The drive for holography

Holographic disk drives have long promised to eclipse even the latest high-density optical storage media. Now finally, as **Duncan Graham-Rowe** reports, the promising three-dimensional approach to storing information is about to make its debut.

The traditional way to cram more data onto optical disks, such as DVDs, is to create smaller features on their surfaces using lasers with shorter wavelengths. The latest storage media, such as Blu-ray disks and high-definition (HD) DVDs, rely on blue laser light for this purpose. But the next generation of disks promises to increase capacity by hundreds of times using a more radical technique — holographic three-dimensional storage.

After almost 40 years of development, holographic data storage is finally due to make its debut with the launch of the very first commercial holographic disk drives. These drives, to be launched within the next few months, will be capable of storing a colossal 300 gigabytes of data — 12 times more than the latest Blu-ray disks and 60 times more than traditional DVDs.

This is possible because, unlike DVDs that store data only on their surface, holographic disks can hold information throughout their volume as well. This three-dimensional aspect allows dozens, if not hundreds, of images of digital data to be superimposed onto a given volume of material, thereby increasing the capacity well beyond what is feasible using conventional optics.

The idea was first conceived in 1963 by Pieter van Heerden of Polaroid Research Labs in Cambridge, Massachusetts, in the USA. The basic concept is to store interference patterns caused by two beams of coherent light intersecting as they pass through a volume of light-sensitive material (Box 1). The material's physical properties change in response to the pattern of light, and in this way information can be stored and retrieved at a later date. In much the same way that holographic images are able to show different perspectives of a scene or object taken from different angles, holographic storage disks will store different 'pages' of data. This information comes in the form of arrays of light and dark patches representing 1s and 0s — with each page or array stored at a slightly different angle within the volume of the recording medium (Box 1).

OPTWARE

Data density goes deep. Holographic media, such as the Optware holographic veratile disk drive featured here, could massively increase optical storage by storing digital data in three dimensions thoughout the volume of the material.

NEW MATERIALS

Promising though this is, a lack of suitable photosensitive recording media meant that the idea did not become practical until the 1990s. One of the main problems was shrinkage, a phenomenon in which the light-sensitive reaction used to record the interference pattern causes the material to deform and reduce in volume. For the purposes of recording holographic images this isn't a problem, but data storage is less forgiving because each bit has to be reliably addressable.

What's more, the early crystalline materials used to record holographic images suffered from problems of chemical leakage. The light-activated chemical reactions were difficult to contain locally, and they leaked out into neighbouring regions. "All previous work had been done on lithium niobide," says Liz Murphy, vice president of marketing for InPhase Technologies based in Colorado in the USA, one of the companies preparing to launch holographic drives. "It would erase more data than it would record."

But by the end of the 1990s the development of advanced photosensitive polymers, by companies such as the Polaroid Corporation and Bell Labs, finally started to make holographic storage look feasible. The first of these disk drives to hit the market will come from InPhase. Set up in 2000 by Lucent Technologies, InPhase has built on Bell Lab's efforts and produced a proprietary recording medium with a high photosensitivity that is tailored towards holographic data storage. The researchers use a light-sensitive free-radical reaction to change the state of the photopolymer and therefore store information. "It's coming out this year.

Box 1 Holographic storage: Photoreactive interference patterns to read and write data

Despite the different chemistries of the photosensitive polymers being developed by both DCE Aprilis (which uses a cationic ring-opening polymerization process) and InPhase Technologies (which relies upon free-radical polymerization reactions), the underlying principle of holographic storage is the same (Fig. B1). Instead of storing digital information in the form of bumps in a reflective surface of the disk — as is the case with DVDs and CDs — holograms are recorded in the volume of interference patterns caused by two coherent laser beams intersecting through a volume of light-sensitive photopolymer material. The three-dimensional nature of the process allows a larger storage density.

A laser is split into two coherent paths. One path is a signal or information-carrying beam that illuminates a particular portion of the disk, the other path is a reference beam that is typically guided by mirrors to illuminate the same section of the disk but from a particular angle. Where the two beams of coherent light coincide they form an interference pattern in the volume of the material. Thus rather than storing a pattern on the surface, the interference pattern is formed in three dimensions within a given volume of the storage location.

Within the photosensitive polymer, the bright portions of the interference pattern cause small monomer molecules to react and link together to form polymer chains. In turn, this creates chemical segregation that results in refractive-index modulation in the storage medium for the specific angle of the reference beam. What this means is that by altering the angle of the reference beam it is possible to record multiple interference patterns in the same small volume of material, each being a recording event for a page of information.

In practice, digital information is first converted into a digital image consisting of black and white squares, where each pixel in an array of, say, a million corresponds to a 1 or 0 depending on the absence or presence of light. So for a given volume of material, hundreds of pages can be stored by forming interference patterns at hundreds of slightly different angles.

These can subsequently be read back by shining the original reference beam onto the same portion at the exact angle that was originally used to create the hologram. The diffractive properties of the three-dimensional interference pattern, namely the hologram, cause the reading beam to be diffracted, producing a similarly patterned beam corresponding to the original signal beam. This is then detected and converted back into the original 1s and 0s.

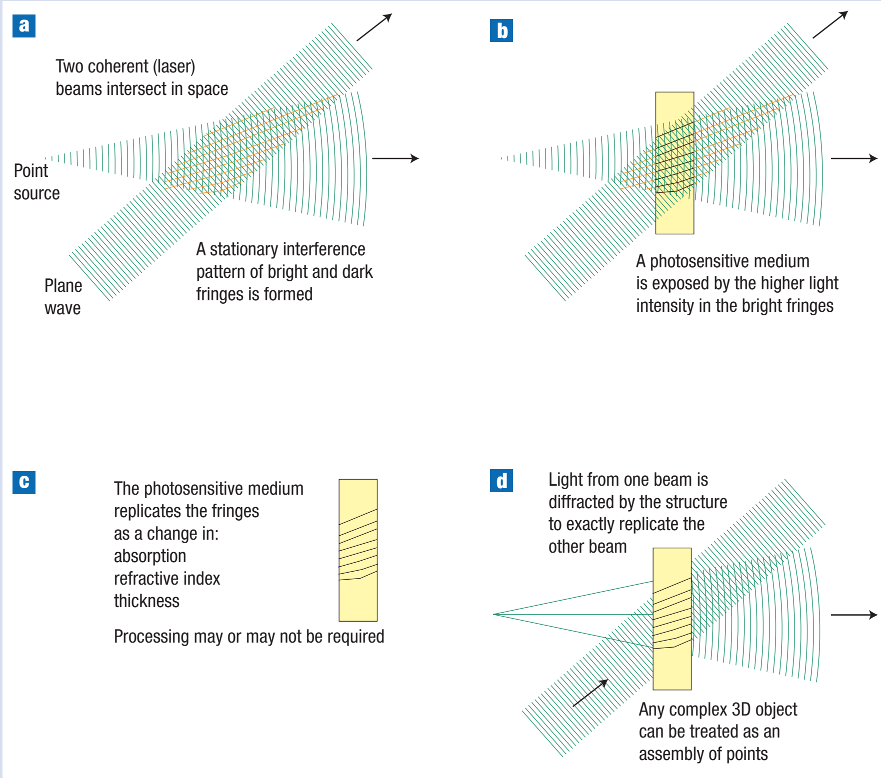


Figure B1 The physics of holography. **a**, The process is based on the interference fringes, **b**, incident on a photosensitive material, **c**, which are used to modify a photosensitive material with respect to the light absorption properties, refractive index or the material thickness. **d**, This pattern can be retrieved from the diffraction of a probe light beam.

We have units already that are under testing," says Murphy.

STOP–START

Known as the Tapestry range (Box 2), this holographic technology will cost $18,000 for the drive and $180 for each 5.25-inch removable disk. Initially the disks will be able to store up to 300 gigabytes of data but, according to Murphy, within a few years this will be ramped up to a vast 1.6 terabytes. Unlike other optical media, such as CDs and DVDs, InPhase's holographic disk is not spun continuously during reading or writing. Instead the disk remains stationary while a blue laser (of wavelength 405 nm) takes a series of snapshots of one part of the disk from different angles. In this way a single page of data can be read or written and when ready for the next page, the disk is rotated slightly, whereupon the process is repeated.

In contrast, the technology being developed by DCE Aprilis (a spin-off of Polaroid founded in 1999) more closely resembles conventional techniques, in which the disk is kept spinning while the information is recorded and read. According to David Waldman, chief scientist of DCE Aprilis in Massachusetts, this approach, combined with the light sensitivity of their proprietary polymer medium, has been shown to offer recording rates in excess of one gigabit per second — considerably faster than the stop–start approach adopted by InPhase, which can only record data at less than about ten megabytes per second.

As DCE Aprilis was set up as a research company for holographic materials and devices, it will not be developing end products itself. Therefore, the precise specifications of any end products will very much depend on the company's commercial partners. "A number of large consumer electronics companies in Japan and South Korea are actively testing and evaluating our holographic recording materials," says Waldman, although he will not disclose precisely who these companies are.

THE DATA MOUNTAIN

Ultimately, the differences in the two approaches taken by these companies will be reflected in the initial applications of their holographic technology. DCE Aprilis is aiming to target the general public with affordable next-generation multimedia disks that will eventually replace existing Blu-ray and HD-DVDs. InPhase, on the other hand, is steering away from the general public and gearing its drives towards companies and manufacturers within the mass storage market, as Murphy explains — hardly surprising given the hefty price tag of their technology. At present, government agencies, broadcasters, medical firms and information-technology companies are having to back up hundreds of gigabytes of data each day. She says that at this sort of scale, digital storage quickly becomes unmanageable and translates into how much warehouse space you have available to store your medium.

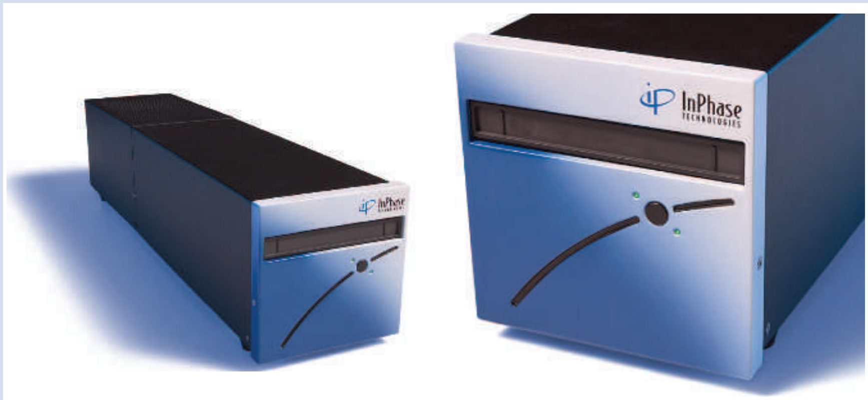
The drive for such media comes not just from a desire to fit more films or tunes on a disk, according to Immo Gathman of the German jukebox manufacturer DSM, one of the companies working with InPhase. With memory-hungry HD file formats being introduced, such as the 720p60 format used in HD television, it won't be long before holographic storage densities will become less of a luxury and more of a necessity.

Box 2 Initial performance

The HDS-300R from Inphase will be the firm's first commercial holographic drive and is due to hit the market later this year with an initial capacity of 300 gigabytes. Here's a round-up of the specifications that Inphase is touting for the drive:

Specifications

Storage capacity: 300 Gbytes
Format: Write once, read many (WORM)
Write/read data-transfer rates: 20 Mbyte s^{-1}
Media load/unload time: 5 s
Drive size: 146 × 133 × 660 mm
Cartridge format: 135 × 11 × 153 mm (contains 130-mm-diameter disk)
System interface: SCSI ultra-2, FC, FTP, GbE
Average seek time: 250 ms
Page capacity: 1.4 Mbits per page
Laser wavelength: 405 nm
Operating temperature: 10–40 °C
Operating voltage: d.c. 5 V or 12 V
Power consumption: 80 W
Mean time before failure: 100,000 power-on hours



INPHASE TECHNOLOGIES

JAPAN'S DRIVE

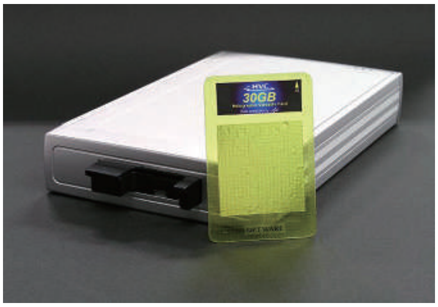
Further afield, Japan is also pushing towards holographic data storage, namely through a company called Optware. Established in 1999 by Hideyoshi Horimai, a former engineer who was working to develop optical disk memory for Sony, Optware now has 13 employees, 9 of whom are engineers. Optware's version of a holographic storage medium is known as the 'holographic versatile disk' (HVD), which relies on an approach known as collinear holography to read and write data. Developed mainly by Horimai himself, the collinear technique is named after the fact that every light beam used to record the data goes back and forth through an objective lens to the recording medium. In the Optware set-up, signal and reference beams are used for recording, the reference beam for retrieving and a 'servo' beam for focusing and position sensing on the medium.

With Optware's technology, the objective lens follows the disk dynamically with a position accuracy of 30 nm or less. "Because of this precision tracking, there is no need to worry about vibrations of the recording medium," says Horimai, now chief technology officer of the company.

The HVD will use green laser light with a wavelength of 532 nm. At the level of research and development, the company has also succeeded in developing recording technology using a blue laser diode. The disk will initially measure 19 inches in diameter, but Optware thinks that it will eventually become the size of a credit card.

Similar to InPhase, Optware is not targeting the consumer but is instead looking to industry, where the HVD could be used to create video and medical archives or applied to other areas that require large volumes of information to be stored. The storage capacity of the HVD can be varied depending on the intended application, from 200 gigabytes up to 1 terabyte.

Like InPhase and DCE Aprilis, Optware's aim is to commercialize the data-storage technology as soon as possible. Their original intention was to commercialize the HVD by the end of 2006, but financial troubles have led to delays in the schedule. The major problem Optware has faced is the hefty price tag that comes with the technology, which incorporates expensive light-source technology, a device to display



OPTWARE

The Optware holographic versatile disk could eventually become the size of a credit card.

holographic data pages and a CMOS sensor to capture those pages. "These prices should become reasonable, otherwise development costs will remain high," Horimai says. At present, Optware is working with materials manufacturers to develop high-quality, less expensive devices that offer stable data recording. Optware now plans to put the HVD on the market sometime in 2008.

THE ROAD AHEAD

Despite the push for holographic technology, magnetic tape is still the preferred medium for mass storage at present. Mattias Kaiserswerth, director of IBM Zurich Research Laboratory in Switzerland explains that this is because magnetic tape is so cheap and is able to read and write data so quickly. Until recently IBM was actively pursuing research into holographic storage. But according to Kaiserswerth, this has now ceased and IBM is instead concentrating on ways to achieve denser magnetic storage. This is hardly surprising given how cheap tape is, according to Mukul Krishna, an analyst with Frost and Sullivan, a business research and consulting company based in San Antonio, Texas. "The cost of maintaining archives is phenomenal," he says. "What is needed is a way to pack more data into a smaller space." Holographic storage does precisely that and so is expected to have a huge impact on this burgeoning market.

In the meantime, though, all three companies have their work cut out for them. For if holographic storage is to really take off, they will need to develop disks that do not just record data but can also re-record it. According to Murphy, InPhase's solution to this problem is still some way off, but will probably involve using one wavelength of laser for writing and another to erase data. To make that possible will require polymers with a completely different chemistry to the ones they have been using. According to Optware, its technology is already re-writable and the firm is now working to make the stored data erasable in the future.

Duncan Graham-Rowe is a freelance science and technology journalist based in Brighton, UK.
e-mail: duncangr@gmail.com

Additional reporting by Ichiko Fuyuno, a journalist for Nature*, based in Tokyo, Japan.*
e-mail: i.fuyuno@natureasia.com