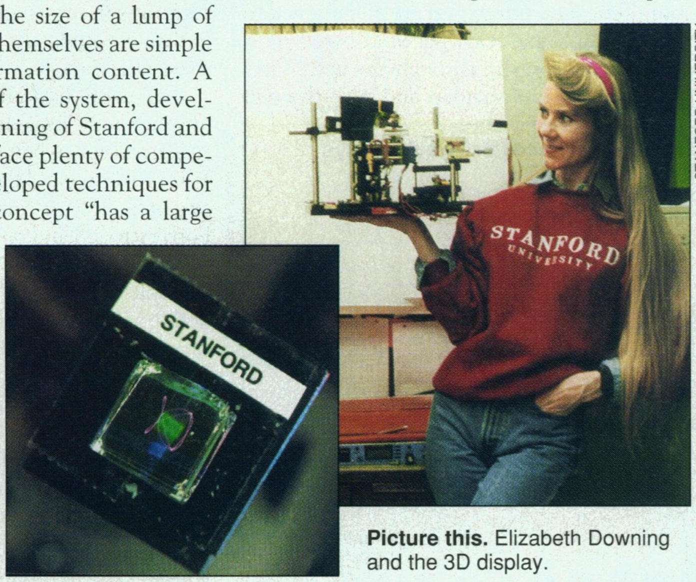
Three-Dimensional Images Are Conjured in a Crystal Cube

The illusion of three dimensions: Moviegoers wearing multicolored glasses in the 1950s were after it, and so are modern-day researchers who put on sophisticated virtual-reality headsets or peer at evanescent holograms. But in this issue of *Science*, a research effort centered at Stanford University reports something that may be better than illusions: true 3D images, traced within a cube of special glass by invisible laser beams. The demonstration, says Daniel Sandin, co-director of the Electronic Visualization Laboratory at the University of Illinois, Chicago (UIC), "sounds like the answer to a dream."

Sandin quickly adds that the work, which is reported on page 1185, is at best the beginning of the answer. The cube that holds the images is only about the size of a lump of sugar, and the images themselves are simple outlines, low in information content. A full-fledged version of the system, developed by Elizabeth Downing of Stanford and her colleagues, would face plenty of competition from better developed techniques for 3D display. But the concept "has a large number of possible applications" in everything from air-traffic control to industrial design and medicine, says Hans Coufal, a physicist at the IBM Almaden Research Center in San Jose, California, who is familiar with the work. Downing herself says that by far the most frequent comment she has heard about the prototype is "just totally cool."

The original idea saw light in an entry in Downing's notebook on 21 July 1988, when she realized that a pair of infrared lasers crossing in a transparent matrix could excite a point of fluorescence if the matrix were doped with the right kind of trace atoms. The trick would be to use atoms that jump into an excited state when they absorb two infrared photons in sequence, one from each laser, then quickly decay by emitting all of the energy in a single photon of visible light. A variety of rare-earth elements behave this way—erbium, for example, can absorb photons at two specific wavelengths and fluoresce in green light. By scanning the crossing point of the infrared lasers through a cube, an image could be traced in three dimensions, just as the electron beam of a cathode-ray tube traces an image in two dimensions on a phosphor-coated screen.

When she searched the technical literature, Downing soon found that virtually the same idea had occurred to a different research team in about 1970. At that time, however, at least two essential ingredients were missing. One was a transparent material with an atomic lattice stiff enough to resist converting the infrared energy into vibrations. In ordinary silicate glass or liquid solutions containing the rare-earth dopants, says Downing, "the energy just gets vibrated away and you don't see any fluorescence." The other essential ingredient was compact solid-state lasers producing the right infrared wavelengths.



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Picture this. Elizabeth Downing and the 3D display.

The invention of fluoride-based glasses in the 1970s took care of the first problem. But solid-state lasers with the right frequencies and enough power are only now becoming available. Last year, Downing persuaded SDL Corp., a laser manufacturer in San Jose, to provide the necessary hardware. "We said, 'This is so interesting and you've got so much energy, we'll help you out,' " says SDL's John Ralston, a co-author on the *Science* paper. "We sent her a box of lasers on the 19th of October. In January she had a demo up."

The resulting device, which Downing built with Ralston and co-authors Lambertus Hesselink of Stanford University and Roger Macfarlane of IBM Almaden, is small enough to sit on a hotel beverage cart. Its heart is a centimeter-sized cube built of multiple glass slices, each slice doped with a rare-earth element that fluoresces in one of the three colors red, green, and blue. Arrayed around the cube are the lasers, equipped with movable mirrors to scan their beams through the cube. Rather than controlling the mirrors with actual image data, as in a working display, Downing couples them to electronic "function generators" that trace changing geometric shapes based on simple equations. The setup can create, for example, a stylized shape that "is like a little butterfly flapping its wings," says Downing.

"You can literally walk around [the image], raise and lower your head, and it's sharp and bright," marvels Guy Marlor, chief scientist at West End Partners Imaging Inc. in Fremont, California, a company that specializes in image technology. The simplicity of the setup that achieves this, he says, "is quite astounding," and he thinks the cubic displays could readily be expanded to sizes as large as 30 centimeters or so on a side. That would let several physicians view a magnetic resonance image of a patient's brain simultaneously, for example, or let air-traffic controllers monitor planes in 3D.

But supplying enough data for the images could be a sticking point. True 3D images are far more data-hungry than, say, stereoscopic virtual-reality displays, which are based on pairs of flat images made from slightly different perspectives. Handling the data for real-time, high-resolution display would take "God's own computer," says Stephen Benton, head of the spatial imaging group at the Massachusetts Institute of Technology's Media Laboratory. Benton adds that compared to stereo views or the holograms he works on, the cubes have another disadvantage: They have trouble rendering opaque surfaces, which he says could confuse an untrained eye. And UIC's Sandin points out that unlike virtual reality, his own specialty, Downing's method won't allow a viewer the illusion of being inside an object—a feature that could be valuable, for example, in evaluating automobile designs or architectural concepts.

Downing and collaborators agree that the data rates will be a challenge, but they think image-compression techniques could reduce the loads, and parallel architectures could split up the computational dirty work among multiple processors, driving arrays of microfabricated lasers. They point out that unlike other techniques, which require specialized headgear or allow only a limited field of view, their true 3D images offer what Ralston calls "shared experience" for multiple viewers. In imaging as in so many other fields, there may be no substitute for the real thing.

–**James Glanz**