A

Seminar report

On

HOLOGRAPHIC MEMORY

Submitted in partial fulfillment of the requirement for the award of degree
of Bachelor of Technology in Computer Science

SUBMITTED TO: | **SUBMITTED BY:**

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Acknowledgement

I would like to thank respected Mr…….. and Mr. ……..for giving me such a wonderful opportunity to expand my knowledge for my own branch and giving me guidelines to present a seminar report. It helped me a lot to realize of what we study for.

Secondly, I would like to thank my parents who patiently helped me as i went through my work and helped to modify and eliminate some of the irrelevant or un-necessary stuffs.
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Next, I would thank Microsoft for developing such a wonderful tool like MS Word. It helped my work a lot to remain error-free.

Last but clearly not the least, I would thank The Almighty for giving me strength to complete my report on time.

Preface

I have made this report file on the topic **Holographic Memory**; I have tried my best to elucidate all the relevant detail to the topic to be included in the report. While in the beginning I have tried to give a general view about this topic.

My efforts and wholehearted co-corporation of each and everyone has ended on a successful note. I express my sincere gratitude to …………..who assisting me throughout the preparation of this topic. I thank him for providing me the reinforcement, confidence and most importantly the track for the topic whenever I needed it.

Abstract

This paper describes holographic data storage as a viable alternative to magnetic disk data storage. Currently data access times are extremely slow for magnetic disks when compared to the speed of execution of CPUs so that any improvement in data access speeds will greatly increase the capabilities of computers, especially with large data and multimedia files. Holographic memory is a technology that uses a three dimensional medium to store data and it can access such data a page at a time instead of sequentially, which leads to increases in storage density and access speed. Holographic data storage systems are very close to becoming economically feasible. Obstacles that limit holographic memory are hologram decay over time and with repeated accesses, slow recording rates, and data transfer rates that need to be increased. Photorefractive crystals and photopolymers have been used successfully in experimental holographic data storage systems. Such systems exploit the optical properties of these photosensitive materials along with the behavior of laser light when it is used to record an image of an object. Holographic memory lies between main memory and magnetic disk in regards to data access times, data transfer rates, and data storage density.

Contents

INTRODUCTION

This paper describes holographic data storage as a viable alternative to magnetic disk data storage. Currently data access times are extremely slow for magnetic disks when compared to the speed of execution of CPUs so that any improvement in data access speeds will greatly increase the capabilities of computers, especially with large data and multimedia files. Holographic memory is a technology that uses a three dimensional medium to store data and it can access such data a page at a time instead of sequentially, which leads to increases in storage density and access speed. Holographic data storage systems are very close to becoming economically feasible. Obstacles that limit holographic memory are hologram decay over time and with repeated accesses, slow recording rates, and data transfer rates that need to be increased. Photorefractive crystals and photopolymers have been used successfully in experimental holographic data storage systems. Such systems exploit the optical properties of these photosensitive materials along with the behavior of laser light when it is used to record an image of an object. Holographic memory lies between main memory and magnetic disk in regards to data access times, data transfer rates, and data storage density.

As processors and buses roughly double their data capacity every three years (Moore's Law), data storage has struggled to close the gap. CPUs can perform an instruction execution every nanosecond, which is six orders of magnitude faster than a single magnetic disk access. Much research has gone into finding hardware and software solutions to closing the time gap between CPUs and data storage. Some of these advances include cache, pipelining, optimizing compilers, and RAM.

As the computer evolves, so do the applications that computers are used for. Recently large binary files containing sound or image data have become commonplace, greatly increasing the need for high capacity data storage and data access. A new high capacity form of data storage must be developed to handle these large files quickly and efficiently.

Holographic memory is a promising technology for data storage because it is a true three dimensional storage system, data can be accessed an entire page at a time instead of sequentially, and there are very few moving parts so that the limitations of mechanical motion are minimized. Holographic memory uses a photosensitive material to record interference patterns of a reference beam and a signal beam of coherent light, where the signal beam is reflected off of an object or it contains data in the form of light and dark areas [1]. The nature of the photosensitive material is such that the recorded interference pattern can be reproduced by applying a beam of light to the material that is identical to the reference beam. The resulting light that is transmitted through the medium will take on the recorded interference pattern and will be collected on a laser detector array that encompasses the entire surface of the holographic medium. Many holograms can be recorded in the same space by changing the angle or the wavelength of the incident light. An entire page of data is accessed in this way.

The three features of holographic memory that make it an attractive candidate to replace magnetic storage devices are redundancy of stored data, parallelism, and multiplexing . Stored data is redundant because of the nature of the interference pattern between the reference and signal beams that is imprinted into the holographic medium. Since the interference pattern is a plane wave front, the stored pattern is propagated throughout the entire volume of the holographic medium, repeating at intervals. The data can be corrupted to a certain level before information is lost so this is a very safe method of data storage. Also, the effect of lost data is to lower the signal to noise ratio so that the amount of data that can be safely lost is dependent on the desired signal to noise ratio. Stored holograms are massively parallel because the data is recorded as an optical wave front that is retrieved as a single page in one access. Since light is used to retrieve data and there are no moving parts in the detector array, data access time is on the order of 10 ms and data transfer rate approaches 1.0 Gbytes/sec [2]. Multiplexing allows many different patterns to be stored in the same crystal volume simply by changing the angle at which the reference beam records the hologram.

Currently, holographic memory techniques are very close to becoming technologically and economically feasible. The major obstacles to implementing holographic data storage are recording rate, pixel sizes, laser output power, degradation of holograms during access, temporal decay of holograms, and sensitivity of recording materials [3]. An angle multiplexed holographic data storage system using a photorefractive crystal for a recording medium can provide an access speed of 2.4 μs, a recording rate of 31 kB/s and a readout rate of 10 GB/s, which is between the typical values for DRAM and magnetic disk. At an estimated cost of between $161 and $236 for a complete holographic memory system, this may become a feasible alternative to magnetic disk in the near future.

HOLOGRAPHIC MEMORY vs. EXISTING MEMORY TECHNOLOGY

In the memory hierarchy, holographic memory lies somewhere between RAM and magnetic storage in terms of data transfer rates, storage capacity, and data access times. The theoretical limit of the number of pixels that can be stored using volume holography is $V^{2/3}/\lambda^2$ where V is the volume of the recording medium and λ is the wavelength of the reference beam. For green light, the maximum theoretical storage capacity is 0.4 Gbits/cm^2 for a page size of 1 cm x 1 cm. Also, holographic memory has an access time near 2.4 μs, a recording rate of 31 kB/s, and a readout rate of 10 GB/s. Modern magnetic disks have data transfer rates in the neighborhood of 5 to 20 MB/s [8]. Typical DRAM today has an access time close to 10 – 40 ns, and a recording rate of 10 GB/s.

Storage Medium	Access Time	Data Transfer Rate	Storage Capacity
Holographic Memory	2.4 μs	10 GB/s	400 Mbits/cm^2
Main Memory (RAM)	10 – 40 ns	5 MB/s	4.0 Mbits/cm^2
Magnetic Disk	8.3 ms	5 – 20 MB/s	100 Mbits/cm2

Holographic memory has an access time somewhere between main memory and magnetic disk, a data transfer rate that is an order of magnitude better than both main memory and magnetic disk, and a storage capacity that is higher than both main memory and magnetic disk. Certainly if the issues of hologram decay and interference are resolved, then holographic memory could become a part of the memory hierarchy, or take the place of magnetic disk much as magnetic disk has displaced magnetic tape for most applications.

HOLOGRAPHIC MEMORY

Wide possibilities in this case are provided by technology of optical recording, it's known as holography: it allows high record density together with maximum data access speed. It's achieved due to the fact that the holographic image (hologram) is coded in one big data block, which is recorded at one access. And while reading this block is entirely extracted out of the memory. For reading and recording of the blocks kept holographically on the light-sensitive material (LiNbO3 is taken as the basic material) they use lasers. Theoretically, thousands of such digital pages, which contain up to a million bits each, can be put into a device measuring a bit of sugar. And theoretically they expect the data density to be 1 TBytes per cubic cm (TBytes/cm3). In practice, the developers expect around 10 GBytes/cm3, what is rather impressive when comparing with the current magnetic method that allows around several MBytes/cm2 - and this without the mechanism itself. With such recording density an optical layer which is approx 1 cm in width will keep around 1TBytes of data. And considering the fact that such system doesn't have any moving parts, and pages are accessed parallel, you can expect the device to be characterized with 1 GBytes/cm3 density and higher.

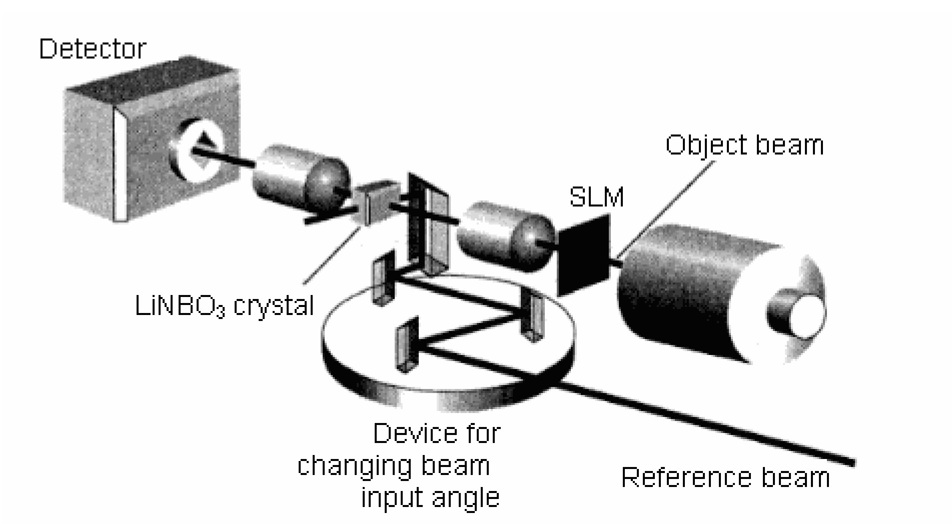

FIGURE-1 SYSTEM OF HOLOGRAPHIC MEMORY

Exceptional possibilities of the topographic memory have interested many scientists of universities and industrial research laboratories. This interest long time ago poured into two research programs. The first of them is PRISM (Photorefractive Information Storage Material), which is targeted at searching of appropriate light-sensitive materials for storing holograms and investigation of their memorizing properties. The second program is HDSS (Holographic Data Storage System). Like PRISM, it includes fundamental investigations, and the same companies participate there. While PRISM is aimed at searching the appropriate media for storing holograms, HDSS is targeted at hardware development necessary for practical realization of holographic storage systems.

How does a system of holographic memory operate? For this purpose we will consider a device assembled by a task group from the Almaden Research Center.

At the first stage in this device a beam of cyan argon laser is divided into two components - **a reference and an object beam** (the latter is a carrier of data). The object beam undergoes defocusing in order it could entirely illumine the SLM (Spatial Light Modulator) which is an LCD panel where a data page is displayed in the form of a matrix consisting of light and dark pixels (binary data).

The both beams go into the light-sensitive crystal where they interact. So we get an interference pattern which serve a base for a hologram and is recorded as a set of variations of the refractive exponent and the reflection factor inside this crystal. When reading data the crystal is illuminated with a reference beam, which interacts with the interference factor and reproduces the recorded page in the image of "chess-board" of light and dark pixels (the holograms converts the reference wave into the copy of the object one). After that, this image is transferred into the matrix detector where the CCD (Charge-Coupled Device) serves a base. While reading the data the reference beam must fall at the same angle at which the recording was made; alteration of this angle mustn't exceed 1 degree. It allows obtaining high data density: measuring the angle of the reference beam or its frequency you can record additional pages of data in the same crystal.

However, additional holograms change properties of the material, and such changes mustn't exceed the definite number. As a result, the images of holograms become dim, what can lead to data corruption when reading? This explains the limitation of the volume of the real memory that belongs to this material. The dynamic area of the medium is defined by the number of pages which can be virtually housed, that's why PRISM participants are investigating limitations to the light sensitivity of substances.

The procedure in 3-dimensional holography which concludes in enclosure of several pages with data into the same volume is called multiplexing. Traditionally the following multiplexing methods are used: of angle of dip of the reference beam, of wavelength and phase; but unfortunately they require complicated optical systems and thick (several mm) carriers what makes them unfit for commercial use, at least in the sphere of data processing. But lately Bell Labs have invented three new multiplexing methods: shift, aperture and correlative, which are based on the usage of change in position of the carrier relative to the beams of light. The shift and aperture multiplexing use a spherical reference beam, and the correlative uses a beam of more complicated form. Besides, considering the fact that the correlative and shift multiplexing enable mechanical moving elements, the access time will be the same as that of the usual optical discs. Bell Labs managed to build an experimental carrier on the same LiNBO3 using the technology of correlative multiplexing but this time with 226 GBytes per square inch.

Another problem standing on the way of development of holographic memory devices is a search of the appropriate material. The most of the investigations in the sphere of holography were carried out with usage of photoreactive materials (mainly the mentioned LiNBO3), but they are not suitable for data recording especially for commercial use: they are expensive, weak sensitive and have a limited dynamic range (frequency bandwidth). That's why they developed a new class of photopolymer materials facing a good perspective in terms of commercial use. Photopolymers are the substances where the light cause irreversible changes expressed through fluctuation of the composition and density. The created material have a longer life circle (in terms of storing data) and are resistant to temperature change, besides, they have improved optical characteristics and are suitable for WORM (write-once/read many).

One more problem concludes in the complexity of the used optical system. For holographic memory the LEDs based on semiconductor lasers used in traditional optical devices are not suitable, since they have insufficient power, give out a wide beam angle, and at last it's too difficult to get a semiconductor laser generating radiation in the middle range of the visible spectrum. There you need as powerful laser as possible which gives the most exact parallel beam. The same we can say about the SLM: yet some time ago there were no any such devices which could be used in the holographic memory systems. But time flies and today you can get inexpensive solid-state lasers; besides, there appeared the MEM technology (Micro-Electrical Mechanical). The devices on its base consist of the arrays of micromirrors around 17 micron in size, they suit very much for the role of SLM.

Since the interference patterns fill up the whole substance uniformly, it gives another useful property to the holographic memory - high reliability of the recorded information. While a defect on the surface of the magnetic disc or tape destroy important data, a defect in holographic medium doesn't cause a loss of information, it leads only to tarnish of the hologram. The small desktop HDSS-devices are to appear by 2003. Since the optical discs. Bell Labs managed to build an experimental carrier on the same LiNBO3 using the technology of correlative multiplexing but this time with 226 GBytes per square inch.

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The holographic memory is not a completely new technology since its basic conceptions were developed about 30 years ago. The only that has changed is availability of the key components - the prices considerably fell down. The semiconductor laser, for example, is not unusual. On the other hand, SLM is a result of the same technology which is used in production of LCD-screens for notebooks and calculators, and the CCd detector array is taken right from a digital video camera.

Well, the new technology has more than enough highlights: apart from the fact that information is stored and recorded parallel, you can reach very high data rate, and in some cases high speed of random access. And the main advantage is that mechanical components are practically absent (those that typical for current storage devices). It ensures not only a fast data access, less probability of failures, but also lower power consumption, since today a hard disc is one of the greatest power-consuming elements of a computer. However, there are problems with adjustment of optical devices, that's why at the beginning the data of the device will probably "fear" exterior mechanical effects.

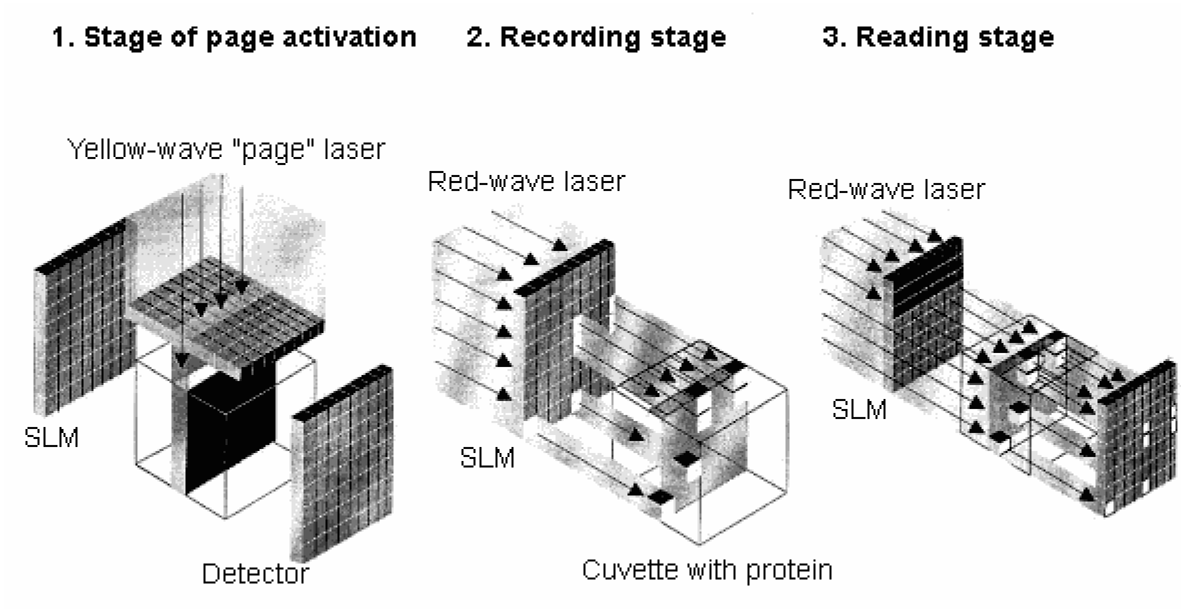
MOLECULAR MEMORY

Another approach in creation of storage devices is a molecular method. A group of researchers of the "W.M. Keck Center for Molecular Electronic" with Professor Robert R. Birge as a head quite a long time ago received a prototype of memory subsystem which uses digital bits of a molecule. These are protein molecules which is called bacteriorhodopsin. It's purple, absorbs the light and presents in a membrane of a microorganism called halobacterium halobium. This bacterium lives in salt bogs where the temperature can reach +150 °C. When a level of oxygen contents is so low in the ambient that to obtain power breathing (oxidation) is not enough, it uses protein for photosynthesis.

Bacteriorhodopsin was chosen because a photocycle (a sequence of structural changes undergone by a molecule when reacting with light) makes this molecule an ideal logically storing element of "&" type or a type of a switch from one condition into another (trigger). According to Birge's investigation, bR-state (logical value of the bit "0") and Q-state (logical value of the bit "1") are intermediate states of the molecule and can remain stable during many years. This property (which in particular provides a wonderful stability of protein) was obtained by an evolutional way in the struggle for survival under severe conditions of salt bogs.

Birge estimated that the data recorded on the bacteriorhodopsin storage device must "live" around 5 years. Another important feature of the bacteriorhodopsin is that these both states have different absorption spectra. It allows easily defining the current state of the molecule with the help of a laser set for the definite frequency.

They built a prototype of memory system where the absorption spectrum stores data in 3-dimensional matrix. Such matrix represents a cuvette (a transparent vessel) filled up with polyacryde gel, where protein is put. The cuvette has an oblong form 1x1x2 inch in size. The protein which is in the bR-state is fixed in the space with gel polymerization. The cuvette is surrounded with a battery of lasers and a detector array based on the device using a principle of CID (Charge Injection Device), they serve for data recording and reading.



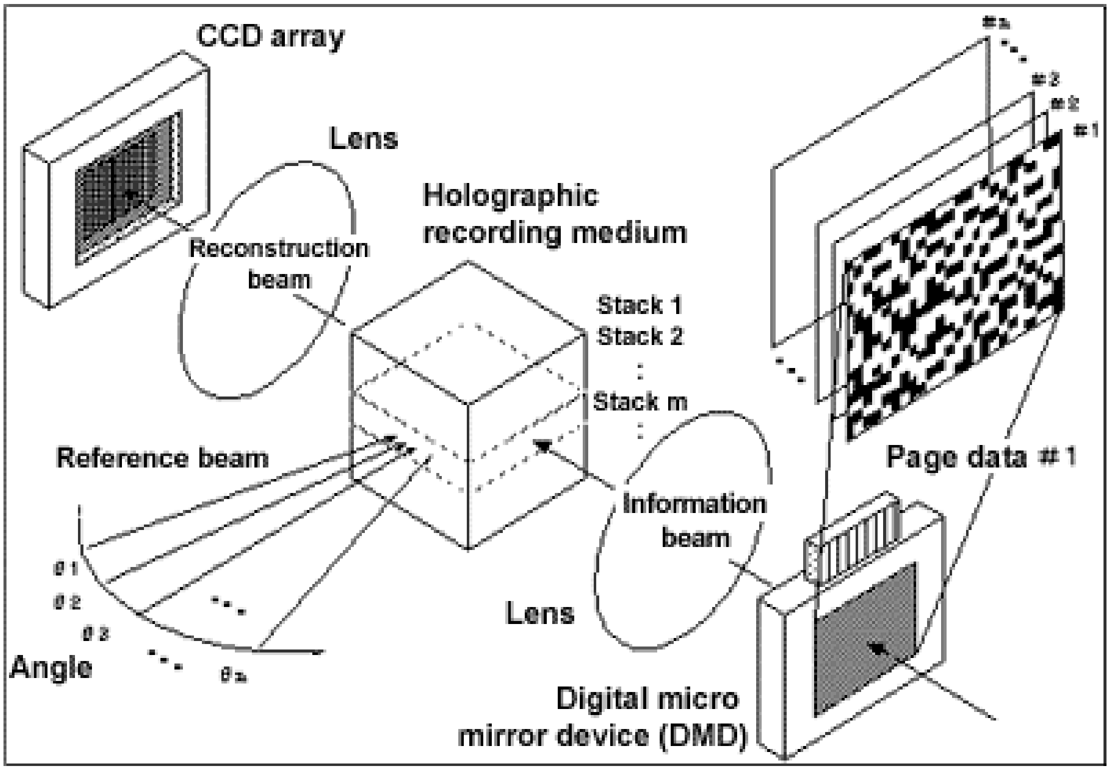
When recording data first you need switch on a yellow-wave "page" laser - for converting the molecules into Q-state. The SLM which represents an LCD-matrix creating a mask on the beam way stimulates appearing of an active (excited) plane in the material inside the cuvette. This poweractive plane is a page of data which can house 4096x4096 bit array. Before returning of protein into the quiescent state (in such state it can remain quite a long time keeping the information) a red-wave recording laser lights on; it's positioned at the right angle to the yellow one. The other SLM displays binary data, and this way creates the corresponding mask on the way of the beam, that's why only definite spots (pixels) of the page will be irradiated. The molecules in these spots will convert into Q-state and will represent a binary one. The remaining part of the page will come into the initial bR-state and will represent binary zeros. In order to read the data you will need again the "page" laser which converts the read page into Q-state. It's implemented so that in the future one can identify binary one and zero with the help of difference in absorption spectra. 2ms later the page is plunged into low-intensive light flux of the red-wave laser. Low intensity is necessary to prevent jumping into Q-state. The molecules that represent a binary zero absorb red light, and those that represent a binary one let the beam pass by. It creates a "chess" picture of light and dark spots on the LCD-matrix which takes a page of digital information.

For erasing information a short impulse of a cyan laser is enough in order to convert the molecules from Q-state back into bR-state. This beam can be obtained not necessary with the laser: you can erase the whole cuvette with a usual ultraviolet lamp. In order to ensure the entirety of data when erasing only the definite pages there used caching of several adjacent pages. For read/write operations two additional parity bits are also used to prevent errors. The data page can be read without corruption up to 5000 times. Each page is traced by a meter and after 1024 reading the page gets refreshed (regenerated) with a new recording operation.
Considering that a molecule changes its states within 1 ms, the total time taken for read or write operations constitutes around 10 ms. But similar to the system of a holographic memory this device makes a parallel access in the read-write cycle, what allows counting on the speed up to 10 Mbps. It is assumed that combining 8 storing bit cells into a byte with a parallel access, you can reach, then, 80 Mbps, but such method requires a corresponding circuit realization of the memory subsystem. Some versions of the SLM devices implement a page addressing, which in cheap constructions is used when sending the beam to the required page with the help of rotary system of galvanic mirrors. Such SLM provides 1ms access but costs four times more.

Birge states that the system suggested by him is close to the semiconductor memory in operating speed until a page defect is come across. On detecting of a defect it's necessary to resend the beam for accessing these pages from the other side. Theoretically, the cuvette can accommodate 1TBytes of data. Limitation of capacity is mainly connected with problems of lens system and quality of protein.

Will the molecular memory be able to compete against the traditional semiconductor memory? Its construction has undoubtedly some advantages. First, it's based on protein which is produced in large volumes and at low price. Secondly, the system can operate in the wider range of temperatures than the semiconductor memory. Thirdly, data are stored constantly - even in case of power switching off, it won't cause data loss. And at last, bricks with data which are rather small in size but contain gigabytes of data can be placed into an archive for storing copies (like magnetic tapes). Since the bricks do not have moving parts, it's more convenient than usage of portable hard discs or cartridges with magnetic tape.

Recently, holographic data storage technologies have again been in the limelight as a next-generation storage system that achieves large storage capacities and high transfer rates simultaneously. This shift was mainly shaped by two USA national projects, the PhotoRefractive Information Storage Materials (PRISM) consortium and the Holographic Data Storage System (HDSS) consortium, launched and conducted from 1994 to 1999. In PRISM, it was shown that photopolymer has entered a commercially practicable realm as a holographic recording material other than crystals. In HDSS, rotating a disk-shaped storage medium to continuously record and reconstruct data was demonstrated [1] [2] [3]. However, a large number of subjects still remain to be tackled regarding commercialization even after the completion of these large-scale USA national projects. We have been developing a holographic memory that has compatibility with the conventional optical disk technologies. Since the reference beam and information beam are coaxially arranged to perform recording and reconstruction, the holographic memory is called a coaxial read/write holographic memory or collinear systemThere have been a number of proposals for holographic memories in which holographic recording media were shaped into a disk[4]. However, simply shaping a recording medium into a disk does not assure practicability and a number of problems have to be tackled from the perspective of commercialization



1. For the two-beam interference method as shown in Fig.1, the reference beam and information beam are configured in two different optical axes. This makes the optical system complex.
2. There are no precise standards or addresses for the holographic recording media, resulting in very poor removability
3. There is no interchangeability between the holographic recording devices and recording media of the same type
4. Insufficient consideration is given to measures to combat plane deflection or eccentricity during rotation of the disk.
5. Holographic recording media require flatness of the order of the optical wavelength, which is unsuitable for volume production
6. No consideration is given to maintaining upward compatibility with existing storage media such as CDs and DVDs

7. Utilization of the existing production infrastructure has not been considered. This means that the production of holographic memories requires investments in new equipment

COLLINEAR SYSTEM

By studying the conventional problems noted above, it becomes especially important to fundamentally reconsider a holographic recording and reconstruction optical system using the two-beam interference method noted in (1).
The collinear system is based on the coaxial read/write type in which the reference and information beams are handled as a pencil of coaxial light, rather than the two-beam interference method that was widely used in the past. This enables the comprehensive optical disk technologies to be easily fused to realize large storage capacity, and high transfer rate memories of a new concept while exploiting the advantages of the holographic memory.

The following shows the concept of collinear holographic memories

1. Thick volume-recording media are used to increase the recording capacities
2. A batch of two-dimensional page data are recorded and reconstructed as a hologram to improve the transfer rates.
3. The information beam and reference beam are collinearly optically arranged on the same axis without angles to perform holographic recording and reconstruction.
4. Disk construction with a coated reflection film is employed to configure an optical system that completes on a single side of the disk
5. An optical disk is preformatted with addresses and optical servo information
6. The optical servo technique is applied so that interference patterns are recorded even in the presence of disk rotation, eccentricity, or plane deflection
7. A two-wavelength optical system is configured to read out addresses at a wavelength that does not photosensitize a holographic recording material, and perform optical servo operations.

8. A beam for the optical servo is utilized to provide upward compatibility with the existing CDs or DVDs

COLLINEAR HOLOGRAPHIC MEDIA EVALUATION SYSTEM S-VRD ™

Fig.2 Collinear Holographic Media Evaluation System S-VRD

To accelerate the commercialization of collinear holographic memories, it is necessary to promote the research and development of holographic recording media. Fig.2 shows the appearance of a recording media evaluation system (abbreviated product name: S-VRD) employing the collinear system. This evaluation system can record and reconstruct two-dimensional digital page data employing the collinear system and evaluate the characteristics of the recording material such as bit error rates and signal-to-noise ratios (SNR) from different angles. Moreover, it can measure small-piece samples to disk samples (option) using a 6-axes control universal sample holder.

Collinear Optical System in S-VRD™

The schematic diagram of the collinear two-wavelength dynamic servo optical system used in the S-VRD evaluation system is shown in Fig.3.

For recording and reconstruction of a hologram, a green laser with a wavelength of 532 nm, that photosensitizes a holographic recording material, is used. Also, a red laser with a wavelength of 650 nm, that doesn't photosensitize the recording material, is used to activate the auto-focus servo. These beams of two different wavelengths are put into the same optical path by the dichroic mirror installed before the objective lens and are then incident to the same objective lens. The recording medium has been coated with a reflection film, and the objective lens is controlled so that the beam is brought into focus on this film.
The following describes the collinear system-based holographic recording and reconstruction processes according to Fig.3.

The recording laser beam is first divided by beam splitters into an information beam and a reference beam. The information beam is converted into two-dimensional page data by the digital micro mirror device (DMD). These two beams are again merged into one on the same optical axis by beam splitters and are incident to the objective lens. Then, data are recorded onto the holographic recording medium in the form of interference patterns. For the reconstruction of information from the stored hologram, only the reference beam is incident to the objective lens, and the reconstruction beam passes through the objective lens and is returned to be received by the CMOS sensor.

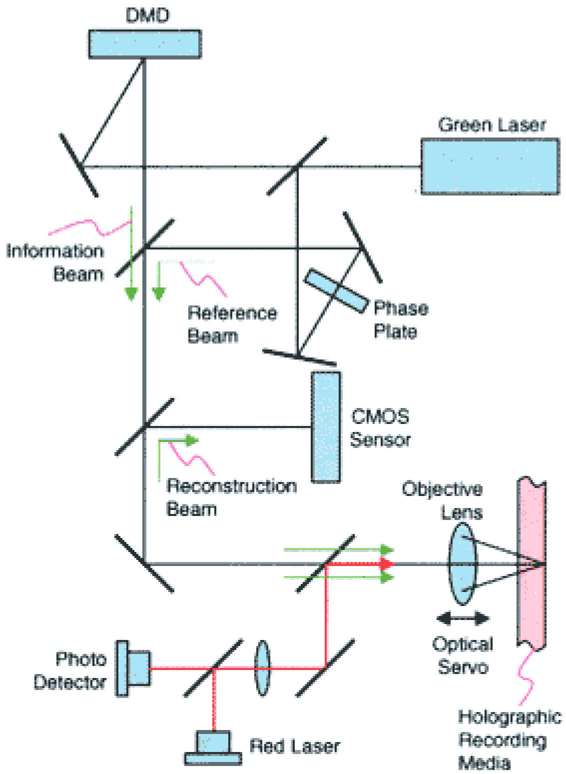


Fig.3 Schematic Diagram of the Collinear Optical System

Evaluation Data

This section describes an example of evaluation of data recorded and reconstructed using the S-VRD system.

Two-dimensional page data information spatially modulated and recorded by the DMD is shown in Fig.4. The size of page data is approx. 3 mm in diameter and that of pixels in the page data is 13.7 μm.

Fig.5 shows a microscopic photo of a hologram actually stored in the recording medium. The size of the stored hologram is approx. 200 μm in diameter.

Fig.6 shows a signal reconstructed from the stored hologram and received by the CMOS sensor. Each bright pixel in the photo represents digital data.

An example of analysis of the reconstruction signal is shown in Fig.7. If each of the bright pixels (Won) and dark pixels (Woff) is displayed as a histogram, the probability of the intersection of the histogram resulting in an error becomes high. The figure shows that the Won and Woff are separated. The error rate was 1 x 10-4 or less.

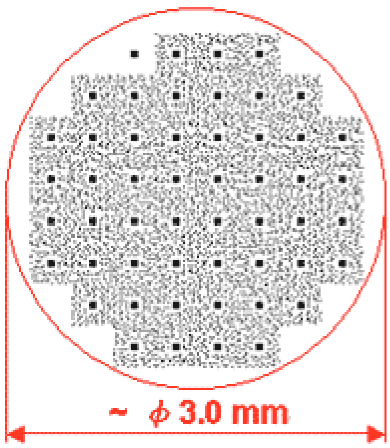


Fig.4 Two-dimensional Page Data Information

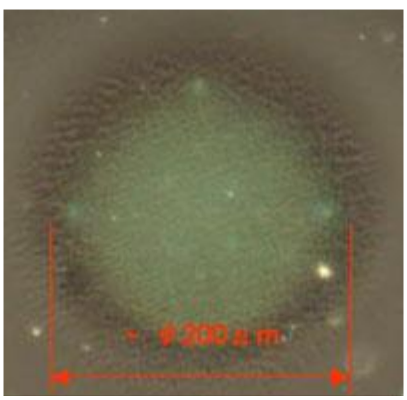


Fig.5 Microscopic Photo of Stored Hologram

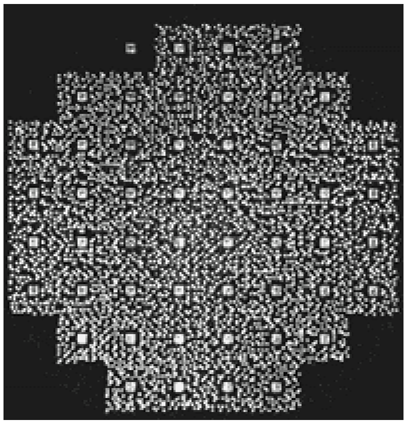


Fig.6 Signal Reconstructed from Stored Hologram

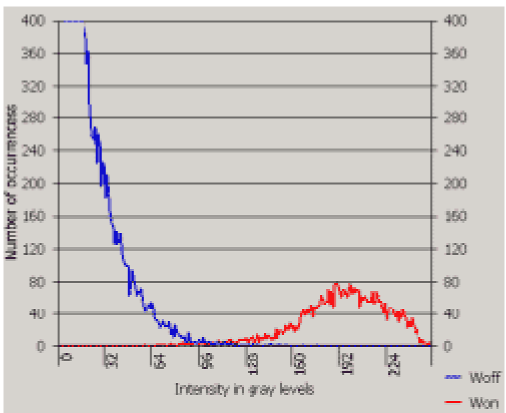


Fig.7 Histogram Analysis of a Reconstructed Signal

Summary

This paper described the collinear holographic memory that handles the reference and information beams as a pencil of coaxial light, centering on its concept. It also showed that the basic characteristics of holographic recording media for data storage could be evaluated using the collinear holographic recording media evaluation system and indicated the possibility of realizing the next storage media of large storage capacities and high transfer rates. From now on, we plan to prototype storage units aiming at practical commercialization, as well as placing expectations on further improved material characteristics

Another Invention Of Holographic Memory

Holographic Memories

"Help me, Obi-Wan Kenobi!" Back in 1977 when Princess Leia transmitted her classic 3-D appeal via R2D2 in the original Star Wars, holography was supposedly poised to transform communications technology in the real world. But a generation later, the classic image remains just that and the only holograms we routinely encounter are on our credit cards.

But the promise of holography to store and transmit volumes of information in three dimensions is real, and today some major players say the fruit of decades of research is about to hit the marketplace.

According to Bill Wilson, chief scientist at InPhase Technologies, holographic storage media will replace CDs and DVDs in the next couple of years. "Typically you can store a single movie on DVD," Wilson says. "You'll be able to store likely somewhere nearly a hundred movies on a piece of media this size using our current holographic materials and strategies."

Wilson says recent breakthroughs by researchers at Bell Labs in both optics and high-performance storage media have made this possible. Inphase has partnered with Bell Labs to commercialize the new technology.

To make a hologram of an object, light from a single laser is split into two beams. One of the beams, called the "reference beam," is sent straight to the target—traditionally photographic film, but in this case, a disc. The other beam, called the signal beam, is reflected off the object that is being holographed. The resulting hologram image reappears only when the two beams are realigned at an extremely precise point in the disk, so that big chunks of data can overlap without interfering with each other. When the "object" is information rather than an image, the principle is the same except that the data is first represented as a digital image similar to a checkerboard.

Bell Labs set out to find a new method for overlapping, or "multiplexing" multiple holograms that didn't rely on large optical systems and moving optical parts. They invented a "fixed" optics system that's compatible with the spinning disk architecture already used throughout the storage industry.

The other big problem was a cheap but reliable storage material. Wilson says the new holographic polymer is "the first real media that seems to be able to

Desktop Holographic Data Storage

After more than 30 years of research and development, a desktop holographic storage system (HDSS) is close at hand. There is still some fine tuning that must be done before such a high-density storage device can be marketed, but IBM researchers have suggested that they will have a small HDSS device ready soon. These early holographic data storage devices will have capacities of 125 GB and transfer rates of about 40 MB per second. Eventually, these devices could have storage capacities of 1 TB and data rates of more than 1 GB per second -- fast enough to transfer an entire DVD movie in 30 seconds. So why has it taken so long to develop an HDSS, and what is there left to do?

When the idea of an HDSS was first proposed, the components for constructing such a device were much larger and more expensive. For example, a laser for such a system in the 1960s would have been 6 feet long. Now, with the development of consumer electronics, a laser similar to those used in CD players could be used for the HDSS. LCDs weren't even developed until 1968, and the first ones were very expensive. Today, LCDs are much cheaper and more complex than those developed 30 years ago. Additionally, a CCD sensor wasn't available until the last decade. Almost the entire HDSS device can now be made from off-the-shelf components, which means that it could be mass-produced.

Although HDSS components are easier to come by today than they were in the 1960s, there are still some technical problems that need to be worked out. For example, if too many pages are stored in one crystal, the strength of each hologram is diminished. If there are too many holograms stored on a crystal, and the reference laser used to retrieve a hologram is not shined at the precise angle, a hologram will pick up a lot of background from the other holograms stored around it. It is also a challenge to align all of these components in a low-cost system.

Researchers are confident that technologies will be developed in the next two or three years to meet these challenges. With such technologies on the market, you will be able to purchase the first holographic memory players by the time "Star Wars: Episode II" is released on home 3-D discs. This DVD-like disc would have a capacity 27 times greater than the 4.7-GB DVDs available today, and the playing device would have data rates 25 times faster than today's fastest DVD players

The Basics

Holographic memory offers the possibility of storing 1 terabyte (TB) of data in a sugar-cube-sized crystal. A terabyte of data equals 1,000 gigabytes, 1 million megabytes or 1 trillion bytes. Data from more than 1,000 CDs could fit on a holographic memory system. Most computer hard drives only hold 10 to 40 GB of data, a small fraction of what a holographic memory system might hold.

Polaroid scientist Pieter J. van Heerden first proposed the idea of holographic (three-dimensional) storage in the early 1960s. A decade later, scientists at RCA Laboratories demonstrated the technology by recording 500 holograms in an iron-doped **lithium-niobate**

crystal, and 550 holograms of high-resolution images in a light-sensitive polymer material. The lack of cheap parts and the advancement of magnetic and semiconductor memories placed the development of holographic data storage on hold.

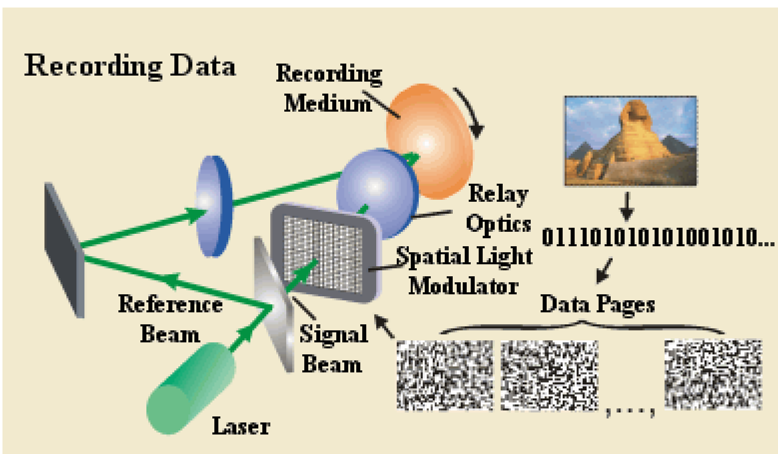
Over the past decade, the Defense Advanced Research Projects Agency (DARPA) and high-tech giants IBM and Lucent's Bell Labs have led the resurgence of holographic memory development. Prototypes developed by Lucent and IBM differ slightly, but most holographic data storage systems (HDSS) are based on the same concept. Here are the basic components that are needed to construct an HDSS:

- Blue-green argon laser
- Beam splitters to spilt the laser beam
- Mirrors to direct the laser beams
- LCD panel (spatial light modulator)
- Lenses to focus the laser beams
- Lithium-niobate crystal or photopolymer
- Charge-coupled device (CCD) camera

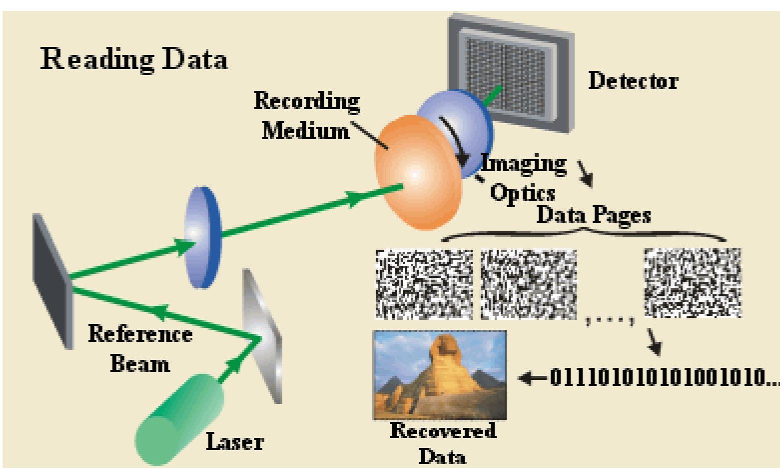
When the blue-green argon laser is fired, a beam splitter creates two beams. One beam, called the object or **signal beam**, will go straight, bounce off one mirror and travel through a **spatial-light modulator** (SLM). An SLM is a liquid crystal display (LCD) that shows pages of raw binary data as clear and dark boxes. The information from the page of binary code is carried by the signal beam around to the light-sensitive lithium-niobate crystal. Some systems use a photopolymer in place of the crystal. A second beam, called the **reference beam**, shoots out the side of the beam splitter and takes a separate path to the crystal. When the two beams meet, the interference pattern that is created stores the data carried by the signal beam in a specific area in the crystal -- the data is stored as a **hologram**.

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 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 charge-coupled device (CCD) camera, which interprets and forwards the digital information to a computer.

The key component of any holographic data storage system is the angle at which the second reference beam is fired at the crystal to retrieve a page of data. It must match the original reference beam angle **exactly**. A difference of just a thousandth of a millimeter will result in failure to retrieve that page of data.



These two diagrams show how information is stored and retrieved in a holographic data storage system.



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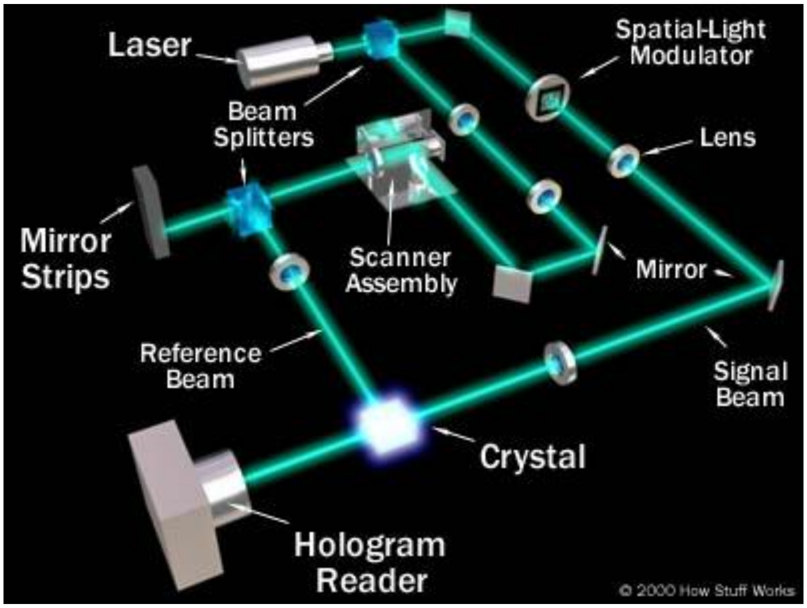
Devices that use light to store and read data have been the backbone of data storage for nearly two decades. Compact discs revolutionized data storage in the early 1980s, allowing multi-megabytes of data to be stored on a disc that has a diameter of a mere 12 centimeters and a thickness of about 1.2 millimeters. 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.



CDs and DVDs are the primary data storage methods for music, software, personal computing and video. A CD can hold 783 megabytes of data, which is equivalent to about one hour and 15 minutes of music, but Sony has plans to release a 1.3-gigabyte (GB) high-capacity CD. A double-sided, double-layer DVD can hold 15.9 GB of data, which is about eight hours of movies. These conventional storage mediums meet today's storage needs, but storage technologies have to evolve to keep pace with increasing consumer demand. CDs, DVDs and magnetic storage all store bits of information on the surface of a recording medium. 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, instead of only the surface area.

Three-dimensional data storage will be able to store more information in a smaller space and offer faster data transfer times. You will learn how a holographic storage system might be built in the next three or four years, and what it will take to make a desktop version of such a high-density storage system.

FUTURE OF HOLOGRAPHIC MEMORY

Today holographic memory is very close to becoming a reality. The basic theory behind it has been shown to be reliable and has been implemented in numerous experiments. Materials research has yielded some promising results in photorefractive crystals such as $LiNbO_3$ and $BaTiO_3$, especially for use with rewritable, refreshed random access memory. Also, a read only version of holographic data storage is certainly feasible with some of the photopolymer films available today. For holographic memory to truly become the next revolution in data storage, data transfer rates must be improved, hologram decay must become negligible, and hologram recording time must be reduced. Then it will be economical for holographic memories to be produced for mass consumption.

Reference

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Appendixes (Figures and tables)