Microspheres Function as Microlenses for Projection Photolithography

Arrays of patterns with features smaller than 200 nm are being generated using a form of photolithography employing transparent polystyrene microspheres as microlenses. George M. Whitesides and Ming-Hsien Wu, both of Harvard University, report in the February 26 issue of *Applied Physics Letters* that their method offers a size reduction of features by factors of ≥1000 in a single exposure, thus producing submicron features starting from a pattern on a transparency with millimeter-size features.

Polystyrene microspheres (with diameter d = 1.5–10 μm, and refractive index of the sphere n_s = 1.59) were positioned in a two-dimensional array by placement in a poly(dimethylsiloxane) layer (PDMS, with refractive index of the membrane n_m = 1.40). This was accomplished by spin-coating a PDMS solution onto a passivated silicon wafer. The microspheres were then crystallized onto the PDMS layer, followed by another spin coating of PDMS. The cured membrane is then removed from the surface of the wafer. For d = 6 μm, n_s = 1.59, and n_m = 1.40, the focal length is ~6 μm. Therefore, the sphere must be positioned accurately to perform as an imaging lens. The elastomeric membrane, which conforms to the surface of the photoresist, assists in accomplishing this. With an optical projector (area of illumination ~25 × 25 cm^2) as the light source, the researchers have generated uniform micropatterns over a circular region with diameter about 0.5–2 cm. The area of high and uniform definition is basically determined by two factors: the distance between the mask and the spheres, and the size and shape of the pattern.

This technique provides a simple and direct method to make submicron structures with large size reduction, although limited to simple array structures with some distortion of the pattern. However, these patterns have characteristics appropriate for applications such as frequency-selective surfaces, photonic crystals, information-storage devices, and flat-panel displays.

ERIN S. CARTER

Monolithic SiGeC/Si Superlattice Structures Cool Electronic Devices

Thermoelectric (TE) refrigeration is a well-known technique for cooling and controlling the temperature of microelectronic and optoelectronic components. However, since many of the efficient TE cooler designs are based on bulk processing, it is often difficult to incorporate these coolers into the integrated-circuit (IC) fabrication process. Solid-state coolers, comprised of semiconductor materials that can be monolithically integrated into an electronic package, typically possess low TE figures of merit and thus poor cooling characteristics. However, a research collaboration led by John Bowers of the University of California—Santa Barbara and Ali Shakouri of the University of California—Santa Cruz has designed and grown a SiGeC/Si superlattice that is both compatible with IC production and capable of efficient refrigeration.

In the March 12 issue of *Applied Physics Letters*, Xiaofeng Fan at UC—Santa Barbara, in conjunction with additional research groups at HRL Laboratories, California Institute of Technology, and UC—Berkeley, describe a technique for fabricating SiGeC/Si microcoolers on a Si wafer. A SiGeC/Si superlattice was grown in a molecular-beam epitaxy system by evaporating Si, Ge, and C onto a 125-mm diameter (001) Si substrate doped to <0.005 Ω cm with As. Prior to deposition, the Si wafer was stripped using 5% HF and rinsed with de-ionized water. To remove any remaining oxide and to prepare the sample for epitaxial growth, the substrate was heated to 850°C and exposed to 0.1 Å/s Si flux for 30 s. The final structure consisted of a 2-μm-thick $Si_{0.89}Ge_{0.10}C_{0.01}$/Si superlattice (100 periods with each sublayer 10 nm in thickness) grown at 500°C and lattice matched to the Si substrate. This structure was doped with Sb to approximately 2×10^{19} cm^{-3}, and the sample was capped with a 100-nm Si layer.

The cross-plane thermal conductivity of the superlattice was found to be 0.085 W/(cmK), or over one order lower than that of Si (1.5 W/[cmK]). The researchers grew SiGeC/Si superlattice microcoolers with dimensions ranging from 40×40 μm^2 to 100×100 μm^2. The coolers were tested on a constant-temperature heatsink by measuring the device cooling as a function of electrical current. Maximum cooling temperatures of 2.8 K and 6.9 K were obtained at heatsink temperatures of 25°C and 100°C, respectively, indicating better microcooler performance at higher temperatures. The maximum cooling temperature was also found to increase with decreasing device size. These cooling temperature data correspond to maximum cooling power densities of the order of 1000 W/cm^2. The SiGeC/Si microcoolers were compared with Si microcoolers, and a threefold improvement in maximum cooling was observed for the SiGeC/Si coolers.

The addition of carbon to SiGe enables the design of a SiGeC layer which is lattice matched to silicon. This allows the SiGeC layer to be grown directly on a Si substrate without strain which reduces the cost of material growth and simplifies integration of the cooler with Si-based devices. Furthermore, the addition of C also enables the use of thermionic emission to enhance TE cooling for SiGeC/Si materials due to the large conduction band offset between SiGeC and Si. According to Fan, "Solid-state coolers that are monolithically integrated with microelectronic and optoelectronic devices are an attractive way to achieve compact and efficient cooling. Our results indicate that efficient refrigeration is possible with coolers made of conventional semiconductor materials."

Steffen K. Kaldor

Self-Assembled Monolayers of BPS Control the Molecular Aggregation of Polymer-Dispersed Liquid-Crystal Films of 5CB

S. Kato and C. Pac of the Kawamura Institute of Chemical Research have controlled the molecular aggregation of polymer-dispersed liquid-crystal (PDLC) films by varying the hydroxyl densities of self-assembled monolayers (SAMs) of BPS, a boronate-terminated silane compound, on the substrates. Previously the researchers demonstrated that in PDLC films of 4-cyano-4′-pentylbiphenyl (5CB), a typical nematic LC, the LC molecules and the polymers form an interface layer at the substrate with different molecular alignment than the interior. In the current work, fluorescence analysis shows that the presence of the SAM on the substrate affects the properties of the interface layer and allows control of the molecular alignment.

As reported in the March issue of *Chemistry of Materials*, PDLC films were made by photopolymerization-induced phase separation (PIPS) of a mixture of 30 wt% 5CB and diacrylate monomers between two quartz substrates modified with SAMs in five ways. Some substrates were immersed in a water/ethanol mixture for different lengths of time, creating samples that were 38%, 57%, or fully hydrolyzed. Some of the fully hydrolyzed samples were reacted with dodecyltrichlorosilane to obtain a long hydrocarbon chain. The fifth substrate type was unhydrolyzed.

The fluorescence spectra of the films were taken by excitation at 290, 310, and 320 nm. At 320 nm, the absorbance of 5CB is low so the signal is from the entire sample. These spectra were nearly identical for each film and show they are excimer-rich. Since the excimer is formed more easily in the nematic phase than in others, this implies that the interior of all types of samples is nematic. At 290 nm, however, the absorbance is higher and the signal is from a layer less than 60 nm thick. The fluorescence results show that as the SAMs become more hydrolyzed, the interface layer becomes less nematic.

The research group also studied the electro-optic effects of the SAMs on PDLC films of 77 wt% 5CB made on indium-tin-oxide-coated glass substrates modified as described with the other sample. The transmittance-voltage response to a 1-kHz sinusoidal voltage at room temperature suggests that the high concentration of 5CB allows the molecular alignment in the interface to affect the molecular alignment in the interior. The group is continuing to study the electro-optic response of PDLC devices.

Elizabeth A. Shack

Infrared Liquid Immersion Microscopy Reveals Details of Green Bodies and Compaction Process

Fabrication of a green body, which is an intermediate form of the final ceramic piece or sample, is a key step in the ceramics manufacturing process. Flaws in the green body will determine the mechanical properties of the final material.

Liquid immersion microscopy is an innovative technique that allows observation of transparent ceramic green bodies in the optical microscope and this allows observation and evaluation of internal defects introduced by the fabrication process. The transparency is achieved by immersing the particle in a liquid with similar refractive index. In this manner, suppression of the reflected light at the interface allows the particle to become optically transparent. This procedure is currently under development by a group of scientists from the Nagaoka University of Technology and the Japan Fine Ceramics Center.

The basic requirements for this technique are thin specimens and an adequate immersion liquid. The refractive index of this liquid has to be within 5% of that of the particle to achieve transparency in visible light. Sometimes such liquids are difficult to find since the refractive indices of many ceramics are very large. In the case of Si_3N_4, the liquid found with appropriate refractive index is unstable and toxic. In the January issue of the *Journal of the American Ceramics Society*, the researchers demonstrate how IR light can be used to expand the range of potential liquids that will achieve transparency. Due to the larger wavelength of IR light, the difference between the refractive indices of the liquid and the particle can be 3.6 times larger than that allowed for visible light.

Granules of Si_3N_4 were obtained after spray drying a slurry prepared by mixing powders with sintering aids, a binder, and a dispersant for 24 h. A green body was obtained by pressing the granules at 19.6 MPa and heating at 1300°C for 2 h. A thin section of about 150 μm was prepared for microscopy observations, and the immersion liquid used was a saturated solution of sulfur in methylene iodide with a refractive index of $n = 1.79$. An infrared camera attached to the microscope operated at a maximum wavelength of 1.8 μm. Radiation of less than 1.3 μm was excluded with a filter.

Inspection of the spray-dried granules in the scanning electron microscope (SEM) revealed that some of them had a small dimple. On the other hand, the IR microscopy observations showed that all of the granules had not only a dimple, but also an internal pore. The thickness of the granules was about one-fourth their diameter.

A Si_3N_4 compact was formed by powder compaction of Si_3N_4 granules under high pressure. SEM observations of the powder compact showed that the boundaries of the granules deformed by the compaction pressure. The IR microscopy