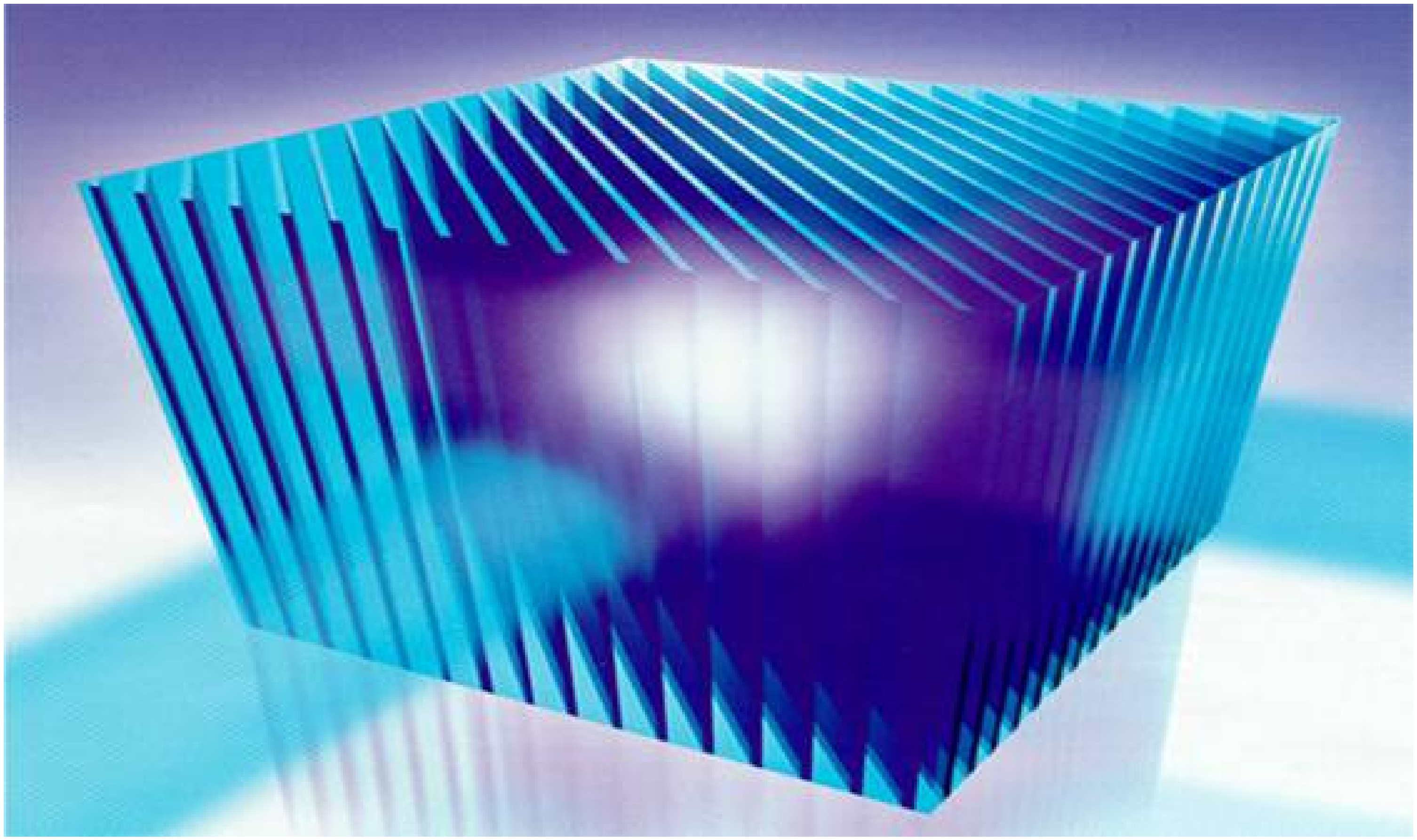
HOLOGRAPHIC DATA storage



abstract

Devices that use light to store and read data have been the backbone of data storage for nearly two decades. Compact disc revolutionized data storage in the early 1980s, allowing multi-megabytes of data to be stored on a disc. In 1997, an improved version of the CD, called a digital versatile disc (DVD), was released, which enabled the storage of full-length movies on a single disc. In order to increase storage capabilities, scientists are now working on a new optical storage method, called **holographic memory**, that will go beneath the surface and use the volume of the recording medium for storage, whereas CDs and DVDs use only the surface area. An advantage of a holographic memory system is that an entire page of data can be retrieved quickly and at one time. In order to retrieve and reconstruct the holographic page of data stored in the crystal, the reference beam is shined into the crystal at exactly the same angle at which it entered the crystal to store that page of data. Each page of data is stored in a different area of the crystal, based on the angle at which the reference beam strikes it. During reconstruction, the beam will be

diffracted by the crystal to allow the recreation of the original page that was stored. This reconstructed page is then projected onto the charged-coupled device (CCD) camera, which interprets and forwards the digital information to a computer.

Holographic memory offers the possibility of storing one terabyte (TB) of data in a sugar-cube-sized crystal. On the other hand, holographic data storage currently suffers from the relatively high component and integration costs faced by any emerging technology.

If this technology were developed we would have easily transformed our current world into a digitalized world were every data ,text ,games ,movies etc can be easily stored on a single holographic cube which can be easily carried without much fuss.

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HOLOGRAPHIC DATA STORAGE

New Multimedia applications, and the normal day to day data operations are placing new demands on storage systems (Multimedia refers to the integration of text, audio, still images, video, and graphics into an easily manipulated digital format). These kind of documents require 10 to 1000 times the storage capacity required by conventional documents. Multimedia programs eat up a large amount of storage space. Each second of full motion, full screen video requires 30 frames of video information at the rate of almost a megabyte (MB) of computer data per frame. That is about 30 MB of information per second, or 1.8 gigabyte (GB) per minute. This amount is not generally available, particularly in portable systems, which is the most promising sector in this industry following the trend toward miniaturization and more compact computers.

Until now, multimedia storage has been achieved using the technique called "compression", which consists of the coding of data in fewer bits that normally done, to save storage space or transmission time. Specialized software automatically compresses and decompresses data.

For this and other reasons, storage is seen by many in the industry as the critical enabling technology for many new multimedia applications and to address its rapidly increasing requirements is the key to bring forward this new technology. Currently, this storage is provided by magnetic and optical technologies, and despite fantastic advances in these technologies, physical limitations are involved in getting data on and off of the conventional (mechanical) rotating devices. For example, disk based storage uses moving parts that poop out at a certain speed, and further progress in CD-ROM technology faces a fundamental limit: the pits that encode information on the surface of a compact disk can be no smaller than the wavelength of the laser light used to read them. Efficient multimedia systems require high density, interchangeable media for the majority of their applications. These applications vary from the initial loading of software, to multimedia presentations, to simple back up of files located on the device. The general characteristics of storage devices for the multimedia product environments are:

a).Store information in a form that can be easily manipulated by electronics.

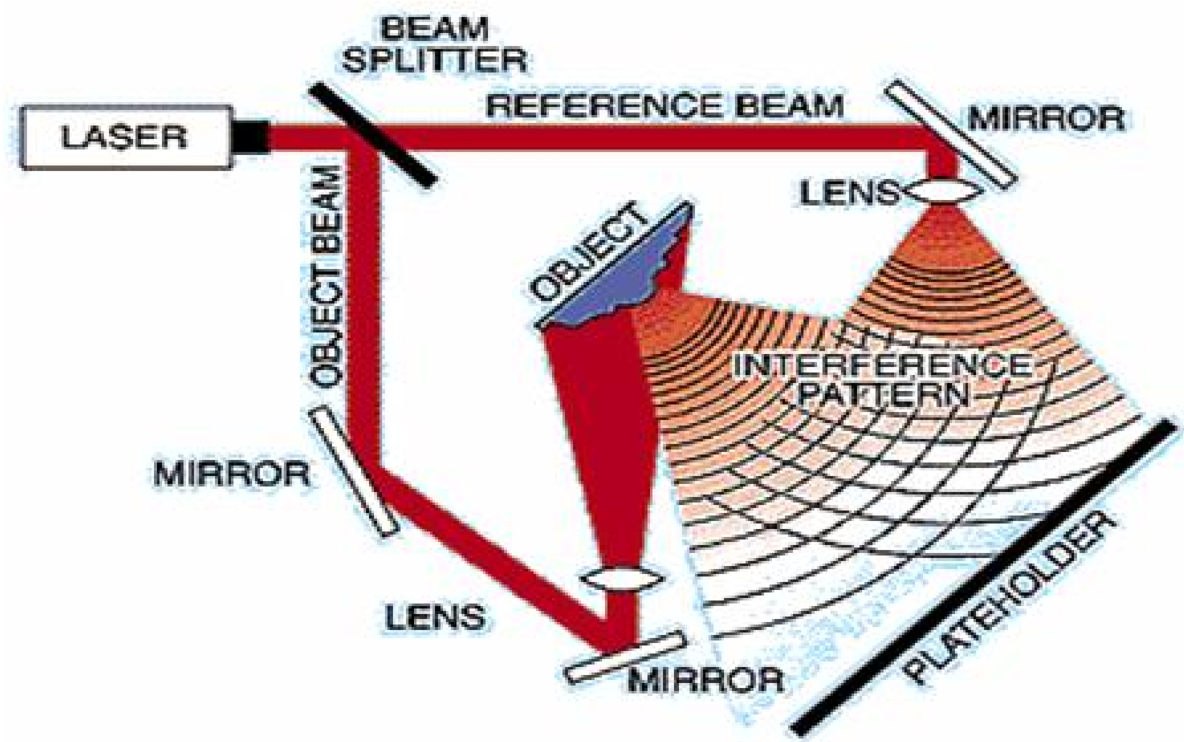
b). Safely store huge amounts of information, typically, one to more than a thousand gigabits so that it can be preserved indifinitively as archives.
c). Any part of the stored information can be read out or changed at any time with the shortest possible delay which, particularly for the fleeting intermediary data occurring in processing, is typically 1 msec or less.
d). Low power consumption (1 watt average)
e). Low cost per megabyte of memory (Less than one dollar per MB)

A new optical technology, called **"Holographic Storage"** may offer exciting possibilities, and the promise of being the most cost-effective solution to the storage requirements of multimedia computing than any existing or projected technology. The new technique enables the storage of digital information as three dimensional (3D) optical holograms. Storing and retrieving data as two dimensional patterns of light, or pages, in a 3D volume of light sensitive crystal, provides the basis for holographic storage technology. Organizing data into pages instead of individual bits, and the use of lasers, provide access to speeds and orders of magnitude faster than the rotating devices of .For example the fastest magnetic disk currently available takes over 5 hours to transfer what, theoretically, a holographic storage device could transfer in 1 second . This means that it can easily handle the demand of computing with images, or multimedia. This technology is based on photo refractive -uses light instead of electricity as in fiber optics- volume holographic storage (PVHS) techniques; it makes possible extremely fast, and potentially removable media. Holographic storage devices would be a good choice for systems that need to provide fast random access for the recording and playback of digital video and high throughput transaction-processing systems (allows quick access to stored information) at the lowest cost

History of Holography

The theory of holography was developed by Dennis Gabor, a Hungarian physicist, in the year 1947. His theory was originally intended to increase the resolving power of electron microscopes. Gabor proved his theory not with an electron beam, but with a light beam. The result was the first hologram ever made. The early holograms were legible but plagued with many imperfections because Gabor did not have the correct light to make crisp clear holograms as we can today . Gabor need LASER Light. In the 1960s two engineers from the University of Michigan: Emmett Leith and Juris Upatnieks, developed a new device which produced a three dimensional image of an object. Building on the discoveries of Gabor, they produced the diffuse-light hologram.

Today, we can see holograms, or 3-D images, on credit cards, magazine covers, art galleries. Yet this unique method of capturing information with lasers-the science of holography-has many more applications in the industrial world and is on the verge of revolutionizing data-storage technology as we know it.


BEAM
SPLITTER
REFERENCE BEAM
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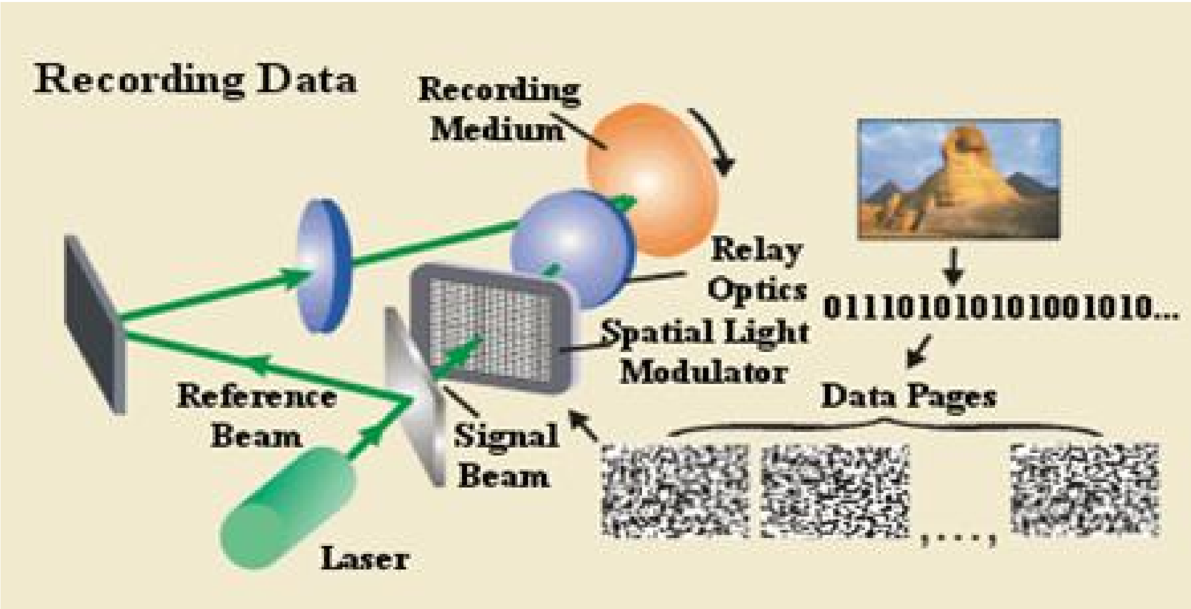
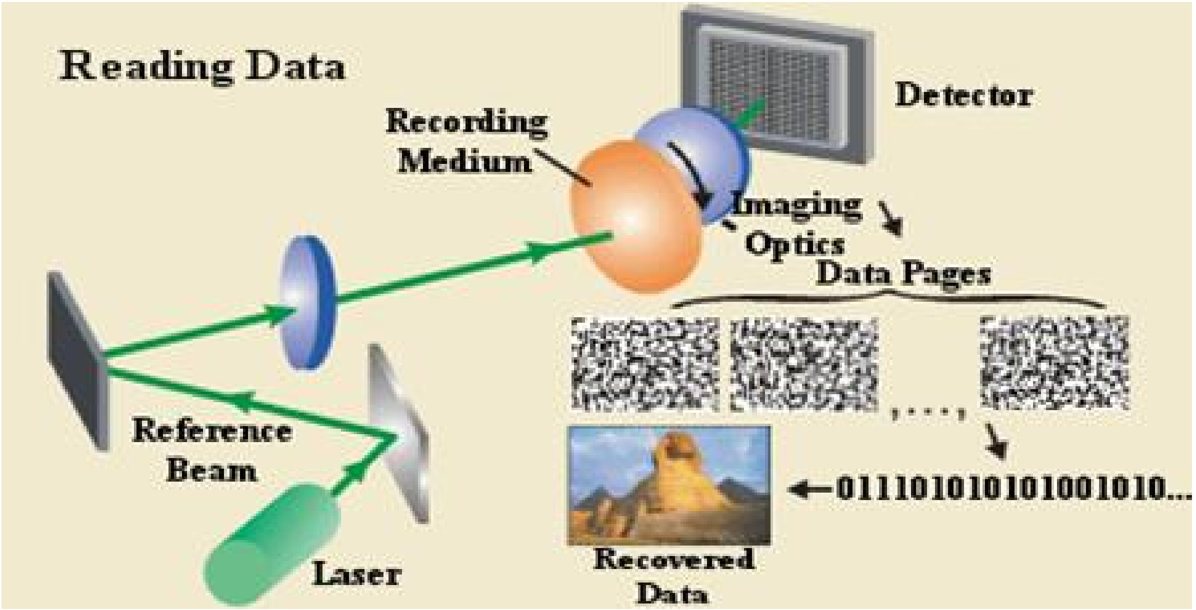
Holography In Data storage



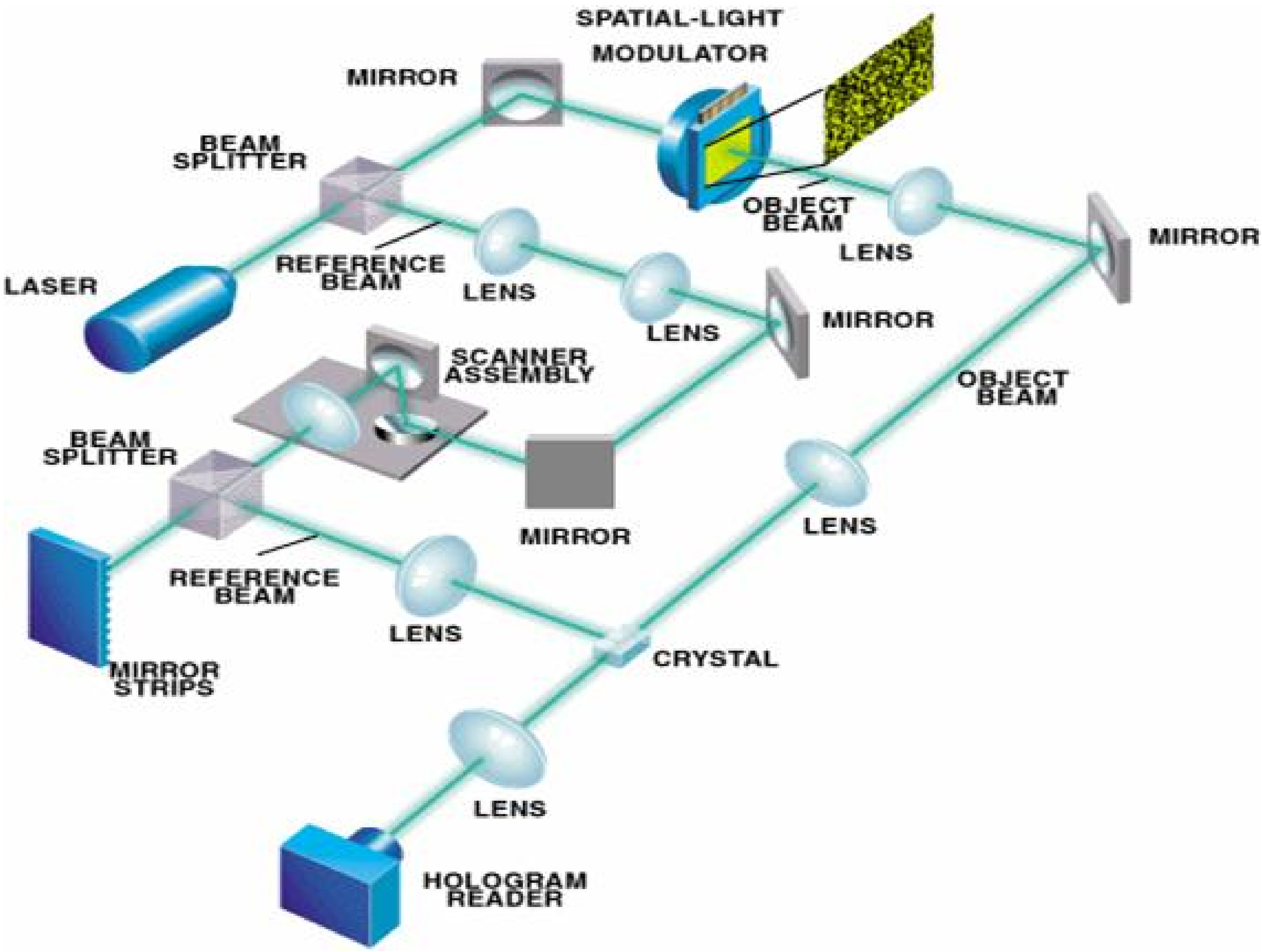


These two diagrams show how information is stored and retrieved in a

holographic data storage system.

Because holographic images have depth of field, information that is digitized into the computer language of zero' s and one' s can be layered deep inside a hologram. Holographic storage is much different form conventional methods of storing digitized data . Magnetic and optical disks line up data digit by digit on flat, single layer tracks.

Holographic data storage, in the other hand, can stack about 40 pages or arrays of digits, using the depth of the medium. Pages deep in the hologram can be read by tilting the angle of the light beam used to read it. To the user, this could mean that drives that fit in tomorrow' s portable computers could store several gigabytes of data and retrieve that information nearly instantly. at prices equal or lower than the cost of today's hard drives.


SPATIAL-LIGHT
MODULATOR
MIRROR
BEAM
SPLITTER
OBJECT
BEAM
LENS
MIRROR
REFERENCE
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LASER
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LENS
MIRROR
SCANNER
ASSEMBLY
OBJECT
BEAM
BEAM
SPLITTER
MIRROR
LENS
REFERENCE
BEAM
LENS
CRYSTAL
MIRROR
STRIPS
LENS
HOLOGRAM
READER

OPTICAL LAYOUT of a holographic memory system shows how a crystal can be imprinted with pages of data. An object beam takes on the data as it passes through a spatial-light modulator. This beam meets another--the reference beam--in the crystal, which records the resulting interference pattern. A mechanical scanner changes the angle of the reference beam, and then another page can be recorded.

Holograms are just a step up from photographs. The object in recording photographic data is to store light intensity, which is done by exposing a photo-sensitive material to light. This information can be retrieved later by illuminating the developed film .Moreover, the object of holography is to store light intensity and direction. The step-by step process of creating a hologram is explained graphically below in Figure 1:

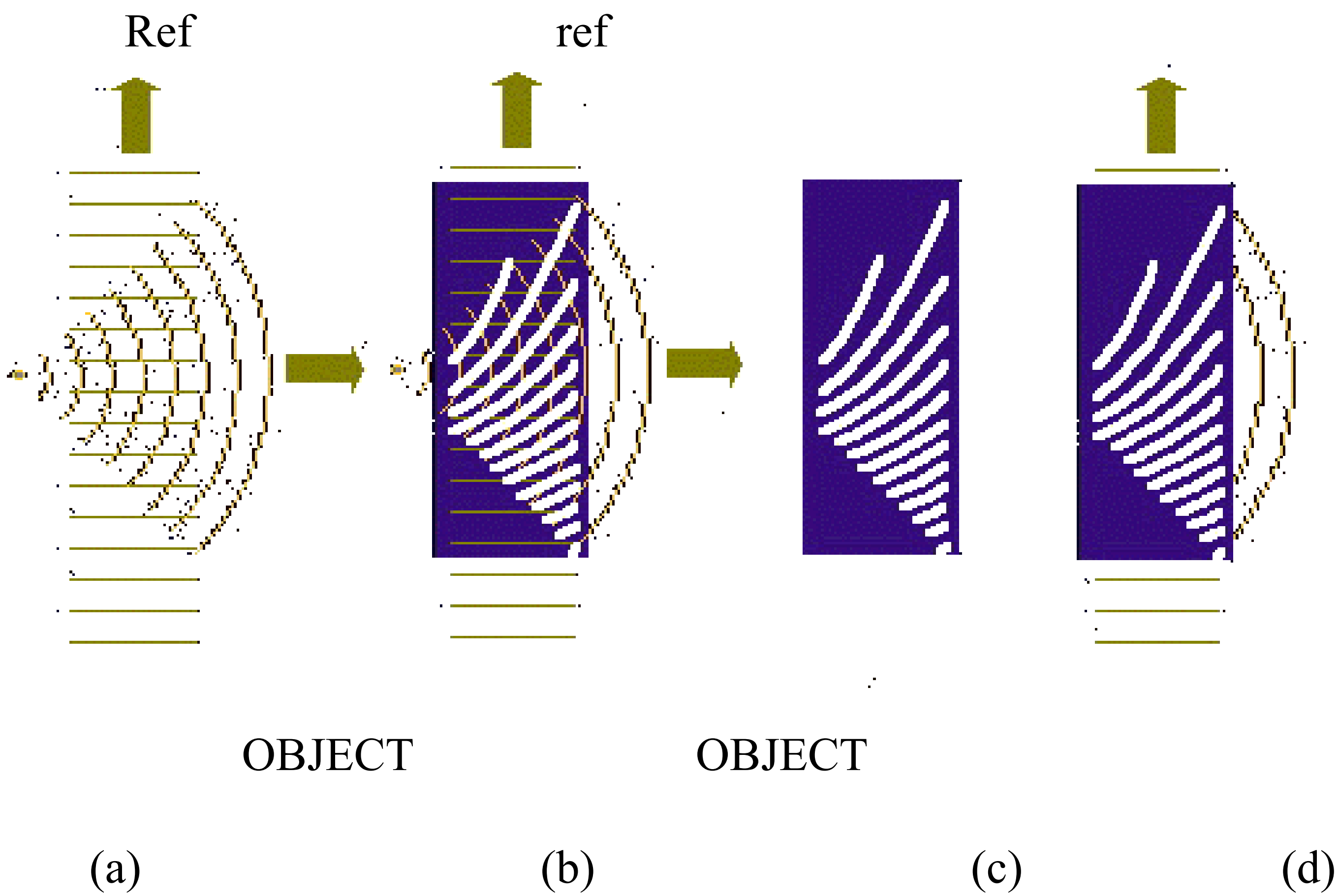


Figure 1: Illustration of volume holographic recording and replay.

Three things are used to create a hologram: the recording material (usually a photosensitive crystal), the reference beam, and the signal beam. First (a), a signal beam from an object (obj) is directed through the recording medium (blue rectangle). A reference beam (ref) crosses paths with this first beam and thus creates interference patterns within the material (b). The material "responds" to the interference pattern and thereby "records" it (c). The result may be viewed/retrieved by sending the same exact reference beam through the material. This reference beam interferes this time with the recorded pattern and the two combine to form the signal beam. This explains why as kids we could only view the baseball card holograms by orienting them to a particular position with respect to a light source. The light source acted as the reference beam in retrieving the encoded information in the card. When the correct orientation was achieved, the two interfered to make the pretty picture.

We thus have two very important consequences that we may use to our advantage. Any given particular hologram in the recording medium can only be accessed by directing the same exact reference wave (amplitude and direction) through the medium. Furthermore, the fact that holograms record direction and amplitude allow us to make 3 dimensional representations of data structures. The two tenets allow for the possibility of holographic data storage.

STORAGE OF DATA

With its omnipresent computers, all connected via the Internet, the Information Age has led to an explosion of information available to users. The decreasing cost of storing data, and the increasing storage capacities of the same small device footprint, have been key enablers of this revolution. While current storage needs are being met, storage technologies must continue to improve in order to keep pace with the rapidly increasing demand.

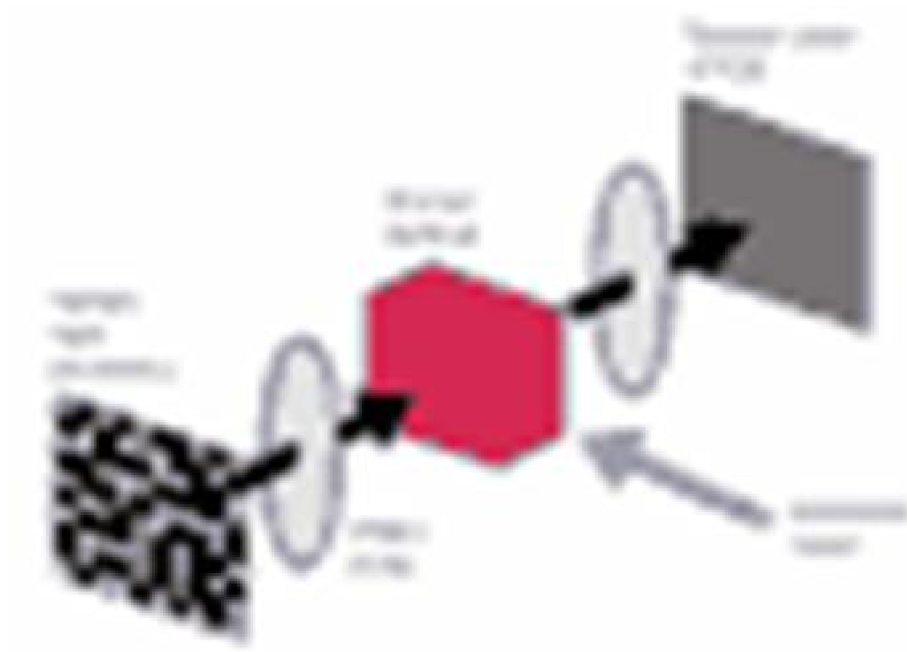
However, both magnetic and conventional optical data storage technologies, where individual bits are stored as distinct magnetic or optical changes on the surface of a recording medium, are approaching physical limits beyond which individual bits may be too small or too difficult to store. Storing information throughout the volume of a medium—not just on its surface—offers an intriguing high-capacity alternative. Holographic data storage is a volumetric approach which, although conceived decades ago, has made recent progress toward practicality with the appearance of lower-cost enabling technologies, significant results from longstanding research efforts, and progress in holographic recording materials.

In holographic data storage, an entire page of information is stored at once as an optical interference pattern within a thick, photosensitive optical material.. This is done by intersecting two coherent laser beams within the storage material. The first, called the object beam, contains the information to be stored; the second, called the reference beam, is designed to be simple to reproduce—for example, a simple collimated beam with a planar wavefront. The resulting optical interference pattern causes chemical and/or physical changes in the photosensitive medium: A replica of the interference pattern is stored as a change in the absorption, refractive index, or thickness of the photosensitive medium. When the stored interference grating is illuminated with one of the two waves that was used during recording some of this incident light is diffracted by the stored grating in such a fashion that the other wave is reconstructed. Illuminating the stored grating with the reference wave reconstructs the object wave, and vice versa . Interestingly, a backward-propagating or phase-conjugate reference wave, illuminating the stored grating from the “back” side, reconstructs an object wave that also propagates backward toward its original source

A large number of these interference gratings or patterns can be superimposed in the same thick piece of media and can be accessed independently, as long as they are distinguishable by the direction or the spacing of the gratings. Such separation can be accomplished by changing the angle between the object and reference wave or by changing the laser wavelength. Any particular data page can then be read out independently by illuminating the stored gratings with the reference wave that was used to store that page. Because of the thickness of the hologram, this reference wave is diffracted by the interference patterns in such a fashion that only the desired object beam is significantly reconstructed and imaged on an electronic camera. The theoretical limits for the storage density of this technique are around tens of terabits per cubic centimeter. In addition to high storage density, holographic data storage promises fast access times, because the laser beams can be moved rapidly without inertia, unlike the actuators in disk drives. With the inherent parallelism of its pagewise storage and retrieval, a very large compound data rate can be reached by having a large number of relatively slow, and therefore low-cost, parallel channels.

The data to be stored are imprinted onto the object beam with a pixelated input device called a spatial light modulator (SLM); typically, this is a liquid crystal panel similar to those on laptop computers or in modern camcorder viewfinders. To retrieve data without error, the object beam must contain a high-quality imaging system—one capable of directing this complex optical wavefront through the recording medium, where the wavefront is stored and then later retrieved, and then onto a pixelated camera chip (Fig3) image of the data page at the camera must be as close as possible to perfect. Any optical aberrations in the imaging system or misfocus of the detector array would spread energy from one pixel to its neighbors. Optical distortions (where pixels on a square grid at the SLM are not imaged to a square grid) or errors in magnification will move a pixel of the image off its intended receiver, and either of these problems (blur or shift) will introduce errors in the retrieved data. To avoid having the imaging system dominate the overall system performance, near-perfect optics would appear to be unavoidable, which of course would be expensive. However, the above-mentioned readout of phase-conjugated holograms provides a partial solution to this problem. Here the reconstructed data page propagates backward through the same optics that were used during the recording, which compensates for most shortcomings of the imaging system. However, the detect the or and spatial light modulator must still be properly aligned.

Fig3



A rather unique feature of holographic data storage is associative retrieval: Imprinting a partial or search data pattern on the object beam and illuminating the stored holograms reconstructs all of the reference beams that were used to store data. The intensity that is diffracted by each of the stored interference gratings into the corresponding reconstructed reference beam is proportional to the similarity between the search pattern and the content of that particular data page. By determining, for example, which reference beam has the highest intensity and then reading the corresponding data page with this reference beam, the closest match to the search pattern can be found without initially knowing its address.

Because of all of these advantages and capabilities, holographic storage has provided an intriguing alternative to conventional data storage techniques for three decades. However, it is the recent availability of relatively low-cost components, such as liquid crystal displays for SLMs and solid-state camera chips from video camcorders for detector arrays, which has led to the current interest in creating practical holographic storage devices.. A team of scientists from the IBM Research Division have been involved in exploring holographic data storage, partially as a partner in the DARPA-initiated consortia on holographic data storage systems (HDSS) and on photorefractive information storage materials (PRISM). .

How Holographic Memories Work

The pattern, known as a grating, forms when two laser beams interfere with each other in a light-sensitive material whose optical properties are altered by the intersecting beams.

Before the bits of data can be imprinted in this manner in the crystal, they must be represented as a pattern of clear and opaque squares on a liquid crystal display (LCD) screen, a miniature version of the ones in laptop computers. A blue-green laser beam is shined through this crossword-puzzlelike pattern, or page, and focused by lenses to create a beam known as the signal. A hologram of the page of data is created when this signal beam meets another one, called the reference, in the photosensitive crystal. The reference beam, in this case, is collimated, which means that all its light waves are synchronized, with crests and troughs passing through a plane in lockstep (indeed, such waves are known as plane waves). The grating created when the signal and reference beams meet is captured as a pattern of varying refractivity in the crystal.

After being recorded like this, the page can be holographically reconstructed by once again shining the reference beam into the crystal from the same angle at which it had entered the material to create the hologram. As it passes through the grating in the crystal, the reference beam is diffracted in such a way that it recreates the image of the original page and the information contained on it. The reconstructed page is then projected onto an array of electrooptical detectors that sense the light-and-dark pattern, thereby reading all the stored information on the page at once. The data can then be electronically stored,

accessed or manipulated by any conventional computer.
The key characteristic is the accuracy with which the "playback" reference beam must match the original one that recorded the page. This precision depends on the thickness of the crystal--the thicker the crystal, the more exactly the reference beam must be repositioned. If the crystal is one centimeter thick and the illumination angle deviates by one thousandth of a degree, the reconstruction disappears completely. Far from being an inconvenience, this basic mechanism is exploited in almost all holographic memories.
The first page of data is holographically recorded in the crystal. The angle of the reference beam is then increased until the reconstruction of the first hologram disappears. Then a new page of data is substituted and holographically recorded. The procedure, known as angle multiplexing, is repeated many times. Any of the recorded holograms can be viewed by illuminating the crystal with the reference beam set at the appropriate angle.
How many pages can be imprinted into a single crystal? The number is limited mainly by the dynamic range of its material: as more holograms share the same crystalline volume, the strength of each diminishes. Specifically, the percentage of light that is diffracted by each hologram (and therefore sensed by the electro-optical detectors) is inversely proportional to the square of the number of holograms superimposed.

If 10 holograms in a crystal yield a diffraction efficiency equal to 1 percent, 1,000 holograms will have a diffraction efficiency of only 0.0001 percent. This effect determines the maximum number of holograms that can be stored, because the drop in diffraction efficiency ultimately makes the reconstructions too weak to be detected reliably amid the noise in the system--fluctuations in the brightness of the lasers, scattering from the crystal, thermally generated electrons in the detector, and so on. This maximum number of holograms can be determined by measuring the optical properties of the crystal material and the various noise sources in the system. In practice, when the diffraction efficiency has dropped too low for the pages to be reliably reconstructed, the rate at which erroneous data are detected--the bit-error rate--becomes unacceptably high.

Hardware for holographic data storage

Fig 3 shows the most important hardware components in a holographic storage system: the SLM used to imprint data on the object beam, two lenses for imaging the data onto a matched detector array, a storage material for recording volume holograms, and a reference beam intersecting the object beam in the material. What is not shown in Fig3 is the laser source, beam-forming optics for collimating the laser beam, beamsplitters for dividing the laser beam into two parts, stages for aligning the SLM and detector array, shutters for blocking the two beams when needed, and waveplates for controlling polarization. Assuming that holograms will be angle-multiplexed (superimposed yet accessed independently within the same volume by changing the incidence angle of the reference beam), a beam-steering system directs the reference beam to the storage material. Wavelength multiplexing has some advantages over angle-multiplexing, but the fast tunable laser sources at visible wavelengths that would be needed do not yet exist. The optical system shown in Fig 3 , with two lenses separated by the sum of their focal lengths, is called the "4-f" configuration, since the SLM and detector array turn out to be four focal lengths apart. Other imaging systems such as the Fresnel configuration (where a single lens satisfies the imaging condition between SLM and detector array) can also be used, but the 4-f system allows the high numerical apertures (large ray angles) needed for high density. In addition, since each lens takes a spatial Fourier transform in two dimensions,he hologram stores the Fourier transform of the SLM data, which is then Fourier-transformed again upon readout by the second lens. This has several advantages: Point defects on the storage material do not lead to lost bits, but result in a slight loss in signal-to-noise ratio at all pixels; and the storage material can be removed and replaced in an offset position, yet the data can still be reconstructed correctly

WHATS THE HOLD UP

The technology itself has only been made feasible in the past few years by advances in the materials science of photorefractive crystals and the control of light with spatial light modulators. However, the best of the holographic material to-date, non-linear photorefractive crystals, are currently very expensive and have limited capabilities.. There are several candidates for materials to date. Current work uses iron-doped lithium niobate, strontium barium niobate, or barium titanate crystals.
Whether or not Holographic Data Storage comes to the shelves within the next decade is not the question. The question is what will come to the shelves within the next decade. Other projects running concurrently include near field recording (optical reader spans rotating disk) and atom-by-atom storage. Just think of it as the CD on the atomic scale. Whatever technology may emerge, holographic is the most likely candidate, as it promises data rates in excess of a gig per second due to parallel access (data is read in pages, not in lines, as in current magnetic storage devices .Until then, we will be patiently waiting for that one "tera" hard drive to cure our lack of space for this ever-growing monster we so lovingly call "data.".

Outlook

Holographic data storage has several characteristics that are unlike those of any other existing storage technologies. Most exciting, of course, is the potential for data densities and data transfer rates exceeding those of magnetic data storage. In addition, as in all other optical data storage methods, the density increases rapidly with decreasing laser wavelength. In contrast to surface storage techniques such as CD-ROM, where the density is inversely proportional to the square of the wavelength, holography is a volumetric technique, making its density proportional to one over the third power of the wavelength. In principle, laser beams can be moved with no mechanical components, allowing access times of the order of 10 μs, faster than any conventional disk drive will ever be able to randomly access data. As in other optical recording schemes, and in contrast to magnetic recording, the distances between the "head" and the media are very large, and media can be easily removable. In addition, holographic data storage has shown the capability of rapid parallel search through the stored data via associative retrieval.

On the other hand, holographic data storage currently suffers from the relatively high component and integration costs faced by any emerging technology. In contrast, magnetic hard drives, also known as direct access storage devices (DASD), are well established, with a broad knowledge base, infrastructure, and market acceptance.

"In summary, we have made a lot of progress in the past few years, but the recording materials are still the key component limiting the overall performance of holographic data storage systems. Much work is currently being carried out at universities and industrial labs around the world. Based on the progress in those labs, it is reasonable to expect that viable products could reach the market around the turn of the century."

THE END

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