colour filters in particular can cause headaches if used over a long period. As a result, polarizing stereoscopic displays have not spread much beyond scientific applications. The development in the past decade of improved 'autostereoscopic' displays that are viewable with the naked eye, in which a 2D display equipped with a lens array brings different images to each of the viewer's eyes, creating an illusion of depth, has renewed interest in 3D imaging[3]. But these displays require the viewer to be situated at the correct distance from the screen to obtain the stereo effect. Multi-view displays, or head-tracking displays that correct the image for the viewer's location, are some help, but increase the cost of making, processing and projecting the images.

Holography is another well-known 3D display technology, and provides high-resolution views over wide angles[4]. Holographic displays are autostereoscopic, in that the 3D image is 'stored' in a material and can be viewed when illuminated with no need for glasses, lens arrays or other devices. They work by recording both laser light scattered from the object to be imaged and a plane-wave laser reference beam to form an interference pattern that is stored in 3D in, for example, a photopolymer. In such polymers, light in the interference pattern activates a chemical reaction that locally modifies the material's refractive index. This process stores all the optical amplitude and phase information needed for 3D image projection, but cannot be repeated: the image on the display is static.

Tay and colleagues' breakthrough[1] is to demonstrate a reasonably sized display, measuring 10 cm × 10 cm, whose base medium is what is known as a photorefractive material. Photorefractive materials also capture image (amplitude and phase) information in 3D. But unlike photopolymers, they are dynamic storage media: information can be stored, erased and rewritten (Fig. 1).

This kind of photorefractivity has been studied extensively in crystals of inorganic oxides such as lithium niobium oxide ($LiNbO_3$; ref. 5). In these materials, the absorption of a holographic interference pattern leads to the generation of mobile charge carriers in bright regions of the interference pattern. Under an applied field (or, in a polar crystal, the internal field), the mobile charges drift and accumulate in the dark regions. The result is a change in the electric-field distribution, and resultant, proportional changes in the crystal's local refractive index through a phenomenon known as the electro-optic effect. Inorganic crystals are known to be extremely photosensitive, and images of high resolution can be produced in this way. Unfortunately, growing crystals of a large enough area for practical displays is both difficult and costly.

This is where photorefractive polymers[6] become interesting: they possess all the capabilities of the inorganic crystals, but can be processed to produce large-area displays using low-cost, solution- or melt-based methods. The photorefractive polymer developed by Tay *et al.*[1] contains a copolymer combining a molecular group that transports positive charge with a dye whose polarization changes nonlinearly in response to light. The dye rotates and aligns under the influence of an applied electric field, modifying the material's refractive index. The copolymer also acts as a photosensitizer, absorbing light and generating mobile charges at the 'writing' wavelength of 532 nanometres.

The material thus developed possesses a remarkable combination of the properties crucial to a photorefractive display. Its optical quality and homogeneity are improved by use of the copolymer to minimize phase separation (the separation of dissimilar components of the material, forming regions that scatter light, degrading the image quality). High photosensitivity, allowing the use of only moderate laser powers for writing and erasing, is assured by adding small amounts of both a fluorinated molecular group with a nonlinear optical response and a plasticizer to promote molecular motion. A diffraction efficiency of close to 90% leads to good display brightness and low read-out power.

Operating their display under an applied voltage of 9 kV during writing, to speed up charge transport, but 4 kV for read-out, the authors could write across the full area of the display in about 3 minutes and hold an image on it for up to 3 hours. A fully automated optical system processed the object beam into strips that were recorded sequentially in adjacent parts of the display, using a laser intensity of around 100 milliwatts per square centimetre and a good writing speed. The principle of operation is entirely scalable: with higher-power lasers or more sensitive photorefractive polymers, larger areas could be written at the same time, or a small area faster.

Future advances in the size and speed of updatable holographic 3D displays would create a powerful and high-resolution visualization technology. But there is fierce competition, driven by the size of the potential military, medical and entertainment markets, with large-area, flat-panel 3D displays and alternative real-time 3D displays that are coming on in leaps and bounds. For film fans and gamers itching to be in the midst of the action, the wait might not be too long. ■

Joseph W. Perry is in the School of Chemistry and Biochemistry, and the Center for Organic Photonics and Electronics, Georgia Institute of Technology, Atlanta, Georgia 30332-0400, USA.
e-mail: joe.perry@gatech.edu

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50 & 100 YEARS AGO

50 YEARS AGO

During the past few months, three great achievements in science and technology have justifiably received world acclaim: (1) the launching of artificial Earth satellites by scientists in the U.S.S.R.; (2) the development and control of thermonuclear fusion by scientists in Great Britain and the United States; (3) the launching of an artificial Earth satellite by scientists in the United States. We have used the expression 'by scientists in' deliberately... Scientific discoveries are not suddenly made by men who, by birth or consent, are entitled to claim a certain nationality; they are the results of good training, patient and sometimes long-continued work often fraught with disappointment, team-work sometimes spiced with real personal genius, and all these are based on the work of previous generations.

From *Nature* 8 February 1958.

100 YEARS AGO

Mr Mallock (January 30, p. 293) seems to presume, as a great many others do, that an apparatus on the aëroplane principle "demands constant attention on the part of the aëronaut" to maintain its stability in the air. We are apt to get ideas from watching the behaviour of little bits of paper floating in the gusts of wind, and to forget that the flying machine of the future may run into tons of weight. Though a frail canoe may easily capsize, the big ship seldom turns over even in the roughest of seas. Even so primitive a contrivance as we may presume that of Mr. Farman to be is some 33 feet across and weighs, complete, half a ton. Such a structure is not easily upset by mere puffs of wind. But it is also evident that a machine can be designed possessing nearly perfect automatic stability... A well-designed and well-balanced machine is automatically stable without any pendulums or other appliances; in fact, it forms a pendulum of itself.

B. Baden-Powell

From *Nature* 6 February 1908.