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## Holographic data storage

### Light on the horizon

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**After years of development, researchers are on the verge of using holograms to store data in memories that are both fast and vast**

THE notion of holographic memory dates back to 1963, when Pieter van Heerden, a researcher at Polaroid, first proposed using the method to store data in three dimensions. In theory, it is a great idea. Existing media store data in only two dimensions. Adding a third would make storage devices far more efficient. But despite massive spending over four decades, a complete, general-purpose system that could be sold commercially has eluded both industrial and academic researchers.

It is still elusive. But it is getting closer. The first commercial holographic memory should be on the market next year, and more are expected to follow. When that happens, there may be a ballooning of computer storage capacity that will make existing disks look like leaflets compared with the Encyclopaedia Britannica.

## A bit of illumination

Holographic data-storage works by recording the differences between two beams of laser light. The first is a reference beam that contains no information. The second carries data that it has picked up by being passed through a liquid-crystal panel known as a spatial light modulator.

Where the two beams intersect, they interfere with one another, and this interference pattern can be captured by the photosensitive molecules of a storage medium located in the overlap region. The result is a hologram, which can be read by applying a beam equivalent to the original reference. This produces a replica of the original data.

The real beauty of holography is that a huge number of holographic files can be stored in an overlapping manner in the same volume of photosensitive material. All that is required for this to happen is that the reference beam for each hologram must arrive at a slightly different angle from all other beams, or must have a different wavelength from those beams. Theoretical calculations suggest that it will be possible to use holographic techniques to store a terabyte (1,000 gigabytes) of data on a CD-sized disk. Today's DVDs, by comparison, have a storage capacity of less than 20 gigabytes.

Moreover, holographic techniques permit the retrieval of data at speeds not possible with current storage methods. Transfer rates of a billion bits a second (at least 60 times faster than current DVDs) have already been demonstrated in the laboratory. Such fast access times are possible because the laser beams that are central to holographic technology can be moved rapidly, without inertia, unlike the components of a conventional disk drive. In short, no other storage technology in development can match holography's capacity and speed.

The challenge is to find the right recording material—a photosensitive substance that is both stable and cheap enough to use commercially. It is this search that has held up progress.

## Making light of storage

Hans Coufal, who manages IBM's research on holographic data storage, says that his company has succeeded in ironing out most of the technical problems involved. The firm has evaluated several materials, including a crystalline substance called lithium niobate.

According to Dr Coufal, IBM has created a number of holographic "test platforms" at its Almaden research centre in San Jose, California. Although the medium in these platforms is three-dimensional, convention dictates that storage densities be recorded, as with disks, in bits per unit area as seen from above, rather than bits per unit volume. IBM's test

platforms can store up to 390 bits per square micron (a micron is a millionth of a metre). DVDs, by contrast, have a storage density of about five bits per square micron.

IBM has also solved another long-standing problem with holography, which is bound up with parallel recording. Cross-talk noise, as it is known, causes faint images of all the files recorded to be called up even when only one is being accessed. Clever encoding and signal-processing algorithms can exorcise such ghosts.

Lithium niobate and its cousins are not favoured by everybody, though. Some companies prefer photosensitive polymers. In this case the material is deposited on the surface of a disk. The current aim is to produce a coating a few hundred microns thick. That is three-dimensional enough for holography, though making coatings thicker is still an important goal.

Polymers are more sensitive than lithium niobate but, as if to compensate, they tend to change volume when the chemical shifts associated with data recording take place within and between their molecules. This distorts the holograms. That is not a problem with lithium niobate.

Aprilis, a firm based in Maynard, Massachusetts, thinks it has found a way of having its cake and eating it too. Aprilis's polymer is an epoxy-modified silicone that does not, according to David Waldman, one of the firm's co-founders, change volume when it is recording. On the back of this knowledge, Aprilis is aiming to produce a drive with a capacity of 200 gigabytes and a transfer rate of 75 megabytes a second by 2005.

A third approach is being taken by InPhase Technologies, of Longmont, Colorado. InPhase aims to commercialise a polymer-based technology that it calls a two-chemistry system. This gets round the distortion problem by using a material in which the chemical processes that hold it together are separate from those that make it photosensitive. According to Chris Pfaff, one of the firm's directors, InPhase's prototype CD-sized disk, called Tapestry, can now hold about 100 gigabytes.

A fourth route is being taken by Polight Technologies, a firm based in Cambridge, England. Its disks are coated with a glassy material dubbed holonide, rather than with crystals or polymers. According to Michael Ledzion, Polight's boss, the first product to use this technology—a disk with a capacity of 500 gigabytes—should be available next year.

## Disk driven

Such numbers are impressive, although, at least to start with, Polight's disk, like those of most of its competitors, will be "non-rewriteable". In other words it will be useful for archiving things, but will not be able to stand in for a hard disk, on which things are constantly changing. But that does not matter in the short term, because holographic storage is well suited to making archives. For, besides its ability to swallow huge amounts of data, the technology can spit it out in novel and useful ways.

In particular, searching a holographic store for a specific set of data is simple. Just as shining the appropriate reference beam produces a replica of the original data beam, so shining the appropriate data beam produces a replica of the reference beam. A beam that carries part of the original data will produce a weaker replica reference beam, making it possible to locate all the files that contain a particular set of data by shining in a beam containing that set and looking at the reference beams that come out. The intensity of each emergent beam indicates the degree to which the data stored in the file producing it match the target. Somebody sifting through a huge database could thus be directed rapidly to the best matches.

With the growing commercial interest in data-mining—which involves sifting through vast amounts of information in order to find useful relationships—this aspect of holographic memory is extremely attractive. Indeed, according to Dr Coufal, it was the cause of IBM's renewed interest in holographic storage.

It all sounds promising. Yet a lot of work still needs to be done before holographic storage becomes fully commercial. Meeting the exacting requirements for aligning lasers, detectors and spatial light modulators in a low-cost system remains a challenge. However, the recent availability of low-cost components, such as solid-state camera chips, from the rapidly maturing opto-electronics industry, has provided the devices needed to build holographic memories on a large scale.

On top of this, there is evidence that magnetic-storage technology may be approaching its limits, as the ever-smaller regions that store bits of information become less stable and harder to access. When this limit will be reached remains an open question. Some experts think that insurmountable barriers will be met in the next decade, but others have argued that these are still a long way off. In either case, though, something will be needed to plug the gap if progress is to continue. Holography may well be the plug of choice.