Photopolymers and Sol-Gels Advance Holographic Data Storage

Available optical devices such as CDs and DVDs record information on the surface of the disc. To increase the capacity of optical storage media, Spanish researchers are adapting enhanced photopolymers and sol-gels to create holographic optical storage materials with potentially far more capacity than today's optical storage media.

“The theoretical information storage capacity of holographic memories is much greater than current techniques, and that is why we are developing thick photopolymers with good holographic properties,” explains Manuel Ortuno of the Departamento Universitario de Optica at the University of Alicante, Spain.

Photopolymers based on polyvinyl alcohol-acrylamide (PVA) have many useful advantages for holographic recording: they have good energy sensitivities, their spectral properties adapt to the type of recording laser by changing the sensitizer dye, and they have high diffraction efficiencies together with acceptable resolution and signal-to-noise ratios. PVA is also relatively inexpensive and easy to manufacture, which makes the material practical for commercial holographic storage applications. The Alicante research team studied 1-mm PVA samples for use as a write-once, read-many holographic storage device.

The PVA solution was deposited in polystyrene molds under the force of gravity in a darkened room. After the material had sufficiently dried it was removed from the molds, cut into squares, and attached to glass substrates before placing it into the holographic system for exposure. A continuous wave argon laser emitting at 514 nm wrote diffraction gratings in the PVA material.

First, the laser was split into two beams of 5 mW/cm² intensity and expanded to 1.5 cm. The object and reference beams were combined at an angle of 16.8° to produce a spatial frequency of 1125 lines/mm. The diffracted and transmitted intensities were monitored using a HeNe laser at 633 nm—a band of the spectrum where PVA has low sensitivity. Holographic efficiencies were measured as a function of the angle of reconstruction using a rotating stage.

The sum of the diffracted and transmitted intensities, which is indicative of the amount of light lost to absorb-

Invert Glass

Vitreous Forms of Crystal Could Enhance Ultrafast Lasers

Using a unique heating and cooling process for making molten glass, researchers have created a vitreous form of forsterite (Mg₂SiO₄) in hopes of gaining understanding into the chemical bonds that hold invert glass materials together, potentially leading to new types of doped optical materials.

Lasers and Levitation

Although conventional wisdom says that alkaline and alkaline-earth orthosilicate materials such as Mg₂SiO₄ cannot be vitrified, researchers at Japan Synchrotron Radiation Research Institute (JASRI; Sayo, Hyogo, Japan), Japan Atomic Energy Research Institute (Ibaraki, Japan), Tokyo University of Science (Oshamambe, Hokkaido, Japan), Argonne National Laboratory (Argonne, IL), and Containerless Research Inc. (Evanston, IL) have done just that using a containerless manufacturing method. Developed at Containerless Research Inc., the levitator suspends raw material in a process gas. A continuous-wave CO₂ laser then quickly heats the material; blocking the laser light from heating the raw material leads to fast cooling and vitrification without the adverse effects of contaminants, such as those found in a melting crucible or container. The method also eliminates crystallization on container walls, enabling many new types of glass to be made.
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The resulting vitreous Mg$_2$SiO$_4$ (v-Mg$_2$SiO$_4$) is a so-called “invert glass,” explains Shinji Kohara, principal investigator at JASRI. Invert glass occurs when the relative amount of SiO$_2$ is reduced to where only isolated SiO$_4$ and Si$_2$O$_7$ dimers exist, causing the short-range order structure and the relaxation phenomena to change drastically.

Distorted Chemical Bonds

According to Kohara, forsterite’s low SiO$_2$ content (33 mol%) prevents formation of an extended SiO$_4$-based network. Mg$_2$SiO$_4$ melt exhibits a very rapid rise of viscosity near the glass transition point ($T_g$), which means it is a very “fragile” liquid. “Thus any interpretation of the physical properties of the forsterite must delineate the network-modifying nature of MgO,” says Kohara. “That, in turn, demands understanding of the SiO$_4$ and MgO$_x$ subunit organization in terms of short-to-intermediate order structure. This we accomplished with a combination of novel synthesis, diffraction, spectroscopy, and computer simulation.”

Neutron and x-ray structure analysis indicated that v-Mg$_2$SiO$_4$ has a unique short- and intermediate-range order structure. A broad, skewed Mg-O peak indicated a distribution of Mg-O distances from 1.8 to 2.5 Å—in other words, highly distorted MgO polyhedra including 4-, 5-, and 6-oxygen coordinations. These results differ markedly from the long-range order structure in crystalline Mg$_2$SiO$_4$ (c-Mg$_2$SiO$_4$), Kohara explains.

Furthermore, the team determined the key difference between v-Mg$_2$SiO$_4$ and c-Mg$_2$SiO$_4$ stems from the Mg-O correlation. The team took Raman measurements to test the connectivity with SiO$_4$ tetrahedra, and the results supported the existence of connected SiO$_4$ tetrahedra in v-Mg$_2$SiO$_4$. The team found that the intermediate-range structure of v-Mg$_2$SiO$_4$ arises almost entirely from connectivity of Mg-O polyhedra that provides the structural network. Also, the structure of the glass differs from its crystalline counterpart in that Si$_2$O$_7$-type dimers fill in the space within the network. Kohara concludes, “Our study of vitreous forsterite prepared by the containerless method may provide insights into the highly nonequilibrium materials processing that occurs in interplanetary and interstellar environments.”

Closer to Earth, Richard Weber, vice president for materials research and development at Containerless Research Inc., says the vitreous glass could lead to improved Cr$^{4+}$:forsterite lasers. “We were interested in synthesizing forsterite to understand the structure of the glass and see if we might be able to plug ions into the structure to make optically active materials,” Weber explains, adding that an improved Mg$_2$SiO$_4$ could lead to ultrafast lasers with even shorter pulses and broader tunability. The Cr$^{4+}$:forsterite laser emits between 1100 nm and 1400 nm and is centered around 1250 nm—the zero-dispersion wavelength of optical fiber, and a low-scattering, low-absorption area of the near infrared spectrum, making the source attractive for applications that include telecommunications and biological studies. —Charles Whipple