Holographic data storage is a potential replacement technology in the area of high-capacity data storage currently dominated by magnetic and conventional optical data storage. Magnetic and optical data storage devices rely on individual bits being stored as distinct magnetic or optical changes on the surface of the recording medium. Holographic data storage overcomes this limitation by recording information throughout the volume of the medium and is capable of recording multiple images in the same area utilizing light at different angles.

Additionally, whereas magnetic and optical data storage records information a bit at a time in a linear fashion, holographic storage is capable of recording and reading millions of bits in parallel, enabling data transfer rates greater than those attained by optical storage.

Recording Data:Holographic data storage captures information using an optical interference pattern within a thick, photosensitive optical material. Light from a single laser beam is divided into two separate optical patterns of dark and light pixels. By adjusting the reference beam angle, wavelength, or media position, a multitude of holograms (theoretically, several thousand) can be stored on a single volume. The theoretical limits for the storage density of this technique is approximately several tens of Terabytes (1 terabyte = 1024 gigabytes) per cubic centimeter. In 2006,InPhase Technologies published a white paper reporting an achievement of 500 Gb/in^2. From this figure we can deduce that a regular disk (with 4 cm radius of writing area) could hold up to a maximum of 3895.6Gb

Reading Data: The stored data is read through the reproduction of the same reference beam used to create the hologram. The reference beam's light is focused on the photosensitive material, illuminating the appropriate interference pattern, the light diffracts on the interference pattern, and projects the pattern onto a detector. The detector is capable of reading the data in parallel, over one million bits at once, resulting in the fast data transfer rate. Files on the holographic drive can be accessed in less than 200 milliseconds.

Longevity:Holographic data storage can provide companies a method to preserve and archive information. The write-once, read many (WORM) approach to data storage would ensure content security, preventing the information from being overwritten or modified. Manufacturers believe this technology can provide safe storage for content without degradation for more than 50 years, far exceeding current data storage options. Counterpoints to this claim are that the evolution of data reader technology changes every ten years; therefore, being able to store data for 50–100 years would not matter if you could not read or access it. However, a storage method that works very well could be around longer before needing a replacement; plus, with the replacement, the possibility of backwards-compatibility exists, similar to how DVD technology is backwards-compatible with CD technology.

HOLOGRAPHIC MEMORY is a storage device that is being researched and slated as the storage device that will replace hard drives and DVDs in the future. It has the potential of storing up to 1 terabyte or one thousand gigabytes of data in a crystal the size of a sugar cube.

Brief History of Holographic Memory

Using holograms as memory storage was first proposed by Pieter Heerden in the 1960s. During the early 1970s, a group of scientists from TRCA laboratories succeeded in storing 500 holograms using an iron doped litium niobate crystal. Moreover, they were also able to store five hundred fifty high-resolution hologram images using a material made up of light sensitive polymer. The high cost of the materials needed for this type of technology as well as the rise of magnetic and optical drives shelved the project in the end.

Now research for holographic memory systems has been reactivated since the components needed for such a technology has become widely available and cheaper. The laser system needed for the device to work, for instance, has shrunk in size so it can easily fit in a conventional CD or DVD player. Moreover, liquid crytal displays or LCDs which were in their infancy during the initial research done on holographic memory systems are now more advanced and quite a lot cheaper. The same goes for the other components such as the "Charge-Coupled Device" or CCD.

Technology behind Holographic Memory Systems

The holographic memory system is made up of the following basic components:

- a charge-coupled device
- lenses to focus the laser beams
- an LCD panel
- a photopolymer or lithium niobate crystal
- mirrors to direct the laser light
- beam splitters
- and an argon laser.

The light from the argon laser is split in two by the beam splitter. The signal or object beam will bounce off a mirror and pass through a spatial light modulator or SLM (and LCD showing raw binary data as dark and clear boxes). The signal or object beam will then carry the information from the SLM to the crystal. The second beam or the reference beam, on the other hand, takes another course towards the crystal and upon hitting it along with the object beam, creates an interference pattern that will be used to store the information relayed by the object beam in a certain location in the crystal. To access the stored data requires directing the light of the reference beam into the exact location in the crystal where the needed information was stored. The crystal diffracts the light of the reference beam to recreate the page that was stored which in turn will be sent to the CCD or charge couple device camera capable of interpreting the data and converting it into digital information that the computer can use.

Advantages of Holographic Memory Systems

Aside from having a tremendous amount of storage space for data, holographic memory systems also have the ability to retrieve data very quickly, up to a 1 gigabyte per second transfer rate.

INTRODUCTION

Devices that use light to store and read data have been thebackbone of data storage for nearly two decades. Compact discs revolutionized datastorage in the early 1980s, allowing multi-megabytes of data to be stored on a discthat has a diameter of a mere 12 centimeters and a thickness of about 1.2millimeters. 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. Adouble-sided, double-layer DVD can hold 15.9 GB of data, which is about eighthours of movies. These conventional storage mediums meet today's storage needs,but storage technologies have to evolve to keep pace with increasing consumerdemand. CDs, DVDs and magnetic storage all store bits of information on thesurface of a recording medium. In order to increase storage capabilities, scientistsare now working on a new optical storage method called holographic memory thatwill 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 storemore information in a smaller space and offer faster data transfer times.

Holographic memory is developing technology that haspromised to revolutionalise the storage systems. It can store data upto 1 Tb in asugar cube sized crystal. Data from more than 1000 CDs can fit into a holographicmemory System.Most of the computer hard drives available today can hold only10 to 40 GB of data, a small fraction of what holographic memory system can hold.Conventional memories use only the surface to store the data.But holographic datastorage systems use the volume to store data.It has more advantages thanconventional storage systems.It is based on the principle of holography.

Scientist Pieter J. van Heerden first proposed the idea of holographic (three-dimensional) storage in the early 1960s. A decade later, scientists at RCALaboratories demonstrated the technology by recording 500 holograms in an iron-doped lithium-niobate crystal and 550 holograms of high-resolution images in alight-sensitive polymer material. The lack of cheap parts and the advancement ofmagnetic and semiconductor memories placed the development of holographic datastorage on hold.

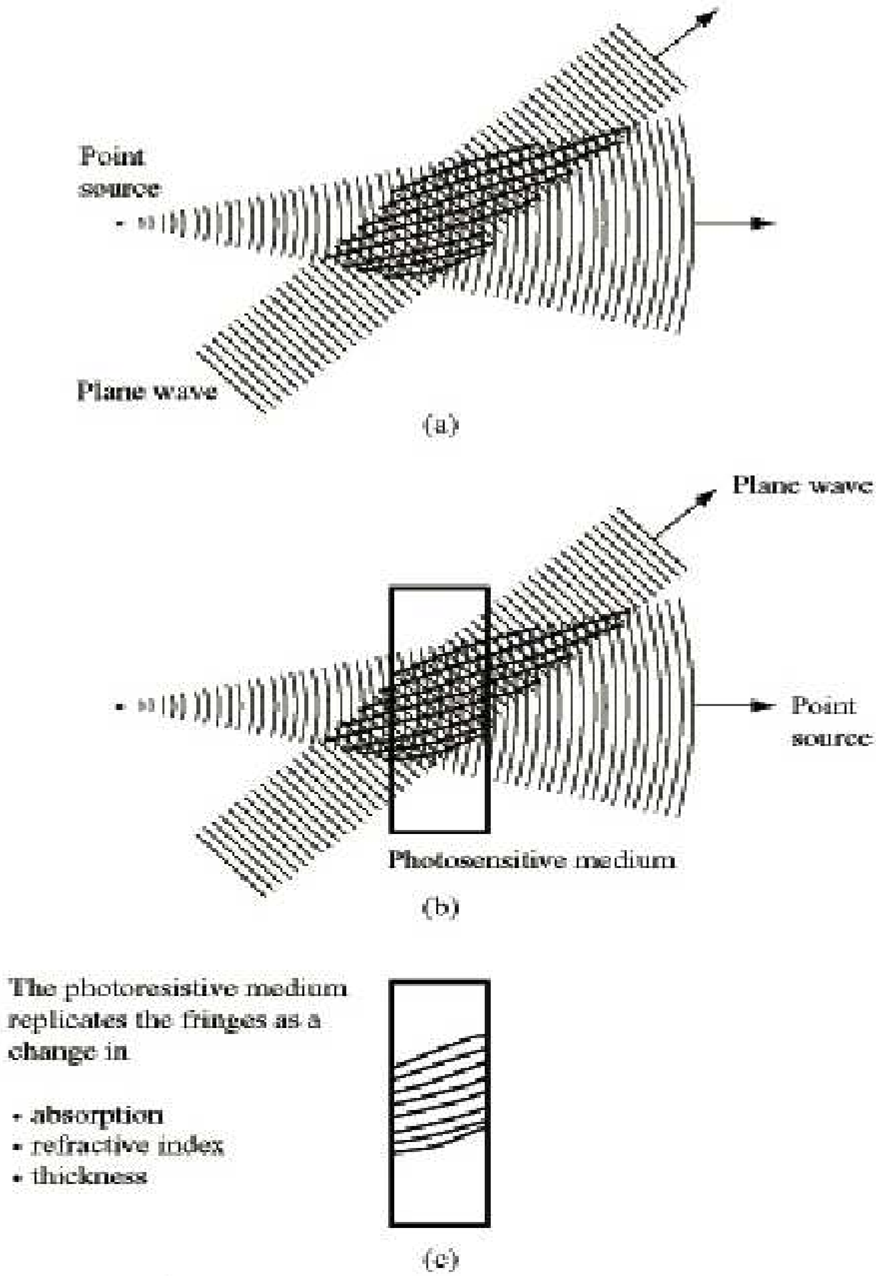
HOLOGRAPHY

A hologram is a block or sheet of photosensitive material whichrecords the interference of two light sources.To create a hologram, laserlightisfirst split into two beams, a source beam and a reference beam. The sourcebeam is then manipulated and sent into the photosensitive material.Onceinsidethismaterial,it intersects the reference beam and the resulting interference of laserlight is recorded on the photosensitive material, resulting in a hologram.Once a hologram is recorded, it can be viewed with only the reference beam.Thereference beam is projected into the hologram at the exact angle it was projectedduring recording. When this light hits the recorded diffraction pattern, thesource beamis regenerated out of the refracted light.An exact copy of thesourcebeam is sent out of the hologram and can be read by optical sensors.Forexample, a hologram that can be obtained from a toy store illustrates this idea.

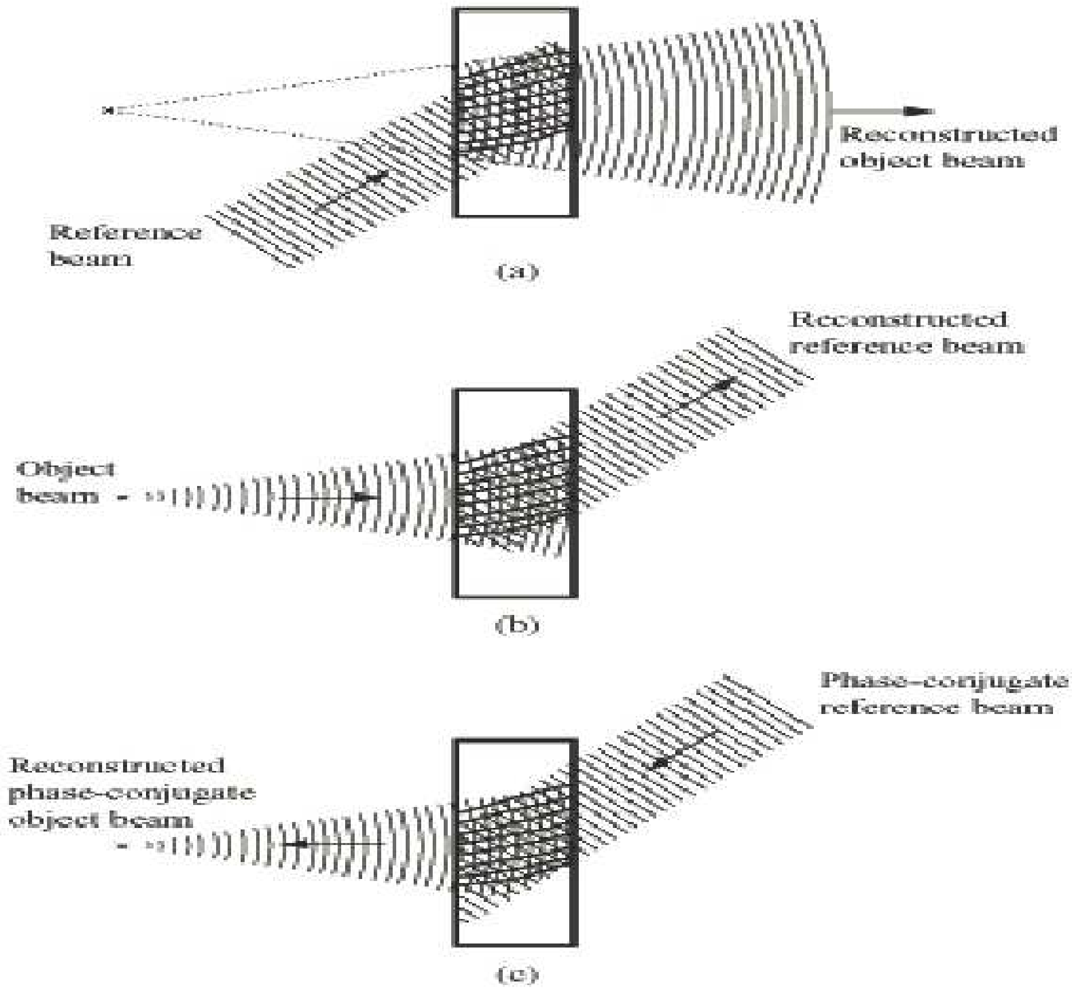
Precise laser equipment is used at the factory to create the hologram.Arecording material which can recreate recorded images out of natural light is used sothe consumer does not need high-tech equipment to view the informationstoredinthehologram.Natural light becomes the reference beam and humaneyes become the optical sensors.

Holography was invented in 1947 by the Hungarian-British physicist
Dennis Gabor (1900-1979), who won a 1971 Nobel Prize for his invention.

CREATING HOLOGRAMS



RETRIEVING HOLOGRAMS



APPLICATION TO BINARY

In order for holographic technology to be applied to computersystems, it must store data in a form that a computer can recognize.In currentcomputer systems, this form is binary.In the previous section, it was mentionedthat the source beam is manipulated.In commonholograms,thismanipulationisthe creation of an optical image such as a ball or human face. In computerapplications, this manipulation is in the form of bits.The next section explains thespatial light modulator, a device that converts laser light into binary data.

SPATIAL LIGHT MODULATOR (SLM)

A spatial light modulator is used for creating binaryinformation outoflaserlight.The SLM is a 2D plane, consisting of pixels whichcan be turned on and off to create binary 1.s and 0.s.An illustration of this is awindow and a window shade.It is possible to pull the shade down over a windowto block incoming sunlight.If sunlight is desired again, the shade can be raised.Aspatial light modulator contains a two-dimensional array of windows which are onlymicrons wide. These windows block some parts of the incominglaser light and letother parts go through.The resulting cross section of the laserbeam is a twodimensional array of binary data, exactly the same as what was represented in theSLM. After the laser beam is manipulated, it is sent into the hologram to berecorded.This data is written into the hologram as page form.It is called this dueto its representation as a two dimensional plane, or page of data. Spatial lightmodulator is a Liquid Crystal Display panel that consists of clear and dark areascorresponding to the binary information it represent.

Spatial light modulator is actually that device which makes holographyapplicable to computers.So it is one of the important components of HolographicData Storage System.

IMPLEMENTATION

The components of Holographic data storage system is composed of

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

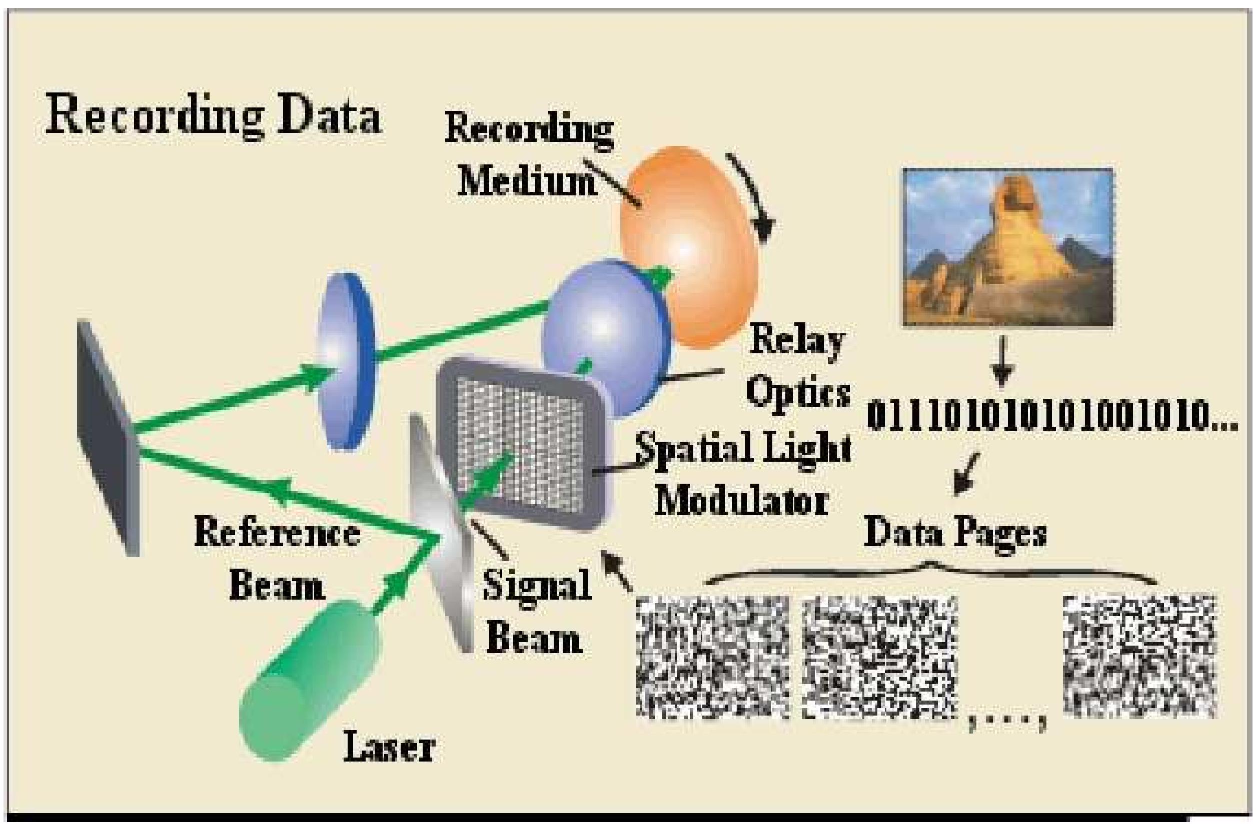
Lithium-niobate crystal or photopolymer

Charge coupled device camera

They can be classified into three sections namely recording medium,optical recording system and photodetector array.The laser is used because itprovides monochromatic light.Only the interference pattern produced by themonochromatic beam of light is stable in time. Lithium niobate crystal is used asphotosensitive material on which hologram is recorded. It has certain opticalcharacteristics that make it behave as photosensitive material.CCDcamera detectsthe information in the light, converts to digital information and forward it to computer.

RECORDING OF DATA IN HOLOGRAPHIC MEMORY SYSTEM

When the blue-green argon laser is fired, a beam splitter createstwo beams. One beam, called the object or signal beam, will go straight, bounce offone mirror and travel through a spatial-light modulator (SLM). An SLM is aLiquid crystal display (LCD) that shows pages of raw binary data as clear and darkboxes. The information from the page of binary code is carried by the signal beamaround to the light-sensitive lithium-niobate crystal. Some systems use aphotopolymer 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 datacarried by the signal beam in a specific area in the crystal -- the data is stored as a hologram.

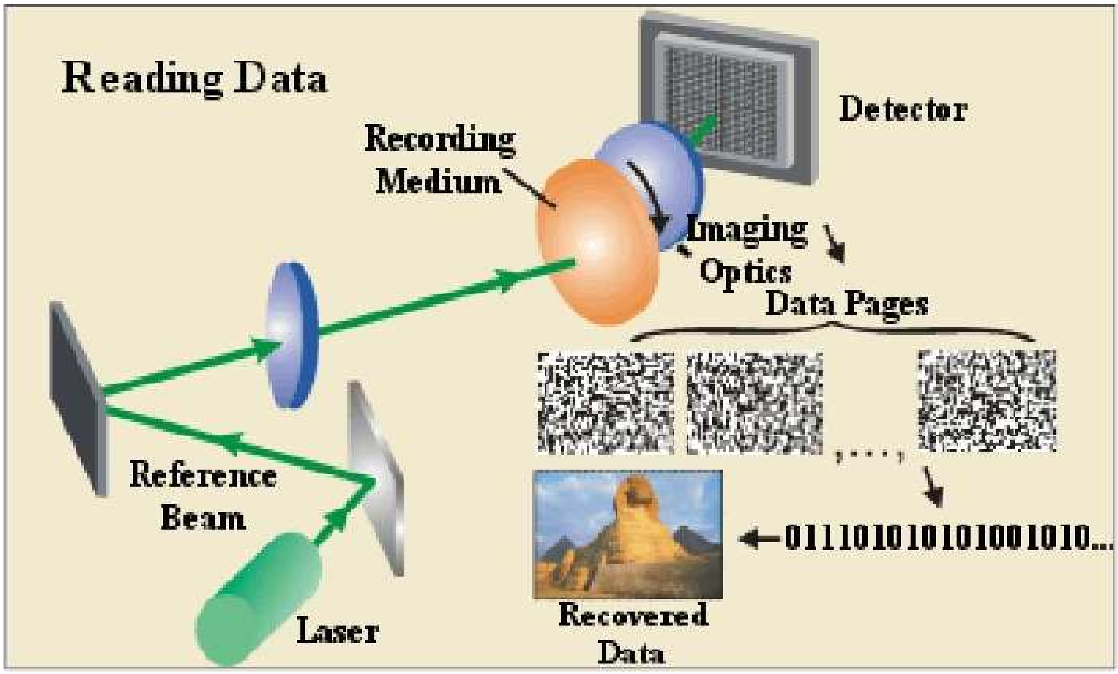


RETRIEVAL OF DATA FROM HOLOGRAPHIC MEMORY SYSTEM

An advantage of a holographic memory system is that anentire page of data can be retrieved quickly and at one time. In order to retrieveand reconstruct the holographic page of data stored in the crystal, the referencebeam is shined into the crystal at exactly the same angle at which it entered tostore that page of data. Each page of data is stored in a different area of thecrystal, 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 projectedonto the charge-coupled device (CCD) camera, which interprets and forwardsthe digital information to a computer.

CCD is a 2-D array of thousands or millions of tiny solar cells, each ofwhich transforms the light from one small portion of the image into electrons.Next step is to read the value (accumulated charge) of each cell in the image. Ina CCD device, the charge is actually transported across the chip and read at onecorner of the array. An analog-to-digital converter turns each pixel's value into adigital value.CCDs use a special manufacturing process to create the ability totransport charge across the chip without distortion. This process leads to veryhigh-quality sensors in terms of fidelity and light sensitivity.CCD sensors havebeen mass produced for a longer period of time, so they are more mature. Theytend to have higher quality and more pixels.

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



PAGE DATA ACCESS

Because data is stored as page data in a hologram, the retrievalof this data must also be in this form.Page data access is the method ofreadingstored data in sheets, not serially as in conventional storage systems.It wasmentioned in the introduction that conventional storage was reaching itsfundamental limits.

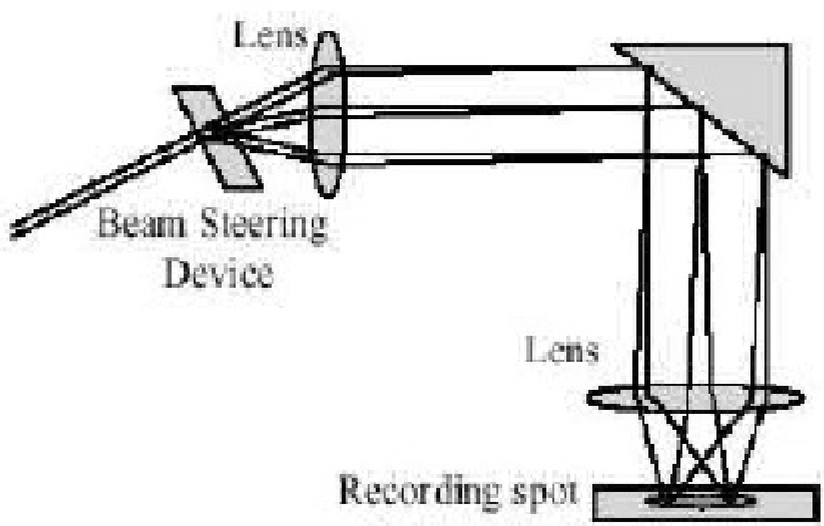
One such limit is the way data is read in streams.Holographic memory reads data in the form of pages instead.For example, if astream of 32 bits is sent to a processing unit by a conventional read head, aholographic memory system would in turn send 32 x 32bits,or1024bitsduetoitsaddeddimension.This provides very fast access times in volumes far greaterthan serial access methods.The volume could be one Megabit per page using aSLM resolution of 1024 x 1024 bits at 15-20 microns per pixel.

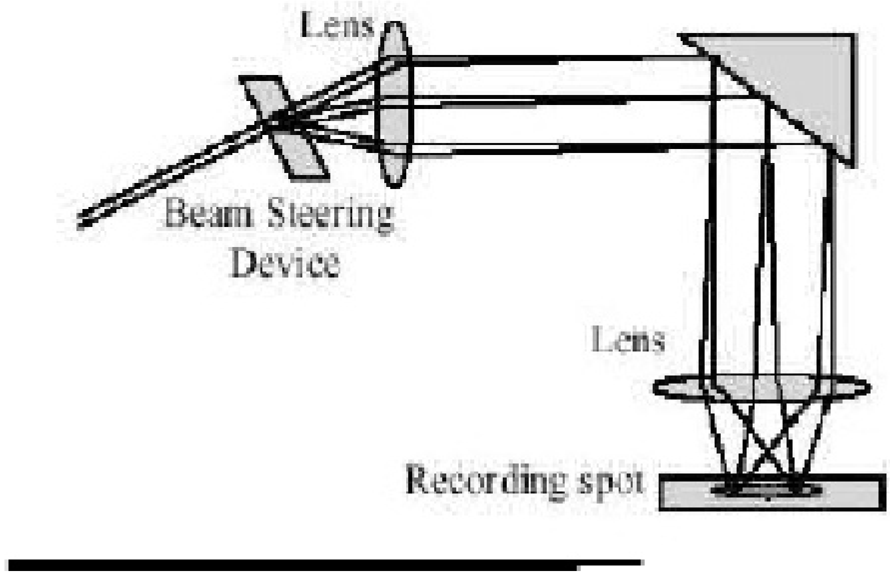
MULTIPLEXING

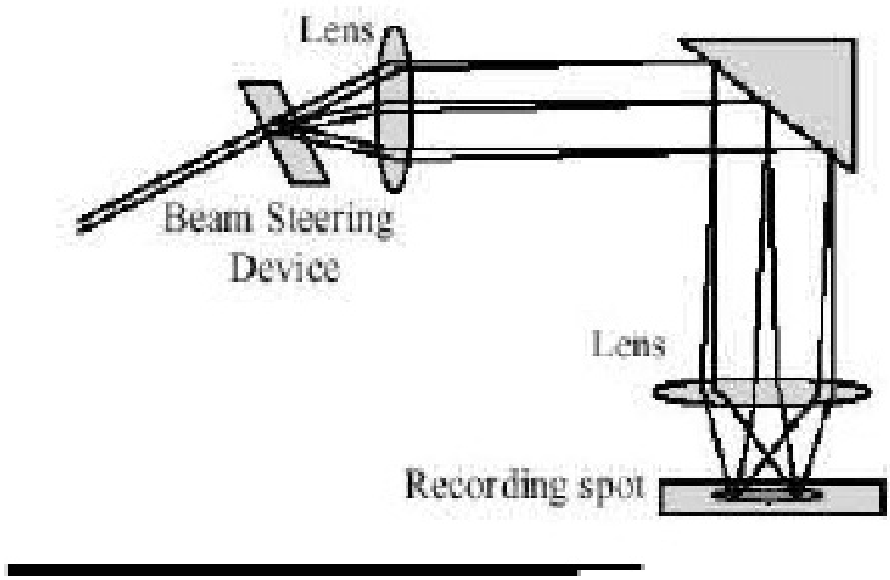
Once one can store a page of bits in a hologram, an interface to acomputer can be made.The problem arises, however, that storing only one page ofbits is not beneficial.Fortunately, the properties of holograms provide a uniquesolution to this dilemma.Unlike magnetic storage mechanisms which store data ontheir surface, holographic memories store information throughout their wholevolume.After a page of data is recorded in the hologram, a small modification tothe source beam before it reenters the hologram will record another page of data inthe same volume. This method of storing multiple pages of data in thehologramiscalled multiplexing.The thicker the volume becomes, the smallerthe modifications to the source beam can be.

ANGULAR MULTIPLEXING

When a reference beam recreates the source beam, it needs to be at the same angle itwas during recording.A very small alteration in this angle will make theregenerated source beam disappear. Harnessing this property, angular multiplexingchanges the angle of the source beam by very minuscule amounts after each page ofdata is recorded. Depending on the sensitivity of the recording material,thousands of pages of data can be stored in thesamehologram,atthesamepointoflaserbeamentry.Staying away from conventional data access systemswhich move mechanical matter to obtain data, the angle of entry on the source beamcan be deflected by high-frequency sound waves in solids.The elimination ofmechanical access methods reduces access times from milliseconds to microseconds.







Holographic Memory
ANGULAR MULTIPLEXING

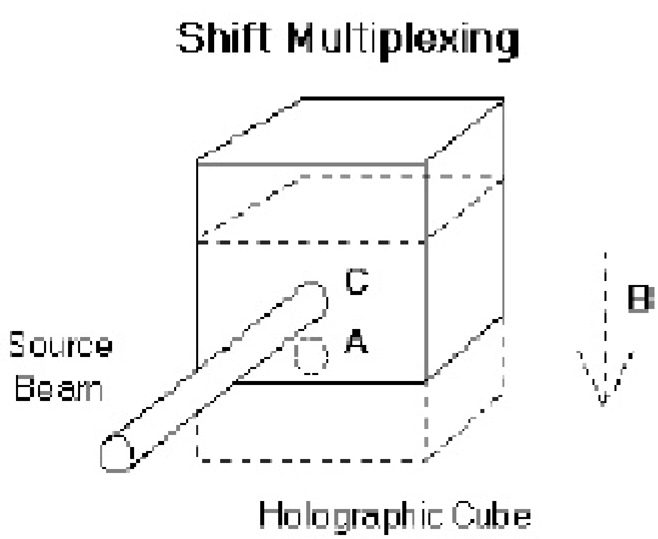
When a reference beam recreates the source beam, it needs to be at the same angle itwas during recording.A very small alteration in this angle will make theregenerated source beam disappear. Harnessing this property, angular multiplexingchanges the angle of the source beam by very minuscule amounts after each page ofdata is recorded. Depending on the sensitivity of the recording material,thousands of pages of data can be stored in thesamehologram,atthesamepointoflaserbeamentry.Staying away from conventional data access systemswhich move mechanical matter to obtain data, the angle of entry on the source beamcan be deflected by high-frequency sound waves in solids.The elimination ofmechanical access methods reduces access times from milliseconds to microseconds.

WAVELENGTH MULTIPLEXING

Used mainly in conjunction with other multiplexing methods, wave length multiplexing alters the wavelength of source and reference beams between recordings. Sending beams to the same point of origin in the recording medium at different wavelengths allows multiple pages of data to be recorded. Due to the small tuning range of lasers, however, this form of multiplexing is limited on its own.

SPATIAL MULTIPLEXING

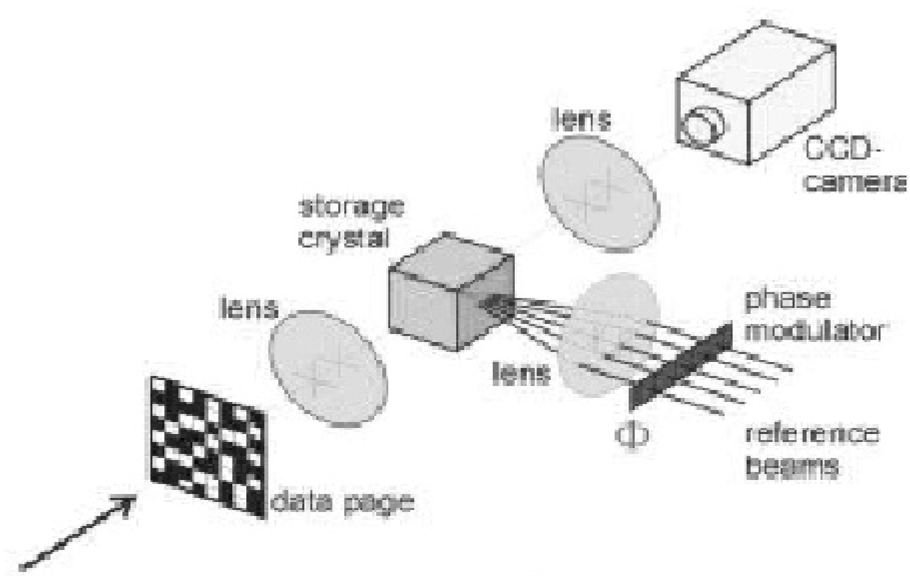
Spatial multiplexing is the method of changing the point of entry of source and reference beams into the recording medium. This form tends to break away from the non-mechanical paradigm because either the medium or recording beams must be physically moved. Like wavelength multiplexing, this is combined with other forms of multiplexing to maximize the amount of data stored in the holographic volume. Two commonly used forms of spatial multiplexing are peristrophic multiplexing and shift multiplexing.



PHASE-ENCODED MULTIPLEXING

The form of multiplexing farthest away from using mechanical means to recordmany pages in the same volume of a holograph is called phase-encodedmultiplexing.Ratherthanmanipulatethe angle of entry of a laser beam or rotateor translate the recording medium, phase-encoded multiplexing changes thephaseof individual parts of a reference beam.The main reference beam is splitupinto many smaller partial beams which cover the same area as the original

reference beam.These smaller beamlets vary byphase which changes the state ofthe reference beam as a whole.The reference beams intersects thesourcebeamand records the diffraction relative to the different phases of the beamlets.The phase of the beamlets can be changed by non-mechanical means, thereforespeeding up access times.



RECORDING ERRORS

When data is recorded in a holographic medium, certain factors can lead toerroneously recorded data.One major factor is the electronic noise generated bylaser beams. When a laser beam is split up (for example, through a SLM),thegeneratedlight bleeds into places where light was meant to be blocked out.Areas where zero light is desired might have minuscule amounts of laser lightpresent which mutates its bit representation.For example, if too much light getsrecorded into this zero area representing a binary 0, an erroneous change to a binary1 might occur. Changes in both the quality of the laser beam and recordingmaterial are being researched, but these improvements must take into consideration the cost-effectiveness of aholographicmemory system.

Theselimitat

ions to current laser beam and photosensitive technology are some ofthemainfactorsforthe delay of practical holographic memory systems.

PAGE-LEVEL PARITY BITS

Once error-free data is recorded into a hologram, methods which read data back out of it need to be error free as well.Data in page format requires a new way to provide error control.Current error control methods concentrate on a stream of bits.Because page data is in the form of a two dimensional array, error correctionneeds to take into account the extra dimension of bits.When a page of datais written to the holographic media, the page is separated into smaller two dimensional arrays.These sub sections are appended with an additional row and column of bits.The added bits calculate the parity of each row and column of data.An odd number of bits in a row or column create a parity bit of 1 and an even number of bits create a 0.A parity bit where the row and column meet is also created which is called an overall parity bit.The sub sections are rejoined and sent to the holographic medium for recording.

MERITS OF HOLOGRAPHIC MEMORY

Holographic memory offers storage capacity of about 1 TB.Speed of retrieval of data in tens of microseconds compared to data access time of almost 10ms offered by the fastest hard disk today.By the time they are available they can transfer an entire DVD movie in 30 seconds. Information search is also faster in holographic memory.Consider the case of large databases that are stored on hard disk today. To retrieve any piece of information you first provide some reference data.The data is then searched by its address, track, sector and so on after which it is compared with the reference data. In holographic storage entire pages can be retrieved where contents of two or more pages can be compared optically without having to retrieve the information contained in them. Also HDSS has no moving parts.So the limitations of mechanical motion such as friction can be removed.

CHALLENGES

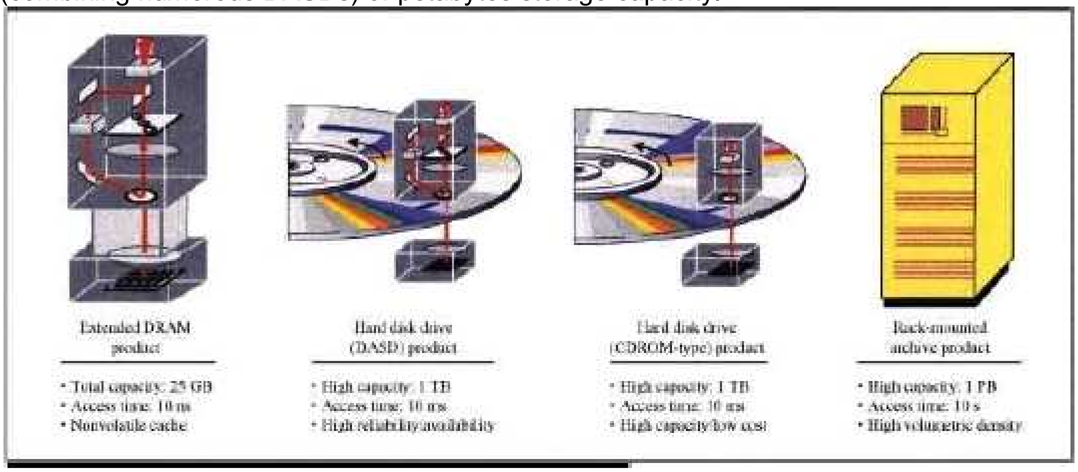
During the retrieval of data the reference beam has to be focused at exactly the same angle at which it was projected during recording. A slight error can cause a wrong data page to be accessed.It is difficult to obtain that much of accuracy. The crystal used as the photographic filament must have exact optical characteristics such as high diffraction efficiency, storage of data safely without any erasure and fast erasure on application of external stimulus light ultra violet rays.With the repeated number of accesses the holograms will tend to decay.

POSSIBLE APPLICATIONS

There are many possible applications of holographic memory. Holographic memory systems can potentially provide the high-speed transfers and large volumes of future computer systems.One possible application is data mining. Data mining is the process of finding patterns in large amounts of data.Data mining is used greatly in large databases which hold possible patterns whichcan't be distinguished by human eyes due to the vast amount of data. Somecurrent computer systems implement data mining, but the mass amount of storagerequiredispushingthe limits of current data storage systems.The many advances in access times and data storage capacity that holographic memory provides could exceed conventional storage and speed up data mining considerably. This would result in more located patterns in a shorter amount of time.

Another possible application of holographic memory is in petaflop computing.A petaflop is a thousand trillion floating point operations per second. The fast access in extremely large amounts of data provided by holographic memory systems could be utilized in petaflop architecture.Clearly advances are needed in more than memory systems, but the theoretical schematics do exist forsucha machine.Optical storage such as holographic memory provide a viable solution to the extreme amount of data which is required for petaflop computing.

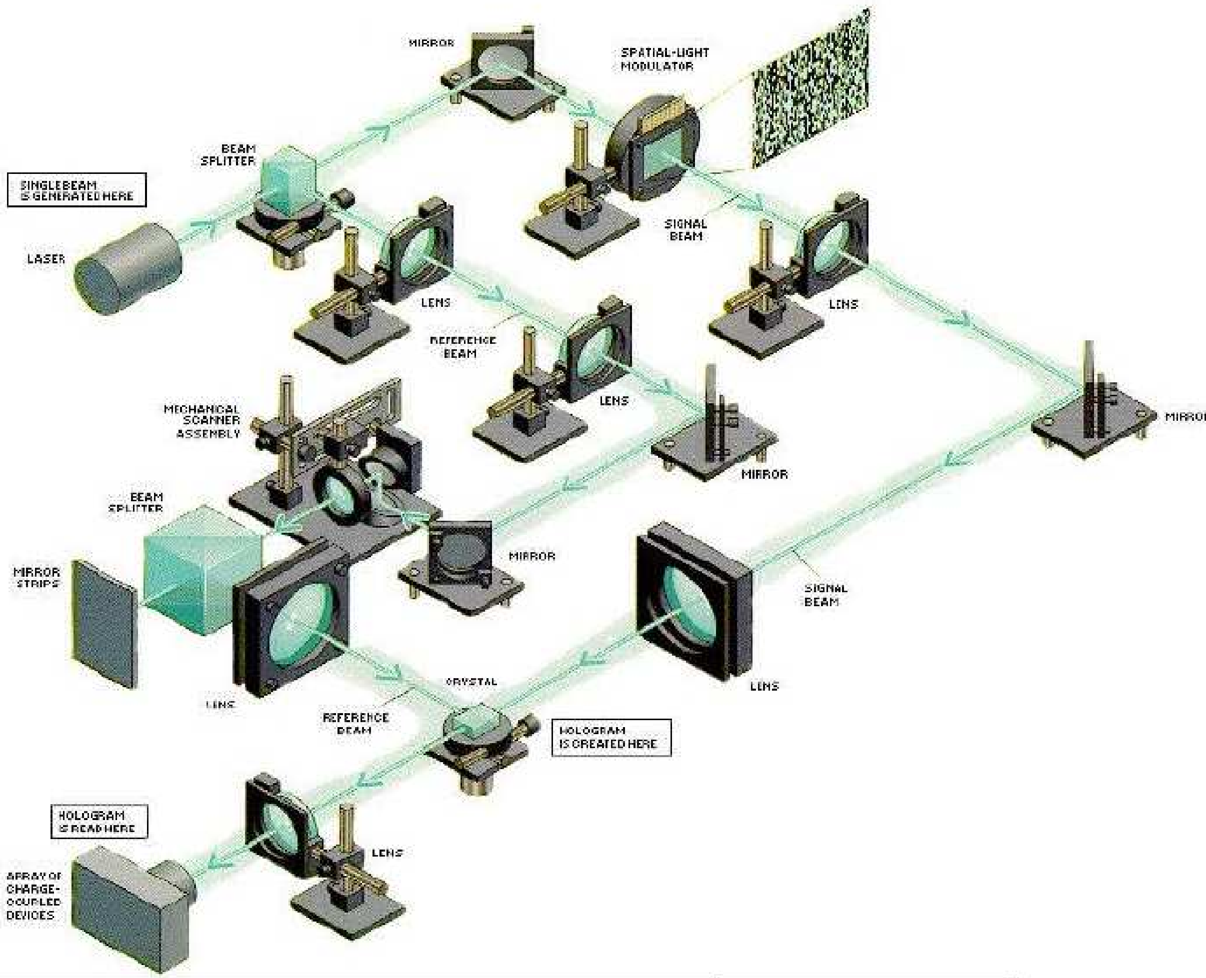
Holographic memory can be used as extended DRAM with 10ns access time, Hard disk drives ,CD ROMs of large storage capacity and rockmounted (combining numerous DASDs) of petabytes storage capacity.

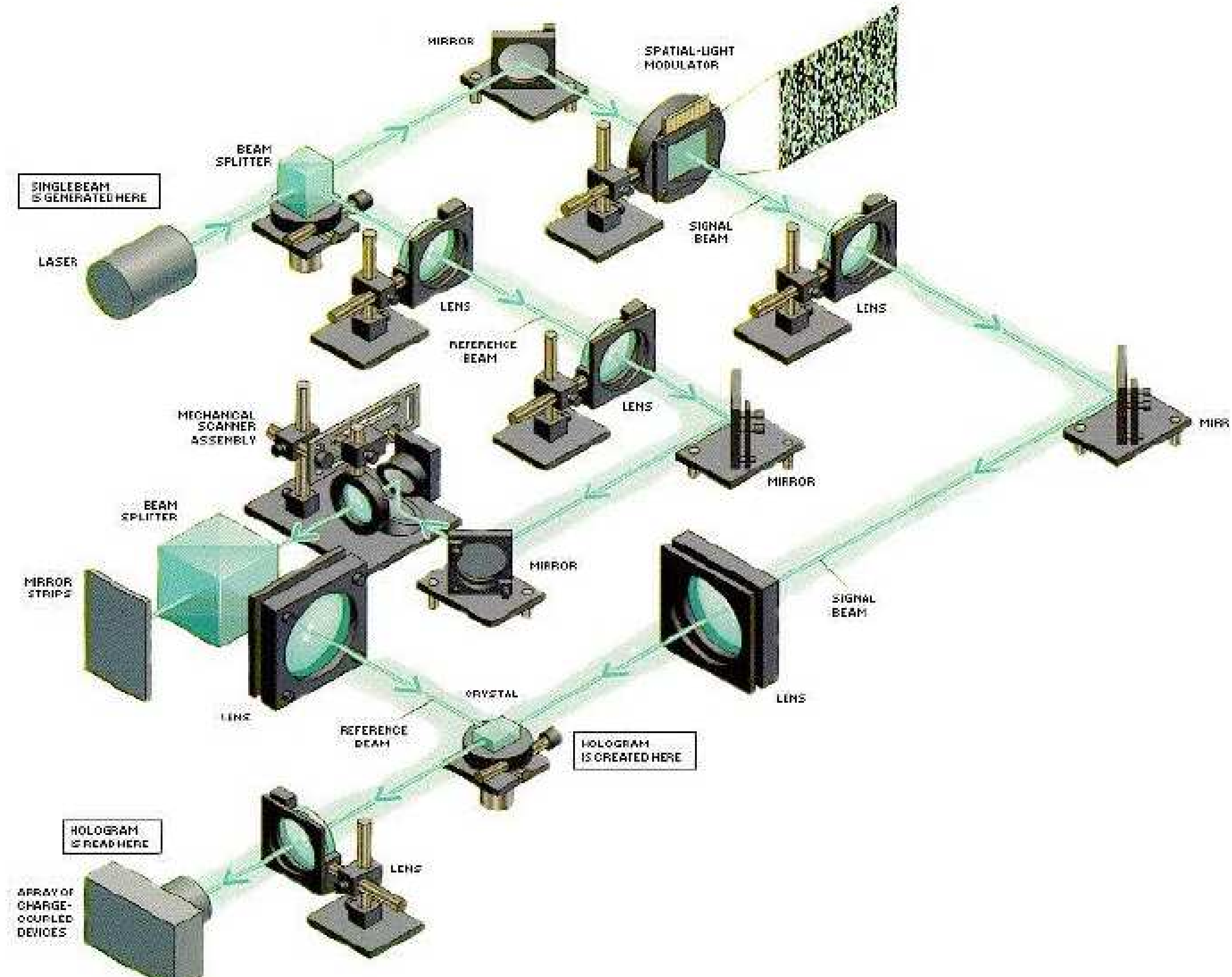


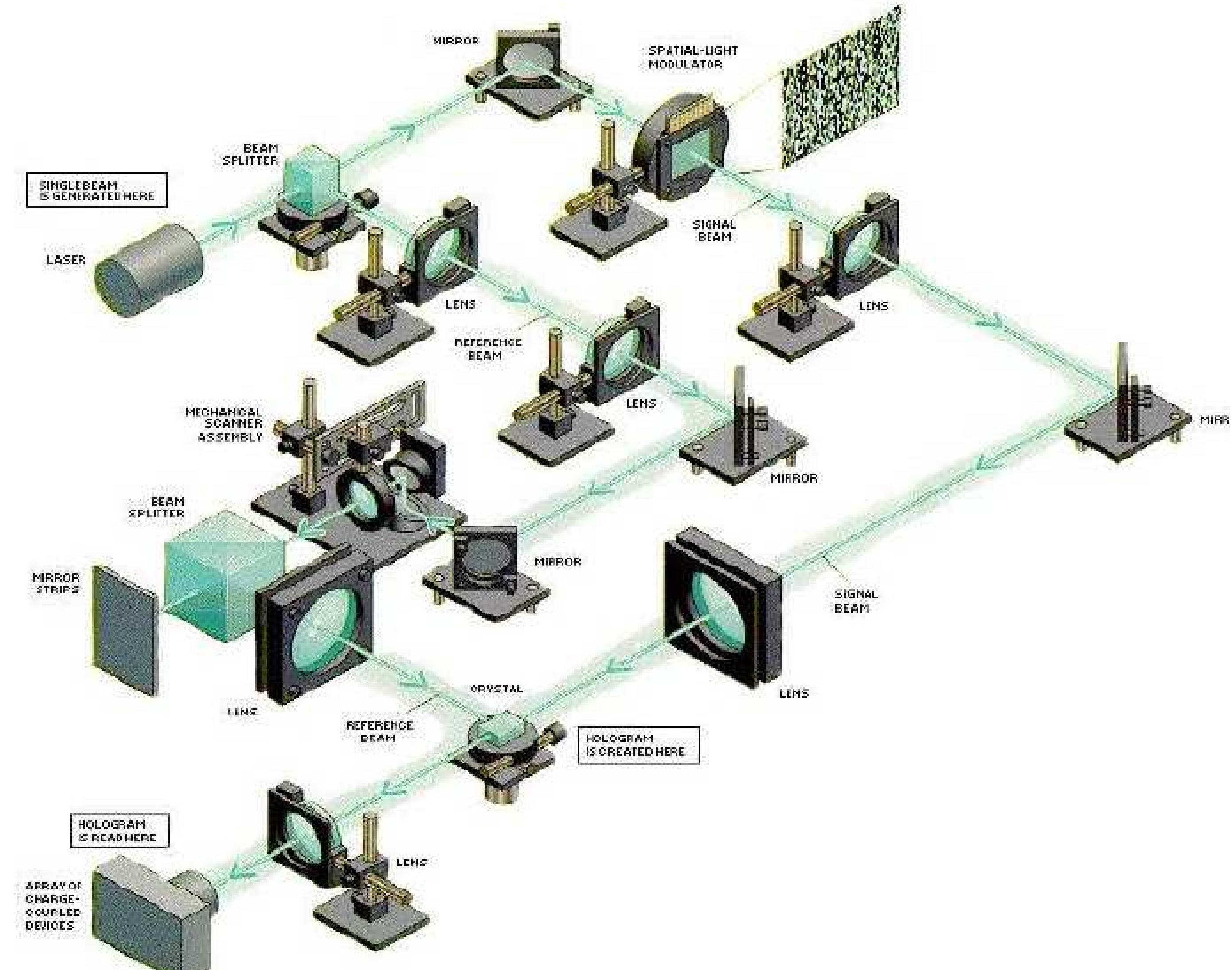
RECENT DEVELOPMENTS

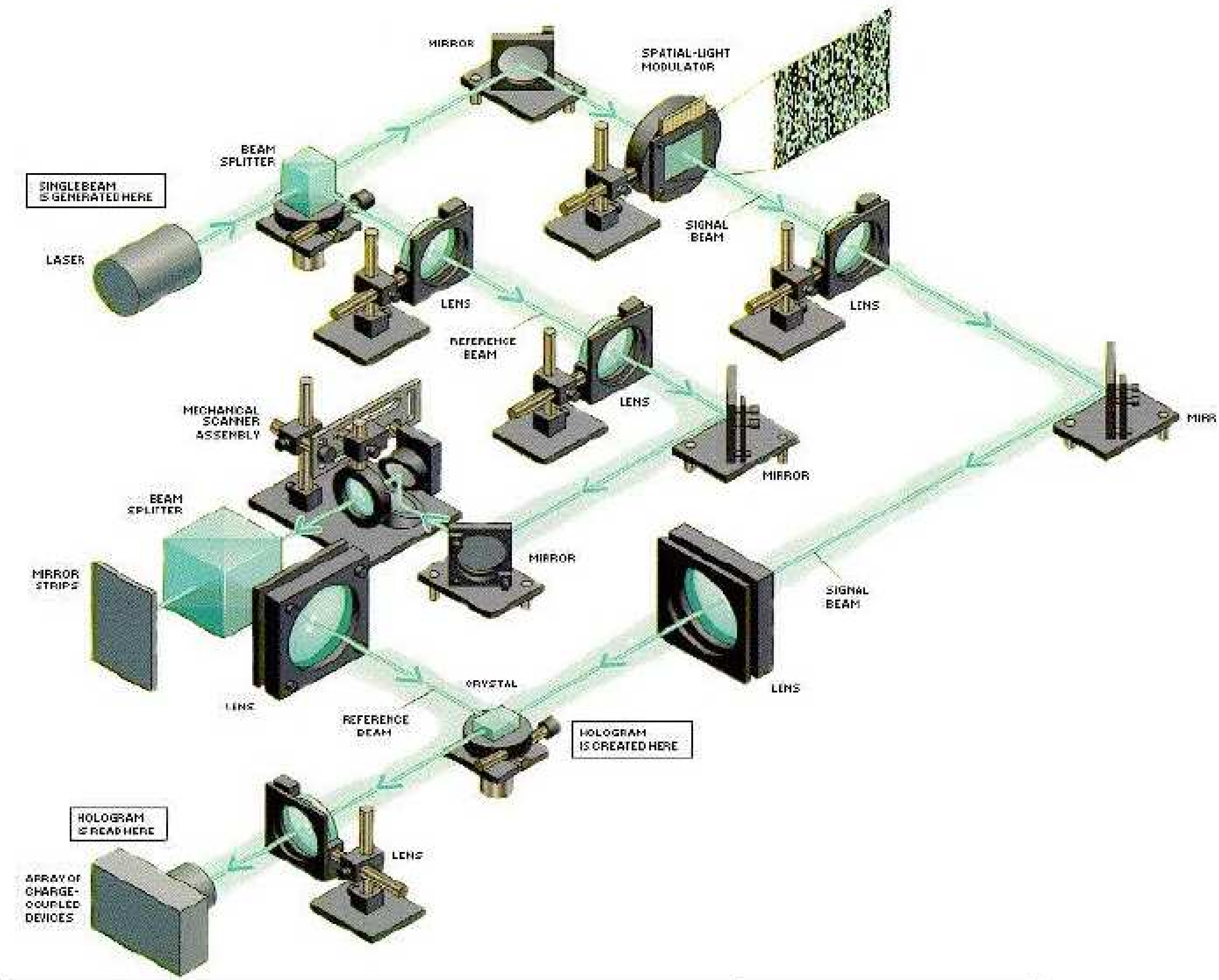
The research on holographic memory is taking place in well guarded and richcompanies like IBM, ROCKWELL and InPhase.InPhase claims to have developeda holographic memory of size slightly larger than a DVD. It has a capacity of about100GB. They are trying to push it upto 1TB.
IBM and ROCKWELL claims to have developed a recording medium less sensitive than lithium niobate crystals.

HOLOGRAPHIC MEMORY LAYOUT


MIRROR
SPATIAL-LIGHT MODULATOR
BEAM SPLITTER
SINGLE BEAM IS GENERATED HERE
LASER
SIGNAL BEAM
LENS
REFERENCE BEAM
LENS
LENS
MECHANICAL SCANNER ASSEMBLY
MIRROR
MIRROR
BEAM SPLITTER
MIRROR
MIRROR STRIPS
SIGNAL BEAM
LENS
CRYSTAL
LENS
REFERENCE BEAM
HOLOGRAM IS CREATED HERE
HOLOGRAM IS READ HERE
LENS
ARRAY OF CHARGE-COUPLED DEVICES


MIRROR
SPATIAL-LIGHT MODULATOR
BEAM SPLITTER
SINGLEBEAM IS GENERATED HERE
LASER
SIGNAL BEAM
LENS
LENS
REFERENCE BEAM
LENS
MECHANICAL SCANNER ASSEMBLY
MIRR
MIRROR
BEAM SPLITTER
MIRROR
MIRROR STRIPS
SIGNAL BEAM
LENS
CRYSTAL
LENS
REFERENCE BEAM
HOLOGRAM IS CREATED HERE
HOLOGRAM IS READ HERE
LENS
ARRAY OF CHARGE-COUPLED DEVICES


MIRROR
SPATIAL-LIGHT MODULATOR
BEAM SPLITTER
SINGLEBEAM IS GENERATED HERE
LASER
SIGNAL BEAM
LENS
REFERENCE BEAM
LENS
LENS
MECHANICAL SCANNER ASSEMBLY
MIRROR
MIRR
BEAM SPLITTER
MIRROR
MIRROR STRIPS
SIGNAL BEAM
LENS
CRYSTAL
LENS
REFERENCE BEAM
HOLOGRAM IS CREATED HERE
HOLOGRAM IS READ HERE
LENS
ARRAY OF CHARGE-COUPLED DEVICES



Holographic Memory
HOLOGRAPHIC MEMORY LAYOUT

The future of holographic memory is very promising.The page access of data that holographic memory creates will provide a window into next generation computing by adding another dimension to stored data.Finding holograms in personal computers might be a bit longer off, however. The large costof high-tech optical equipment would make small-scale systems implemented withholographic memory impractical. Holographic memory will most likely be used in next generation super computers where cost is not as muchofanissue.Current magnetic storage devices remain far more cost effective than any other medium on the market.As computer systems evolve, it is not unreasonable to believe that magnetic storage will continue to do so.As mentioned earlier, however, these improvements are not made on the conceptual level.The current storage in a personal computer operates on the same principles used in the first magnetic data storage devices.The parallel nature of holographic memory has many potential gains on serial storage methods. However, many advances in optical technology and photosensitive materials need to be made before we find holograms in computer systems.

REFERENCES

http://www.howstuffworks.com

http:// www.sandj@cda.mrs.umn.edu