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Optical feats loom large

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Photonic feats

It was a year in which metamaterials began to take shape as optics, 80-attosecond pulses probed intra-atom electronic properties, optical interconnects benefited the digital revolution, and superbroadband fibers diversified.

What is the biggest and most influential technological change to come along in the past 50 years, and one of the few that deserves to be called a revolution? Is it the introduction of the Sony Walkman? Whole-wheat spaghetti? The "Baby on Board" car sign?

No, few would disagree that it is the introduction of digital technology into our daily lives, in the form of PCs and the Internet—as well as ATMs, cell phones, DVDs, and so forth. While many trace the roots of this revolution back to the fabrication of the first integrated circuits by Jack Kilby of Texas Instruments and Robert Noyce of Fairchild Semiconductor, photonic technology has been insinuating itself into the digital era from the start. Optical lithography is the preferred method of patterning computer chips; once capable of producing features no smaller than tens of microns in size, it is now used for volume production of chips with 45 nm features. Fiber-optic communications, digital cameras, diode lasers for printers and CD players—all contribute to our digitally driven world.

And now photonics is aiming right at the core. Multicore processor chips—which are the semiconductor industry's latest approach to maintaining Moore's Law (a doubling of the number of transistors on a computer chip every two years)—will require communications capacities beyond what electronics can provide. Ultimately interchip, and then intrachip, optical interconnects will enable years more growth in computer speed and capacity, leading to a degree of networking in our daily lives the likes of which we now merely guess about.

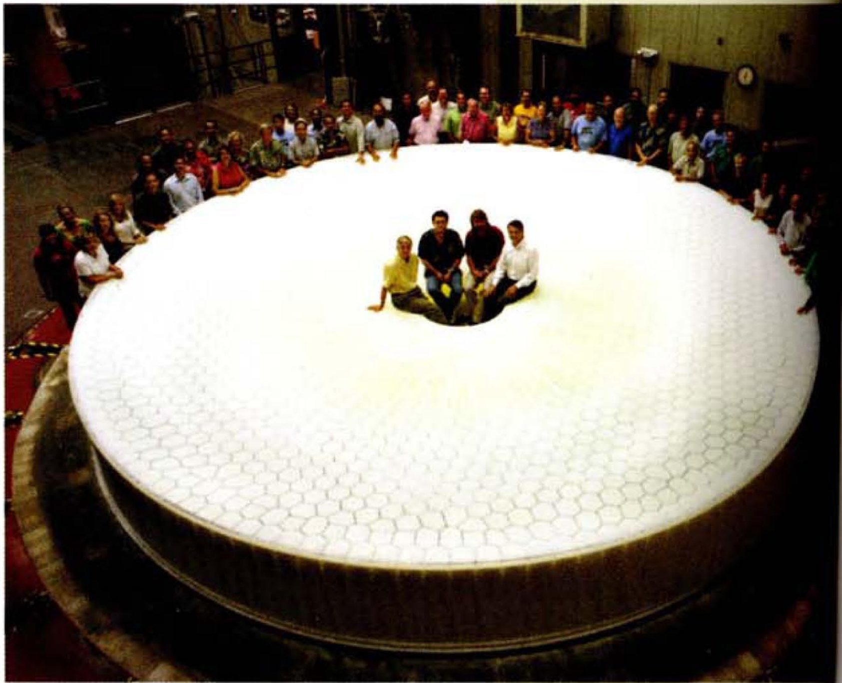

FIGURE 1. The LSST mirror has been cast and is ready for grinding and polishing. The outer 5- to 8.4-m-diameter portion will serve as the primary mirror; the inner 5-m-diameter portion will be ground to a steeper curvature and will become the telescope's tertiary mirror. (*Courtesy of the University of Arizona*)

In this and many other ways, scientists and engineers are exploiting the photon for practical use, as well as for the sake of knowledge. From the creation of the largest combined primary and tertiary telescope mirror ever, to the use of light (and sound) to detect explosives, and to designs for small, quickly focusing lenses for digital cameras, this past year has seen more than its share of achievements in photonics—some of them not well-publicized.

Optics, macro and micro

One of the world's largest single telescope mirrors, and the largest monolithic combination of two mirrors, is the 8.4 m mirror for the Large Synoptic Survey Telescope (LSST), to be located at Cerro Pachon, Chile. The 26-ton lightweighted disk of Ohara E6 borosilicate glass emerged this year, cooled, from its spin-casting oven at the University of Arizona's Steward Observatory Mirror Lab (Tucson, AZ), ready to be ground and polished (see Fig. 1). With a focal length of 9.9 m, the completed telescope will survey a 20,000-degree^2 area of sky 1000 times over 10 years in six visible bands, producing 30 Tbytes per night of data. The site will require 200 Pbytes (2×10^{17} bytes) of data storage.

Toward the other end of the size scale is a 0.5-mm-diameter laser-scanning mirror fabricated by researchers at Toyota Technological Institute (Nagoya, Japan) and Tohoku University (Sendai, Japan), which combats the problem most scanning mirrors have: too much mass. The mirror, which is flat to $\lambda/10$ in visible light, consists of a polycrystalline silicon (Si) membrane across a rigid crystalline Si ring; the membrane is under 600 MPa of tension.[1] The crystallization-induced stress is independent of temperature, making the flatness stable over a wide temperature range even when the mirror is coated with metal.

Small variable-focus liquid lenses are being more widely developed, and have made their entry into the marketplace. Shenzhen Akkord Electronics (Shenzhen City, China) is now selling a cheap ($20) webcam that has a liquid lens made by Varioptic (Lyon, France), which has been working on the technology for years (see www.laserfocusworld.com/articles/224009). Although the ability of the lens to shift focus in 0.02 seconds is likely not much of an advantage while imaging a sitting Web surfer, the lens' low cost (which can only go lower as production is ramped up) most certainly is.

In a well-publicized announcement, researchers at Rensselaer Polytechnic Institute (Troy, NY) described their version of a liquid lens: a droplet of water overfilling a hole in a hydrophobic plate and oscillating at its natural frequency of 100 Hz (see www.laserfocusworld.com/articles/343739). Because the droplet is cycling through a range of focal lengths many times a second, the optical system's imaging camera need only snap a picture at the right instant to take advantage of a particular focal length. Much less publicized was the equally significant deposition of a polymer thin film and a conductive transparent silver film directly onto a liquid droplet by scientists at the University of Tokyo (Tokyo, Japan), creating an encapsulated, electrostatically focused microlens.[2] Various versions with diameters from 20 μm up to a whopping 30 mm were created; the focal length of a prototype 1-mm-diameter lens could be varied down to 20% of its initial 3.7 mm value.

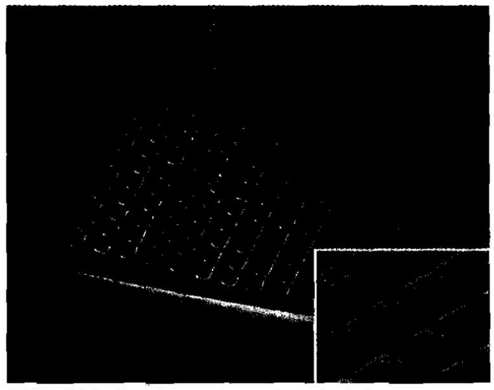

FIGURE 2. One face of a metamaterial prism reveals its fishnet structure. The prism has a refractive index of -1.35 at a 1.775 μm wavelength. The metamaterial consists of alternating layers of metal and dielectric (inset). *(Courtesy of the University of California, Berkeley)*

Peekaboo

Optical metamaterials appeal to the geek in many of us because of what the materials can theoretically do: not only could their odd properties result in some very unusual optical systems, but someday they may make us invisible (if you believe the popular press). In reality, researchers at the University of California, Berkeley, have demonstrated a 3-D negative refractive index in an optical metamaterial made of many fishnet metal/dielectric layers, by fabricating a prism of the material about 10 μm in size (see Fig. 2).[3] When laser light was shone on the prism and tuned from a 1.2 to 1.775 μm, the refractive index decreased from 0.65 to -1.35, as revealed by the refraction angles. One important property of the material is its transparency, which is high in comparison to other metamaterials, thus allowing optical elements to be fabricated (however small).

While theoreticians have come up with certain optical-metamaterial configurations that could serve as cloaking devices ("invisibility cloaks"), and scientists have actually constructed small cloaking devices that work at microwave frequencies, the rapid advances in 3-D optical metamaterials have caused some scientists to state that a real-life invisibility cloak may be only a few years away. Such a shield might, when fabricated, manage to cloak a dusk speck at a single wavelength; however, the popular press has translated such a device into a human-size cloak—which would be valuable indeed, especially if you could zip it up against the wind.

Now, as an antidote to the metamaterial invisibility cloak, three researchers from Shanghai Jiao Tong University (Shanghai, China) have introduced—the anti-cloak.[4] Such an apparatus, which would also be made of an optical metamaterial and would have to be placed *inside* the invisibility cloak, would partially cancel the cloak's invisibility properties, revealing the speck of dust—or the person—inside. And rumors are flying of an even-more-effective anti-cloaking approach, which takes the form of a handheld device and is colloquially referred to as a can of spray paint.