

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  $0.143 \text{ cm}^3/\text{g}$  to  $0.083 \text{ cm}^3/\text{g}$ , 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  $40^\circ\text{C}$  to  $120^\circ\text{C}$ . The maximum value of conductivity was  $4.2 \times 10^{-2} \text{ S/cm}$  at  $120^\circ\text{C}$  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 three-fold 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 mate-

rials 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  $12.6 \text{ dB/cm}$ . Optimizing the growth conditions for the garnet materials can result in absorption losses as low as  $0.5 \text{ dB/cm}$ .

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 ABIJADE

### 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 ( $3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$ ) 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  $\alpha$ -alumina particles with an average size of  $0.26 \mu\text{m}$  and tetraethylorthosilicate, the investigators formed a supersaturated silica sol suspension. Transmission electron microscopy revealed a silica layer of  $\sim 20 \text{ nm}$  on each alumina particle, formed by hetero-

geneous nucleation and growth. They calcined the composite particles in 50 g batches, in temperatures ranging between  $1400^\circ\text{C}$  and  $1600^\circ\text{C}$ , 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  $1400$ – $1450^\circ\text{C}$ , 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  $1500^\circ\text{C}$ , the powders were exclusively mullite and as the temperature was increased to  $1600^\circ\text{C}$ , the XRD pattern peaks sharpened. The single-phase mullite obtained showed a fine uniform particle size distribution with an average particle diameter of  $0.53 \mu\text{m}$ , 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  $\text{SF}_6/\text{O}_2$  atmosphere. A double resist layer consisting of a PMMA950k layer over a lift-off ZEP520A7 film was exposed by the electron beam. Next,  $30 \text{ nm}$  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  $300 \text{ nm}$  and a top diameter of  $200 \text{ nm}$  were arranged in a hexagonal pattern with a nearest-neighbor distance of  $1 \mu\text{m}$  on the silicon wafer. Wet etching was used to remove the remaining chromium. A monolayer of tridecafluoro