss of 12.6 dB/cm. Optimizing the growth conditions for the garnet materials can result in absorption losses as low as 0.5 dB/cm.

The researchers have demonstrated that miniaturized integrated devices, such as optical isolators and circulators, are possible by directly bonding SOI waveguides and a magneto-optical material. They said that the use of a standard semiconductor substrate simplifies the materials design for large-scale photonic integrated circuits.

JEREMIAH ABIADE

Mullite Powders Produced by Heterogeneous Nucleation

Fabrication of ceramic components usually involves the sintering of fine powders by various methods that ensure a homogeneous particle size distribution. Additionally, in the case of composite materials, a homogeneous distribution of the second phase becomes key in obtaining a high-quality product with the desired properties. Mullite ($3Al_2O_3{\cdot}2SiO_2$) is a ceramic material widely used in electronic applications, and a wide variety of methods are available for preparing mullite powders. Heterogeneous nucleation has been proposed as an alternative technique by Y.F. Tang of Nanjing University, Z.D. Ling of Nanjing University of Technology, and their colleagues. These investigators have developed a technique to process fine mullite powders from alumina particles coated with amorphous silica. With this method, they delivered a highly homogeneous fine powder, as they explain in the March issue of the *Journal of the American Ceramic Society* (p. 520).

With a combination of α-alumina particles with an average size of 0.26 μm and tetraethylorthosilicate, the investigators formed a supersaturated silica sol suspension. Transmission electron microscopy revealed a silica layer of ~20 nm on each alumina particle, formed by heterogeneous nucleation and growth. They calcined the composite particles in 50 g batches, in temperatures ranging between 1400°C and 1600°C, and then ball-milled the resulting powders with alumina ceramic balls for 6 h.

X-ray diffraction (XRD) patterns revealed that the choice of temperature used to calcine the powders influenced the type of phase and amount present. After calcinations for 2 h at 1400–1450°C, the researchers observed small amounts of cristobalite and corundum together with mullite as the larger constituent. Even after calcining for 48 h, cristobalite and corundum were still present. At 1500°C, the powders were exclusively mullite and as the temperature was increased to 1600°C, the XRD pattern peaks sharpened. The single-phase mullite obtained showed a fine uniform particle size distribution with an average particle diameter of 0.53 μm, as observed by scanning electron microscopy.

SIARI SOSA

Vertical InP Nanowire Arrays Fabricated by Nanoimprint Lithography

Semiconductor nanowires have been widely studied in the applications of electronics (such as resonant tunneling diodes and single-electron transistors), photonics (such as light-emitting diodes), and life science. Numerous studies have focused on how to control the growth of nanowires in arrays and understand their electrical and optical properties. T. Mårtensson, L. Samuelson, and their colleagues from the Nanometer Consortium at the Lund University, Sweden, have implemented nanoimprint lithography in order to fabricate arrays of vertical semiconductor nanowires.

Nanoimprint lithography achieves comparable results as electron-beam lithography, but at a lower cost and with higher throughput. As reported in the April 14 issue of *Nano Letters* (p. 699), a stamp was made on a silicon wafer using electron-beam lithography and dry etching in a SF_6/O_2 atmosphere. A double resist layer consisting of a PMMA950k layer over a lift-off ZEP520A7 film was exposed by the electron beam. Next, 30 nm of chromium was evaporated on the developed resist and then lifted off. The chromium then served as a mask for the reactive ion etch. After such treatments, columns with a height of 300 nm and a top diameter of 200 nm were arranged in a hexagonal pattern with a nearest-neighbor distance of 1 μm on the silicon wafer. Wet etching was used to remove the remaining chromium. A monolayer of tridecafluoro

https://doi.org/10.1557/mrs2004.111 Published online by Cambridge University Press