Focusing on Fresnel lenses

Fresnel lenses are garnering attention at all ends of the spectrum. Whether the focus is on broadband x-ray Fresnel lenses as reported by researchers at the recent SPIE annual meeting (29 July–3 August; San Diego, CA) or diamond-based Fresnel lenses for infrared applications, the technology offers advantages over conventional refractive designs for a variety of applications.

A Fresnel lens consists of concentric, optically opaque annular zones of decreasing width, interspersed with annular zones transparent to the wavelength of interest (see figure 1). Fresnel lenses are often less than a micron in thickness. Unlike conventional bulk glass lenses, which control light by refraction, Fresnel lenses control light by diffraction.

This is a particularly useful property for x-ray optics. The index of refraction for most materials at x-ray wavelengths is almost unity and the materials are highly absorptive, so a conventional refractive design is simply not feasible. A system based on diffractive Fresnel lenses, however, is.

Christian David of the Paul Scherrer Institute (Switzerland) garnered attention in the x-ray micro- and nano-focusing session with his work on broadband x-ray Fresnel lenses (paper #4499-16).

Typically, Fresnel lenses focus light over a narrow band of soft x-ray wavelengths. Using semiconductor fabrication methods in conjunction with materials such as silicon, silicon nitride, germanium, chromium, and tantalum, David has developed Fresnel lenses that cover the entire x-ray spectral band, including hard x-rays with wavelengths so short they are instead defined by kilo-electron volt energies.

To focus hard x-rays (energies above 6 keV), he uses Bragg-Fresnel lenses (BFLs), which combine Bragg reflection from a crystal with the focusing properties of a Fresnel zone plate pattern etched into the crystal surface. Using reactive ion etching, he carved 1 mm-deep linear Fresnel structures with outer zone widths of 100 nm into a silicon substrate (see figure 2). This is
significant smaller than any other silicon BFL reported so far,” David says. The linear BFLs range from 125 mm to 1000 mm in width and 5 mm to 10 mm in length and yield efficiency values of up to 26% at 13.25 keV photon energies.

Three points particularly impressed session chair Ian McNulty of the Advanced Photon Source (Chicago, IL) concerning David’s work. “Traditionally, people have only been able to fabricate these plates in a few materials such as gold and nickel, which limits what wavelengths they can be used with,” McNulty says. David makes zone plates in six or seven different kinds of materials, however, increasing their utility over a broader range of energies.

David’s lenses have been tested at x-ray energies up to 30 keV, but he hopes to move even further into the hard x-ray range. “There are no other competitors in that range above 10 keV,” he says. “Fresnel zone plates have been considered unsuitable for that range, and I consider that untrue.”

Meanwhile, researchers at the Russian Academy of Sciences (Moscow, Russia) have developed chemical-vapor-deposited diamond (CVDD) lenses for use with high-power (about 4 kW CW) or high-intensity (about 10 kW/cm² CW) carbon-dioxide laser beams. The diamond material offers a thermal conductivity about five times better than that of copper, together with low thermal expansion.

The Russian group has focused on a 10-mm diameter design with a theoretical efficiency of more than 90% and a focal length of 127 mm (with a convergent input beam). De Beers Industrial Diamonds (Johannesburg, South Africa) grows and polishes the substrates. The Fresnel structure is then ablated pixel by pixel using an excimer laser. The lenses are robust, says says Manfred Berger, technical managing director of L.O.T.-Oriel GmbH (Darmstadt, Germany). “Of the more than approximately 1000 windows we have supplied over the years for high-intensity laser beams, we never got a specimen back for rework or refurbishing,” Berger says. So it’s true what they say: Diamonds are forever.

Laurie Ann Toupin

**new optical memory promises 1 TB per cubic inch**

Glass doped with rare-earth ions may offer the next big jump in memory capacity, say researchers at Central Glass Co. (Tokyo, Japan). Working with Professor Kazuyuki Hira of Kyoto University (Kyoto, Japan), they found that ions of samarium (Sm) and europium (Eu), such as Sm³⁺ and Eu³⁺, could be permanently and space-selectively photoreuced to Sm²⁺ and Eu²⁺ using focused bursts of an infrared femtosecond laser. “Femtosecond lasers are the only ones that can cut a molecule. And they are the only ones that irradiate without heat,” says Hira. The group presented its work in the Interopto exhibit (Chiba, Japan; 16–20 July).

The researchers used a focused 800 nm, 120 fs, 200 kHz Ti: Sapphire laser with a stretcher/compressor and a regenerative amplifier, pumped by an Ar laser to irradiate the rare earth ions in the Sm-doped fluoride (ZBLAN) glass at its submicron focal point, triggering the photoreduction necessary to produce the required dot. Because of the valence change in the ions, the spots in the glass created in this way can be read as a change in fluorescent intensity.

In experiments, Central Glass’s researchers created 3-D alphabetical characters in cubes of glass, constructing them of small dots only 400 nm in diameter (see figure). Each character consisted of 300 to 500 dots, which can be spaced 100 nm apart on a glass surface. The group also found that the dotted surfaces could be layered. Experiments showed that some 2000 layers of dotted glass—the equivalent of 8 Tb of data—could be stacked into one cubic centimeter, says Shigeki Sakata of Central Glass. —Charles Whipple

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**Figure 1** Using the beam from an ultrafast laser, researchers wrote 400-nm dots in glass doped with Sm and Eu ions, forming the letters shown above.

**Figure 2** This cross-section through a Bragg-Fresnel lens was etched into a 100-nm outmost zones was etched into a <111> oriented silicon substrate using reactive ion etching.