

STUDY OF DEVELOPMENT ISSUES IN 3D OPTICAL STORAGE DEVICES

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Abstract

3D optical data storage is any form of optical data storage in which information can be recorded or read with three-dimensional resolution (as opposed to the two-dimensional resolution afforded, for example, by CD). This innovation has the potential to provide petabyte-level mass storage on DVD-sized discs (120 mm). Data recording and read back are achieved by focusing lasers within the medium. However, because of the volumetric nature of the data structure, the laser light must travel through other data points before it reaches the point where reading or recording is desired. Therefore, some kind of nonlinearity is required to ensure that these other data points do not interfere with the addressing of the desired point. No commercial product based on 3D optical data storage has yet arrived on the mass market, although several companies are actively developing the technology and claim that it may become available 'soon'.

Keywords: Laser Beam, Optical Fiber, Layers of Written Data

I.INTRODUCTION

The origins of the field date back to the 1950s, when Hirschberg developed the photo chromic spiropyrans and suggested their use in data storage. In the 1970s, Barachevskii demonstrated that this photochromism could be produced by two-photon excitation, and finally at the end of the 1980s Peter T. Rentzepis showed that this could lead to three-dimensional data storage. This proof-of-concept system stimulated a great deal of research and development, and in the following decades many academic and commercial groups have worked on 3D optical data storage products and technologies. Most of the developed systems are based to some extent on the original ideas of Rentzepis. A wide range of physical phenomena for data reading and recording have been investigated, large numbers of chemical systems for the medium have been developed and evaluated, and extensive work has been carried out in solving the problems associated with the optical systems required for the reading and recording of data. Currently, several groups remain working on solutions with various levels of development and interest in commercialization.

One of the reasons that computers have become increasingly important in daily life is because they offer unprecedented access to massive amounts of information. The decreasing cost of storing data and the increasing storage capacities of ever smaller devices have been key enablers of this revolution. Current storage needs are being met because improvements in conventional technologies such as magnetic hard disk drives, optical disks, and semiconductor memories have been able to keep pace with the demand for greater and faster storage.

However, there is strong evidence that these surface-storage technologies are approaching fundamental limits that may be difficult to overcome, as ever-smaller bits become less thermally stable and harder to access. Exactly when this limit will be reached remains an open question: some experts predict these barriers will be encountered in a few years, while others believe that conventional technologies can continue to improve for at least five more years. In either case, one or more successors to current data storage technologies will be needed in the near future.

An intriguing approach for next generation data-storage is to use light to store information throughout the three-dimensional volume of a material. By distributing data within the volume of the recording medium, it should be possible to achieve far greater storage densities than current technologies can offer.

For instance, the surface storage density accessible with focused beams of light is roughly $1/(\lambda/2)$ (Wave length). With green light of roughly 0.5 micron wavelength, this should lead to 4 bits/sq. micron or more than 4 Gigabytes (GB) on each side of a 120mm diameter, 1mm thick disk. But by storing data throughout the volume at a density of $1/(\lambda/3)$ (3Wave length), the capacity of the same disk could be increased 2000 fold, to 8 Terabytes (TB).

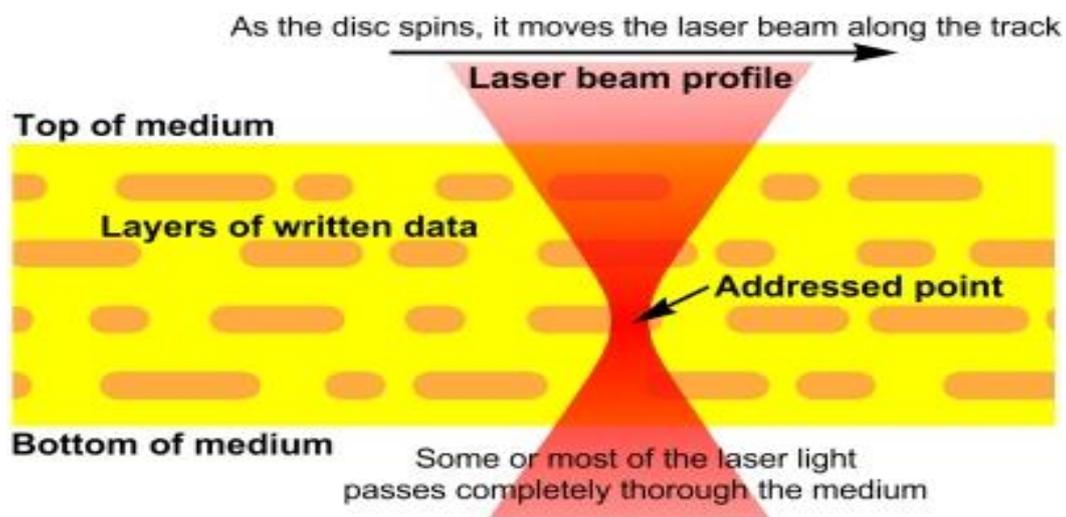


Fig 1: Schematic representation of optical fiber.

Schematic representation of a cross-section through a 3D optical storage disc (yellow) along a data track (orange marks). Four data layers are seen, with the laser currently addressing the third from the top. The laser passes through the first two layers and only interacts with the third, since here the light is at a high intensity.

Current optical data storage media, such as the CD and DVD store data as a series of reflective marks on an internal surface of a disc. In order to increase storage capacity, it is possible for discs to hold two or even more of these data layers, 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. These interactions cause noise that limits the technology to perhaps ~10 layers. 3D optical data storage methods circumvent this issue by using addressing methods where only the specifically addressed voxel interacts substantially with the addressing light. This necessarily involves nonlinear data reading and writing methods, in particular nonlinear optics. 3D optical data storage is related to (and competes with) holographic data storage, but operates on different principles.

As an example, a prototypical 3D optical data storage system may use a disk that looks much like a transparent DVD. The disc contains many layers of information, each at a different depth in the media and each consisting of a DVD-like spiral track. In order to record information on the disc a laser is brought to a focus at a particular depth in the media that corresponds to a particular information layer. When the laser is turned on it causes a photochemical change in the media. As the disc spins and the read/write head moves along a radius, the layer is written just as a DVD-R is written. The depth of the focus may then be changed and another entirely different layer of information written. The distance between layers may be 5 to 100 micrometers, allowing >100 layers of information to be stored on a single disc.

In order to read the data back, a similar procedure is used except this time instead of causing a photochemical change in the media the laser causes fluorescence. This is achieved e.g. by using a lower laser power or a different laser wavelength. The intensity or wavelength of the fluorescence is different depending on whether the media has been written at that point, and so by measuring the emitted light the data is read.

II.PROCESSES FOR WRITING DATA

Data recording in a 3D optical storage medium requires that a change take place in the medium upon excitation. This change is generally a photochemical reaction of some sort, although other possibilities exist. Chemical reactions that have been investigated include photoisomerizations, photodecompositions and photo bleaching, and polymerization initiation. Most investigated have been photochromic compounds, which include azobenzenes, spiropyrans, stilbenes, fulgides and diarylethenes. If the photochemical change

is reversible, then rewritable data storage may be achieved, at least in principle. Also, multilevel recording, where data is written in 'grayscale' rather than as 'on' and 'off' signals, is technically feasible.

2.1 Writing by Multiphoton Absorption

Although there are many nonlinear optical phenomena, only multiphoton absorption is capable of injecting into the media the significant energy required to electronically excite molecular species and cause chemical reactions. Two-photon absorption is the strongest multiphoton absorbance by far, but still it is a very weak phenomenon, leading to low media sensitivity. Therefore, much research has been directed at providing chromophores with high two-photon absorption cross-sections.

2.1.1 Two-Photon Absorption

Writing by 2-photon absorption can be achieved by focusing the writing laser on the point where the photochemical writing process is required. The wavelength of the writing laser is chosen such that it is not linearly absorbed by the medium, and therefore it does not interact with the medium except at the focal point. At the focal point 2-photon absorption becomes significant, because it is a nonlinear process dependant on the square of the laser fluence.

Writing by 2-photon absorption can also be achieved by the action of two lasers in coincidence. This method is typically used to achieve the parallel writing of information at once. One laser passes through the media, defining a line or plane. The second laser is then directed at the points on that line or plane that writing is desired. The coincidence of the lasers at these points excited 2-photon absorption, leading to writing photochemistry.

Another approach to improving media sensitivity has been to employ resonant two-photon absorption. Nonresonant two-photon absorption (as is generally used) is weak since in order for excitation to take place, the two exciting photons must arrive at the chromophore at almost exactly the same time. This is because the chromophore is unable to interact with a single photon alone. However, if the chromophore has an energy level corresponding to the (weak) absorption of one photon then this may be used as a stepping stone, allowing more freedom in the arrival time of photons and therefore a much higher sensitivity. However, this one-photon absorbance is a linear process, and therefore risks compromising the 3D resolution of the system. Two photon absorption (TPA) is the simultaneous absorption of two photons of identical or different frequencies in order to excite a molecule from its ground state to an excited state. The first TPA process was observed in doped europium salts.

Two-photon absorption can be measured by several techniques. Two of them are two-photon excited fluorescence (TPEF) and nonlinear transmission (NLT). Pulsed lasers are most often used because TPA is a third-order nonlinear optical process, and therefore is most efficient at very high intensities.

In non resonant TPA two photons combine to bridge an energy gap larger than the energies of each photon individually. If there were an intermediate state in the gap, this could happen via two separate one-photon transitions in a process described as "resonant TPA", "sequential TPA", or "1+1 absorption". In non resonant TPA the transition occurs without the presence of the intermediate state.

The "nonlinear" in the description of this process means that the strength of the interaction increases faster than linearly with the electric field of the light. In fact, under ideal conditions the rate of TPA is proportional to the square of the field intensity. This dependence can be derived quantum mechanically, but is intuitively obvious when one considers that it requires two photons to coincide in time and space. This requirement for high light intensity means that lasers are required to study TPA phenomena. Further, in order to understand the TPA spectrum, monochromatic light is also desired in order to measure the TPA cross section at different wavelengths. Hence, tunable pulsed lasers (such as frequency-doubled Nd: YAG-pumped OPOs and OPAs) are the choice of excitation.

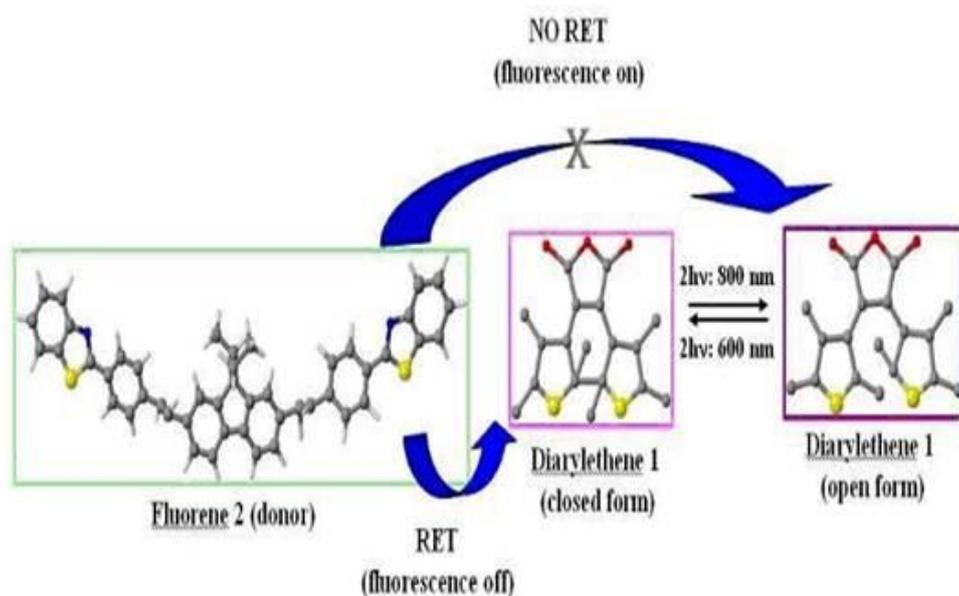


Fig 2: TPA

2.1.2 Description

A two-photon 3D optical data storage system consisting of a bichromophoric mixture of diarylethene and fluorine derivative as the storage medium is demonstrated here. Binary information bits were recorded throughout all three dimensions of the storage medium by two-photon localized excitation on the diarylethene molecules, transforming the closed form of diarylethene into the open form. The readout

method is based on the modulation of the two-photon fluorescence emission of fluorine by the closed form of diarylethene.

III.DEVELOPMENT ISSUES

3.1 Development Issues

Despite the highly attractive nature of 3D optical data storage, the development of commercial products has taken a significant length of time. This is the result of the limited financial backing that 3D optical storage ventures have received, as well as technical issues including:

3.1.1 Destructive reading

Since both the reading and the writing of data are carried out with laser beams, there is a potential for the reading process to cause a small amount of writing. In this case, the repeated reading of data may eventually serve to erase it (this also happens in phase change materials used in some DVDs). This issue has been addressed by many approaches, such as the use of different absorption bands for each process (reading and writing), or the use of a reading method that does not involve the absorption of energy.

3.1.2 Stability

Many chemical reactions that appear not to take place in fact happen very slowly. In addition, many reactions that appear to have happened can slowly reverse themselves. Since most 3D media are based on chemical reactions, there is therefore a risk that either the unwritten points will slowly become written or that the written points will slowly revert to being unwritten. This issue is particularly serious for the spiropyran, but extensive research was conducted to find more stable chromophores for 3D memories.

3.1.3 Laser

As we have noted, 2-photon absorption is a weak phenomenon, and therefore high power lasers are usually required to produce it. Researchers typically use Ti-sapphire

Lasers or Nd: YAG lasers to achieve excitation, but these instruments are not suitable for use in consumer products.

3.1.4 Commercial development



Fig 7: Examples of optical storage devices

Examples of 3D optical data storage media.

Top row - Written Call/Recall media, Mempile media.

Middle row – FMD, D-Data DMD and drive.

Bottom row - Landauer media, Microholas media in action.³

3.2 Fluorescent Multilayer Disc

It is an optical disc format developed by Constellation 3D that uses fluorescent, rather than reflective materials to store data. Reflective disc formats (such as CD and DVD) have a practical limitation of about two layers, primarily due to interference, scatter, and inter-layer cross talk. However, the use of fluorescence

allows FMDs to have up to 100 layers. These extra layers allow FMDs to have capacities up to a terabyte, while maintaining the same physical size of traditional optical discs.



Fig 8 : Example of an FMD

3.2.1 Operating Principles

The pits in an FMD are filled with fluorescent material. When coherent light from the laser strikes a pit the material glows, giving off incoherent light of a different wavelength. Since FMDs are clear, this light is able to travel through many layers unimpeded. The clear discs, combined with the ability to filter out laser light (based on wavelength and coherence) yield a much greater signal-to-noise ratio than reflective media. This is what allows FMDs to have many layers. The main limitation on the number of layers in a FMD is the overall thickness of the disc. A 50 GB prototype disc was demonstrated at the COMDEX industry show in November 2000. First generation FMDs were to use 650 nm red lasers, yielding roughly 140 GB per disc. Second and third generation FMDs were to use 405 nm blue lasers, giving capacities of up to a terabyte.

3.3 Tapestry Media

Tapestry Media is a digital optical disc about the size of a DVD with a capacity of 300GB. It will go on sale in 2009, according to its American developer, InPhase Technologies.

Traditional DVDs record data by measuring microscopic ridges on the surface of a spinning disc. Two competing successors to the DVD format — Blu-ray Disc and HD DVD — use the same technique, but exploit shorter wavelengths of light to fit more information onto the surface.

The Tapestry system uses micro holography that is light from a single laser split into two beams: the signal beam and the reference beam. The hologram is formed where these two beams intersect in the recording medium.

The process for encoding data onto the signal beam is accomplished by a device called a spatial light modulator, which translates the electronic data of 0s and 1s into an optical "checkerboard" pattern of light and dark pixels. The data is arranged in an array or "page" of around a million bits.

At the point of intersection of the reference beam and the signal beam, the hologram is recorded in the light sensitive storage medium. A chemical reaction occurs in the medium when the bright elements of the signal beam intersect the reference beam, causing the hologram.

By varying the reference beam angle, wavelength or media position many different holograms can be recorded in the same volume of material. Tapestry media is capable of storing up to 1.6TB with a data transfer rate of 120 MB/s (960 Mbit).

3.4 Teradisc

Mempile, a leader in next generation optical storage technology, announced today that it has proven its TeraDisc technology to be capable of storing up to one Terabyte (TB) of data. The company recently demonstrated this concept to several Japanese CE manufacturers by recording and reading over 100 virtual layers on a single DVD-size optical disc.

The demonstration attendees were amazed to see this breakthrough which showed Mempile's capability of recording at least 500GB of data on what appears to be a simple plastic transparent disc – 300GB more than the announced roadmap of competing blue-laser technologies in the year 2010.

Existing optical media store the data through the use of light-reflective semi-transparent technologies. While increasing in capacity, even the newer blue-laser technologies are nonetheless limited to a very small number of layers. The partial reflection from the multiple layers leads to signal reduction simultaneously raising background noise and coherent interferences.

Mempile's patented non-linear two-photon technology allows for 3D recording of transparent virtual layers on the entire volume of the disc. Mempile's recent demonstration proved that more than 100 layers could be recorded and read – showing storage capabilities of slightly less than 300GB over a thickness of 0.6 mm of active material. By increasing this active material to the thickness of a DVD, 1.2 mm, Mempile will be able to demonstrate the recording and reading of at least 500GB of data. Future optimization will allow the recording of 200 layers and of up to 5GB of data per layer.

Due to the increase in data retention and compliance requirements, there is also a growing need for very reliable, removable and cost-effective storage solutions such as Mempile's in the healthcare, financial, government and enterprise vertical markets. Each of these sectors now require archival storage technologies that can hold a high-capacity of information, are secure, user-friendly and are permanent yet removable and affordable. Mempile's technology is easily integrated into existing hardware manufacturing and software design processes making it a natural fit for these markets.

A Mempile disc contains light sensitive molecules (chromophores) capable of switching between two distinct states upon the application of light. Due to the nonlinear nature of the light-matter interaction, when focusing the applied light inside the material using a lens, only those molecules present near the focal point will interact and switch state. This provides for true three-dimensional accessing of small volumes within the material, allowing the writing of data bits selectively within the bulk of the material. Reading is performed in a similar way, where light that does not result in writing excites the chromophores making them emit light.

3.5 Versatile Multilayer Disc

High Definition Versatile Multilayer Disc's or Versatile Multilayer Disc (VMD or HD VMD) is a high-capacity red laser optical disc technology designed by New Medium Enterprises, Inc. VMD is intended to compete with the blue laser HD DVD and Blu-ray Disc formats and has an initial capacity of 20 GB to 40 GB per disc.

Although initial details are sketchy, it appears that the format uses 5 GB per layer, similar to standard DVDs. The larger formats come from adding more layers. Whereas DVDs hold up to 2 layers per side, standard VMD's can use 4 layers, for 20 GB of storage. There are also reports of 8- and 10-layered versions which can hold 40 and 50 GB, respectively.

3.6 Stacked Volumetric Optical Disc

The Stacked Volumetric Optical Disk (or SVOD) is an optical disk format developed by Hitachi/Maxell, which uses an array of wafer-thin optical disks to allow data storage of around 1TB. Each "wafer" (a thin polycarbonate disk) holds around 9.4GB of information, and the wafers are stacked in layers of 100 or so, giving overall data storage increase of 100x or more. SVOD will likely be a candidate, along with HVDs, to be the next-generation optical disk standard.

IV.MERITS AND DEMERITS

MERITS

- A high definition movie requires about 13 GB of storage with compression so it can fit in a single disc, and there is enough space to add some extra contents such as out-takes, additional scenes, etc.
- Enables dramatic improvements in piracy protection, by taking.
- Highest optical capacity.
- Lowest cost per gigabyte.
- Highest data bit density of any storage device.
- Lowest power requirements per gigabyte.
- Long storage life.
- Have highest data transfer potential.

DEMERITS

- Reusable.
- The write-once read-many (WORM) characteristic of some optical media makes it excellent for archiving, but it also prevents you from being able to use that media again.
- Writing time. The server uses software compression to write compressed data to your optical media.
- This process takes considerable processing unit resources and may increase the time needed to write and restore that data.

V.CONCLUSION

Computers have become very important in our life because they provide us access to storage of large amount of information. Conventional technologies have very limited amount of storage and their storage capacity cannot be increased any further. Since storage needs are increasing at a faster rate and conventional technologies are not able to keep the pace with demand for greater and faster storage requirements. So a new type of data storage technique with increased capabilities is required. These needs can be fulfilled by 3D Data Storage Devices. Further they are cost effective in the sense that they have the lowest cost per byte. They will also have faster data transfer rates compared to current technologies. 3D Data storage devices will have wide range of applications in fields such as satellite data storage, space researches, digital libraries, defence where large amount of data storage capacity is required. Hence we can undoubtedly say that 3D Data storage provides an effective solution for tomorrow's storage needs.

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