International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 - 5161

Available at http://inpressco.com/category/ijcet

Review Article

A Review Paper on 3D Optical Data Storage

Ishan Goradia[Ȧ*], Jheel Doshi[Ȧ] and Khushali Deulkar[Ȧ]

[Ȧ]Computer Department, DJSCOE, Vile Parle (W), Mumbai – 400056, India

Accepted 15 August 2014, Available online 25 Aug 2014, **Vol.4, No.4 (Aug 2014)**

Abstract

Since the past couple of decades, optical data storage has been the most primary means of digital circulation. To accommodate new demands and applications, there has been an improvement in the storage capacity of such devices. However, limitations in the optics have hindered the growth of these devices. The demand for bigger, faster memories has led to significant improvements in conventional memory technologies—hard disk drives & optical disks. But there is strong proof that these two-dimensional storage technologies are approaching fundamental limits- as the wavelength of light and the thermal stability of stored bits. Such limitations may be difficult to surmount. Storing data in three dimensions is a suitable approach to overcome these limitations and to also increase the storage level by a large amount.

Keywords: *Optical Storage, Holographic Storage, Hologram, Shift Multiplexing, Angle Multiplexing*

1. Introduction

Optical storage is the storage of data on an optically readable medium. Data is recorded by making marks in a pattern that can be read back with the aid of light, usually a laser beam precisely focused on a spinning disc. There are other means of storing data optically and new methods are in development. Optical storage varies from other data storage techniques that make use of other technologies such as magnetism or semiconductors.

Since the late 1980s, three-dimensional (3D) optical data storage has become a significant area of interest. As formats progressed from Laserdisc to compact Disc (CD) (700MB) to Digital Video Device (DVD) (4.7GB) to Blue Ray Disc (25GB), 2D storage devices have remained a standard for cheap, stable data storage. The overall storage capacity was increased with each new generation of devices. 3D optical data storage is the term given to any form of optical data storage in which information can be recorded and/or read with three-dimensional resolution.

Current optical data storage media store data as a series of reflective marks on an internal surface of a disc. It is possible for disks to hold two or even more of these data layers, in order to increase storage capacity, but their number is severely limited since the addressing laser interacts with every layer that it passes through on the way to and from the addressed layer. This results in noise that is limiting this technology to only 10 layers.

2. Features

The general operating principles of 2D optical storage formats rely upon controlled reflection patterns. Most commercial disks store information on a thin aluminium film that is housed within a transparent plastic disk. Information is stored on such a device during the fabrication process as the aluminium films are stamped with a pattern. The information is later read by reflecting a focused laser beam at the surface. The disk is spun about its axis, which translates the pattern relative to the laser. The resultant reflection from the disk is modulated with the information from the pattern, and the reflection is captured by a photodiode. As a result the photodiode produces a modulated electrical signal which conveys the information to the next step in the process. These aluminium based disks are the most prevalent kind of write-once-read-many (WORM) disk.

3. Description

3.1 3 D optical storage

3D optical data storage methods bypass the above issue through the use of addressing methods where only the explicitly addressed volumetric pixel interacts considerably with the light,. This involves nonlinear data reading and writing methods, like non-linear optics. 3D optical data storage is related to holographic data storage. This invention is said to have the possibility to provide mass storage on DVD sized disks. Data recording and readback is achieved with the help of focusing lasers within the medium. However, the laser light must travel through other points before it reaches the point where reading or recording is desired (G.W. Burr, *et al*, 1998).

This is due to the volumetric nature of the data structure. Some kind of nonlinearity is required to prevent other data points from interfering with the addressing of the desired point. Overlaying many holograms within the

*Corresponding author: **Ishan Goradia**

same volume of material helps in achieving high density. Two-dimensional pixelated images are used to encode and retrieve the data, with each image representing a bit. The inherent parallelism enables fast readout rates: if a thousand holograms can be retrieved each second, with a million pixels in each, then the output data rate can reach 1 Gbit/second. For comparison, an optical digital video disk (DVD) outputs data at about 10 Mbits/second. Thus the potential of such a storage technology has generated a lot of research efforts.

3.2 Hologram

A hologram is a three-dimensional image formed by the interference of light beams from a laser or other coherent light source. Typically, the signal path and the reference path are two paths into which light from a single laser is split. Fig. 1 shows this holographic recording arrangement. The beam that propagates along the signal path carries information whereas the reference beam is designed to be simple to reproduce. A light beam that propagates without converging or diverging, i.e. a plane wave is used as a common reference beam. Interference pattern between the two beams is recorded by overlaying the two paths on the holographic medium. A significant property of this recording is that when illuminated by a readout beam, the signal beam is replicated. Actually since some light is diffracted from the readout beam, a weak copy of the signal beam is reconstructed. The reconstructed hologram makes a 3D object appear behind the holographic medium if the signal beam was created by reflecting light off that 3D object. When the hologram is recorded in a thin material, the readout beam can vary from the reference beam used for recording and the scene will still appear (G.W. Burr, *et al*, 1998).

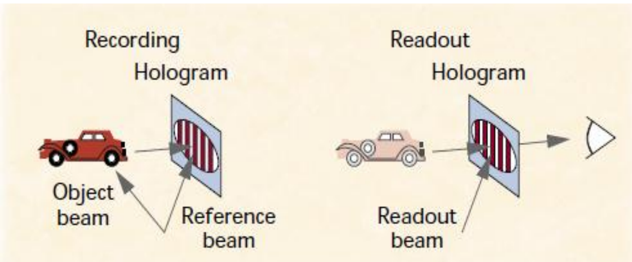

Fig. 1 After recording a hologram with object and reference beams, a readout beam is used to reconstruct the object beam and make the object visible to the viewer.

3.3 Storing and Retrieving Data

The digital data to be stored must be reproduced onto the object beam for recording, and then recovered from the reconstructed object beam during readout- this is how volume holography is used as a storage technology. The input device for the system is called a spatial light modulator, or SLM. The SLM is a planar array of thousands of pixels; each pixel is an independent optical switch that can be set to either block or pass light. The output device is a similar array of detector pixels, such as a charge-coupled device (CCD) camera or CMOS pixel array. The object beam often passes through a set of lenses that image the SLM pixel array onto the output pixel array, as Fig. 2 shows.

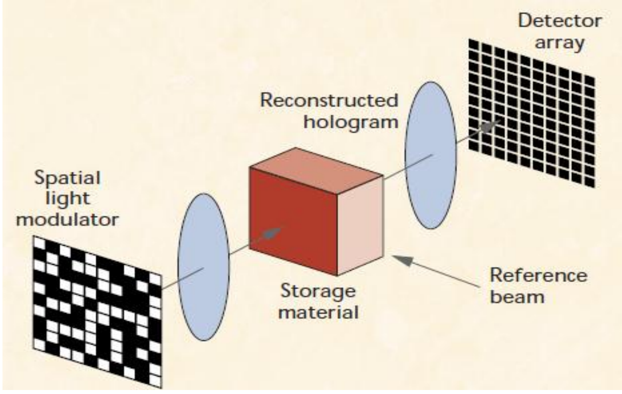

Fig. 2 For data storage, information is put onto the object beam with SLM and removed from the reconstructed object beam with a detector array.

The imaging path between the input pixel array and the output pixel array is where the hologram can be formed. To maximize storage density, the hologram should be recorded where the object beam achieves a tight focus. Upon reconstruction of the hologram by the reference beam, the object beam continues along the original imaging path, where the optical output can be detected by the camera in parallel and converted to digital data. Capacity and readout rate are maximized when each detector pixel is matched to a single pixel on the SLM array.

4. Methods of Optical Storage

Optical data storage techniques are categorized in three basic groups. (D. Psaltis, *et al*, 1998)

4.1 Surface or 2D recording

The following techniques are already in use

- CD/DVD- Data is stored in reflective pits which are then scanned with a focused laser. Disks of these types are easily replicated from a master disk.
- CD-Recordable- Reflective pits are thermally recorded by focused laser. Read only CDs are of a higher density than CD-Recordable devices.
- Magneto-optic disks- A combination of magnetic field and focused laser are used to record spots in the disks.

The following techniques cannot be used due to some issues:

- Near-field optical recording- Placing a small light source close to the disk is used to achieve higher 2D density as compared to conventional surface recording. Light turnout and readout speed are concerns.
- Optical tape- Parallel optical I/O has no long-term interaction between tape layers wound. Flexible photosensitive media is a problem.

4.2 Volumetric recording

Holographic- Interference fringes store data with vastly paralleled I/O. But appropriate recording material is still needed.

Spectral hole burning- A tunable narrowband laser is used to address a small subset of molecules. Else, all molecular subsets are addressed with ultra-short laser pulses. It may add a fourth storage dimension to holography but requires cryogenic temperatures and materials development.

4.3 Bit-by-bit 3D recording

Sparsely layered disks- To access the inner layers, the focus of the CD laser is modified. The standard of this disk includes two layers per side.

Densely layered disks- A tightly focused beam is to write small markings in a continuous or layered material.
2-photon- Two beams which are of diverse wavelengths, hits writes, and then read in parallel using fluorescence. Material sensitivity is a concern.

5. Storage Materials

5.1 Read-write materials

Most read-write materials are inorganic photorefractive crystals doped with transition elements such as iron or rare-earth ions such as praseodymium, grown in large cylinders. Thick holograms are made possible by cutting and polishing large samples. Photo-ionized electrons are transported and trapped when these materials react to the light and dark regions of an interference pattern. These crystals exhibit a linear photo-electric effect. This creates a trapped charge which thereby creates electrical fields which give rise to a suitable phase or index for diffracting light. This leads to refraction index becoming identical to the spatial variations in light intensity present in the interference pattern. The trapped charge can be reorganized by ensuing illumination, which makes it possible to erase recorded holograms and replace them with new ones.

5.2 Write-once materials

Irreversible photochemical reactions are triggered by the bright regions of the optical interference pattern while writing permanent volume holograms. For example, a photopolymer material will polymerize (bind short monomer chains together to form long molecular chains) in response to optical illumination. However, contrastingly the molecules in a photochromic material undergo a change in their absorption behavior. Such materials are inexpensive to make in quantity. Authentic reproduction of the object is a problem in both types of materials- shrinkage causes a problem in photopolymer materials whereas oversensitivity to average local intensity causes the problem in photochromic materials. Careful system design can minimize these problems.

6. Holographic 3D Disks

Moving the storage material and leaving optics and other components stationary constitutes spatial multiplexing. The thickness of disk is about 1mm due to which many holograms can be stored on the surface. A number of radial tracks are available and the motion of head selects a track, and access to these tracks is provided by disk rotation. By improving the surface density, the thickness can be increased, thereby increasing the number of holograms. But this increases the surface area which may result in a decrease of the surface density. It would be advantageous to fabricate the disk of about 1mm so as to yield a density of approximately 100 bits per square micron. Even though the data is stored in 3D disk it is the surface density that matter for most practical purposes. Another method for multiplexing holograms on holographic disks is angle multiplexing. It would be convenient using a single reference beam that could attain same density without a bulky deflector. This can be done by considering a convergent or spherical beam which can be obtained by bringing in all the angles simultaneously instead of one at a time. (G.W. Burr, *et al*, 1998)

7. Future Possibilities

Holographic storage is a strong contender for future storage options. It is being researched by various companies in order to further increase the storage capacity. If the cost of manufacture can be matched with the currently available storage options then a stronger role can be envisaged for 3D data storage. Possible configurations in the future can be:

1. Pre-recorded 3D disks supports more than 100 Gbytes and has readout rates more than 188 Mbits/sec. Appropriate applications are distributed computing, movies, and multimedia.
2. Volatile write-once, read-many drives support terabytes of storage, 1 Gbit/second readout rates. Suitable applications include video on demand and large Web servers.
3. Write-once 3D disks supporting more than 100Gbytes, access time to 100 Mbyte blocks of 10–100 milliseconds, with readout rates greater than 500 Mbits/sec. Fitting applications include archiving of data requiring permanent storage yet quick access, such as healthcare data and satellite images.

Conclusion

Holographic storage technology has the potential to offer 100’s of GBs or more of storage which can be used not only for storing applications, but also for distribution of physical content (if the costs of production can be reduced). Holographic storage development could become another option for high definition content distribution, if research continues. Optical storage for content distribution faces new competition from cloud based content access, like other storage technologies. However, as the size of content grows with higher resolution there is still a role for local storage technologies, such as optical disks, at least for some time in the future. Real-time storage assists social networking and downloading to mobile devices but it won’t replace our need for some local storage any time soon.

Acknowledgement

We would like to thank our honorable principal Dr. Hari Vasudevan of D. J. Sanghvi College of Engineering and Dr. Narendra Shekhokar, Head of Department of Computer Engineering, for giving us the facilities and providing us with a propitious environment for working in college. We would also like to thank S.V.K.M. for encouraging us in such co-curricular activities.

References

F.H. Mok, G.W. Burr, and D. Psaltis, (1996), System Metric for Holographic Memory Systems, *Optics Letters*, pp. 896-898.

K. Blotekjaer, (1979), Limitations on Holographic Storage Capacity of Photochromic and Photorefractive Media, *Applied Optics*, pp.57-67.

M.A. Neifeld and M. McDonald, (1994), Error Correction for Increasing the Usable Capacity of Photorefractive Memories, *Optics Letters*, pp. 1,483-1,485.

B.H. Olson and S.C. Esener, (1994), Partial Response Precoding for Parallel Readout Optical Memories, *Optics Letters*, pp. 661-663.

A. Pu and D. Psaltis, (1996), High-Density Recording in Photopolymer-Based Holographic Three-Dimensional Disks, *Applied Optics*, pp. 2,389-2,398.

G. Barbastathis, M. Levene, and D. Psaltis, (1996), Shift Multiplexing with Spherical Reference Waves, *Applied Optics*, pp. 2,403-2,417.

G.W. Burr and D. Psaltis, (1998), Holographic Data Storage, *Computer*, pp. 52-60.