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3-D OPTICAL STORAGE WITH FLUORESCENT PHOTOSENSITIVE GLASSES

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In this paper, various aspects of 3-D optical storage have been reviewed. Novel fluorescent photosensitive glasses possess physico-chemical properties that warrant serious consideration in their application to the design of an ideal optical storage media. The persistent extinction of fluorescence emission of Eu3+ in glasses activated with europium and cerium, and the device based on this phenomenon are discussed in details.

Key words: Optical storage; Rare earths; Fluorescent photosensitive glass.

1. INTRODUCTION

As silicon-based memory chips approach their fundamental limitations of storage capacity, marginal improvements become progressively more expensive and eventually become unfeasible. The proliferation of online telecommunications, corporate networking and the usage of multi-media will continually drive consumer demand for greater data storage capacity with ultrafast data access. Most information is stored in four media: paper, film, optical (multi-dimensional media) and magnetic. Using data for the worldwide production of each storage medium, one can estimate that there is clearly a need for continued research and development in the storage arena, especially new storage materials, to satisfy the proliferating demand [1, 2]. Although there are serious limitations to the continued scaling of magnetic recording devices, time is running out to explore alternative storage media. It is likely that the rate of improvement in areal density (and hence cost per bit) will level off during the next ten years. Subsequently, 3-D technologies, as Hyper CD-ROM and holography offer immense potential as alternatives (fig.1).

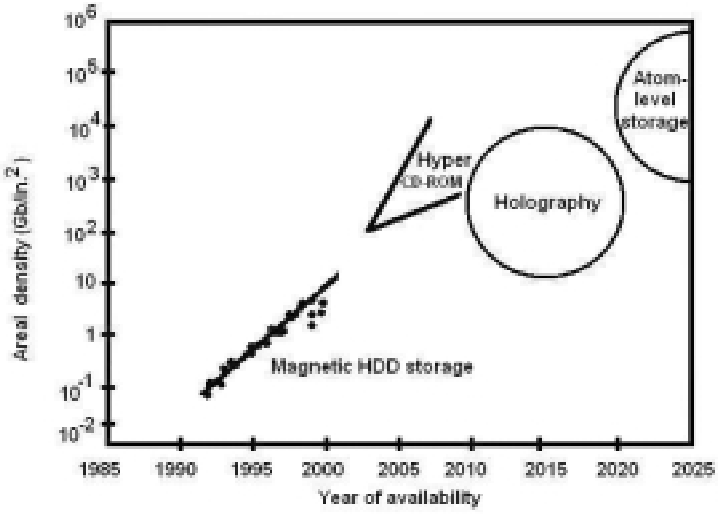

Fig.1- Optical storage technology roadmap

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2. ATTRIBUTES OF AN OPTICAL STORAGE MEDIUM

Two general attributes describe characteristics of an ideal optical storage device. Optical media should be physically capable of manifesting at least two steady states. If there are two states, this corresponds to one bit of digital information. The thermal stability of the optical medium is very important. For any given optical medium, a fundamental requirement is the availability of methods for writing and reading information. These methods are specific for the optical medium.

3. FLUORESCENT PHOTOSENSITIVE GLASS

Glass, as a material, has advantageous characteristics for many applications including: isotropy, considerable flexibility as to the shape and size of the finished glass objects; amenability to uniform doping at high concentrations; flexibility in achieving desired physical properties by virtue of the good solubility of the various glass composition constituents; and relatively low production costs. Generally, glass is obtained by cooling a melt in such a way that crystallization is suppressed. Glass also can be produced by the known sol-gel method. Most glasses are oxide glasses. The structure of oxide glasses consists of a continuous network of glass-forming oxides in which long range order is missing. Glass-forming oxides such as SiO_2, P_2O_5, GeO_2, Al_2O_3, B_2O_3, and Ga_2O_3 have the strongest bonding strength among glass-forming oxides. Such glass-forming oxides are known as glass network formers. Oxides with weak bonding strength, such as oxides of alkali, alkaline earths, and rare earths cannot form a glass network and are known as modifiers. Some glasses are fluorescent. Fluorescent glasses, when exposed to ultraviolet light, convert that ultraviolet light into visible light. The fluorescence of rare earth metal ions in glass was first observed in 1880s [3]. Fluorescent glasses are used in lasers, and the discovery of the lasing phenomenon gave a strong impetus to the development of rare earth activated fluorescent glasses. Various fluorescent glasses and their industrial applications are disclosed in [4-7]. Some glasses are photosensitive. When photosensitive glasses are irradiated with short wave radiation such as ultraviolet radiation or X-rays, the optical properties of the glass in the irradiated areas are modified. Photosensitive glasses generally contain photosensitive elements such as copper (Cu), silver (Ag), and gold (Au). The photosensitive elements in the glass, upon exposure to the incident radiation, absorb that radiation. Upon heat treatment of the glass (typically at or above the annealing point of the glass), metal particles are precipitated thus changing the colour of the glass in the irradiated areas. Upon cooling of the glass, the coloured areas remain coloured unless the glass is subsequently reheated to a high temperature. Photosensitivity was initially observed by Dalton [8,9]. Development of photosensitive glasses is described in [10]. The novel fluorescent photosensitive glass [11] combines the characteristics of two known glass types – fluorescent glasses and photosensitive glasses. In the inventive glass, the degree of fluorescence can be manipulated via controlled irradiation of the glass. When the glass is irradiated in a specific area, the fluorescence in that area can be inhibited by the photosensitive agents in the glass (fig.2).

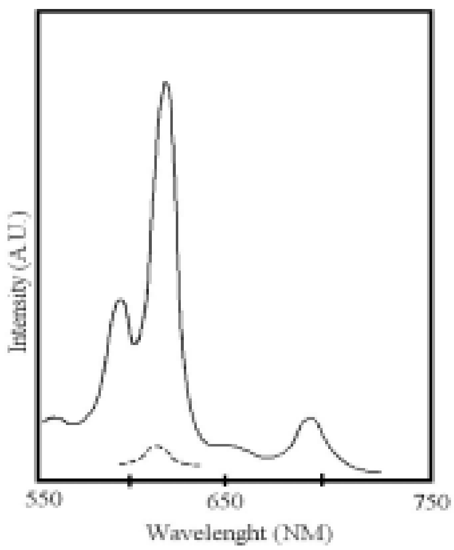

Fig. 2 – Emission spectra of fluorescent photosensitive glass activated with Eu and Ce before (solid line) and after (dashed line) laser irradiation.

The unirradiated areas retain their fluorescence. In accordance with [11], glasses are prepared which also include two or more rare earths. One or more of the rare earths imparts fluorescent properties to the glass while the other of the rare earths included in the glass impart photosensitive properties to the glass. Suitable rare earths for imparting fluorescent properties to the glass include ytterbium (Yb), samarium (Sm), europium (Eu) and combinations thereof. Suitable rare earths for imparting photosensitive properties to the glass include erbium (Er), thulium (Tm), praseodymium (Pr), ytterbium (Yb), holmium (Ho), samarium (Sm), cerium (Ce), dysprosium (Dy), terbium (Tb), neodymium (Nd) and combinations thereof. In preferred embodiments of the invention [11], silicate and phosphate glasses are prepared which also include two or more rare earths. A phosphate glass activated with Eu and Ce was studied in [12 - 14]. The complete extinction of the Eu^{3+} -ion emission was obtained as an effect of laser irradiation of the glass sample. The mechanism for writing/reading was explained by the following processes:

$$Ce^{3+} \rightarrow Ce^{3++} + e^-$$

$$Eu^{3+} + e^- \rightarrow [Eu^{3+}]^-$$

Eu^{3+} is a fluorescent ion while $[Eu^{3+}]^-$ is a non-fluorescent ion. When a specific area of the fluorescent photosensitive glass is irradiated, fluorescence in that specific area diminishes. Areas which have not been irradiated continue to exhibit a strong fluorescence.

4. EXISTING OPTICAL STORAGE TECHNOLOGIES

Optical Disk Drives (ODD)

ODD is part of Removable Media Storage Devices, Optical RMSD. Optical RMSD formats use laser light source to read and/or write digital data to a disk. Compact Disk (CD) and Digital Versatile Disk (DVD, originally referred to as digital video disk) are the two major optical formats. CDs and DVDs have similar compositions consisting of a label, a protective layer, a reflective layer (aluminum, silver, or gold), a digital-data layer molded in polycarbonate, and a thick polycarbonate bottom layer. There are two formats: CD, the old technology and DVD, the newer, improved higher data density formats.

CD formats include:

- CD-ROM, Compact Disk-Read Only Memory
- CD-R, Compact Disk-Recordable
- CD-RW, Compact Disk-ReWriteable

CD-ROM

The CD-ROM standard was established in 1984 when the CD-audio standard was modified to give PCs access to the technology. CD-ROM drives and disks quickly evolved into a low-cost digital storage option because of the established CD-audio industry. Data bits are permanently stored on a CD in the form of physically molded pits in the surface of a plastic data layer that is coated with reflective aluminum. CDs are extremely durable because the optical pickup (laser light source) never touches the disk. Because data is read through the disk, most scratches and dust on the disk surface are out of focus, so they do not interfere with the reading process. Storage capacity is 650MB per disk. CD-ROM is the lowest cost drive and media and has the widest distribution.

CD-R

CD-R enables the user to record digital data once and use it for either archiving or distribution. The standard is well supported by most CD-ROMs. CD-Rs use disks with a photosensitive dye layer that can be burned with a laser to simulate the molded pits of a conventional CD. The dye layer is relatively transparent until it is burned with a laser to make it darker and less reflective. CD-R disks also use a gold or silver reflective layer in place of the aluminum layer used in CDs. When CD-R disk is read, the lands reflect laser light off the gold or silver layer through the more transparent areas of the dye. The less reflective areas, produced from recording data on the dye, read as pits. Storage capacity: 650MB.

CD-RW

CD-RW enables the user to repeatedly record and read data on disk media. Compatibility of media is limited to drives that support the MultiRead standard. CD-RW disks use an alloy layer composed of silver, indium, antimony, and tellurium that changes state at different temperatures. This material forms a crystalline structure when heated above 200 degC and cooled, but also forms an amorphous or noncrystalline structure when heated higher to (500 to 700 degC) and cooled. The alloy can be changed between the two states using two different laser settings.

The crystalline state for this material reflects more light than the noncrystalline form, so it simulates the lands of a regular CD. Data bits are encoded by changing small target areas to noncrystalline form. This writing process can be repeated approximately 1,000 times per disk. A third, lower-power laser setting, (like the laser setting used in CD-ROM drives), is used to read the lands and pits of the CD-RW disk. Storage capacity: 650MB

DVD formats include:
DVD-ROM, Digital Versatile Disk – Read Only Memory
DVD-R, Digital Versatile Disk – Recordable
DVD-RAM
DVD-RW, Digital Versatile Disk – Rewritable

DVD-ROM

This is “Read only” drive. DVD-ROM disks achieve four times the storage capacity of CDs by using a reduced laser wavelength to read the smaller-sized pits. This reduced laser wavelength also reduces the distance between recording tracks. DVD disks can also store two layers of data because they can have a translucent reflective layer with data on top of a second opaque reflective layer containing more data. The drive changes the focus of the laser to switch between the two layers. DVD drives can also store data on both sides of the disk; optionally, a two-sided structure can be created by bonding two thinner substrates together, providing the potential to double a DVD storage capacity. Storage capacity is 4.7GB for single data-layer disk (DVD-5). Single-sided, double data-layer disks increase the capacity to 8.5GB (DVD-9). Double-sided, single data-layer disks offer 9.4GB (DVD-10), and double-sided, double data-layer disks provide 17GB of storage capacity (DVD-18).

DVD-R

The drive provides write-once capability and unlimited reads. The disks employ a photosensitive dye technology similar to CD-R media. Storage capacity: 4.7GB.

DVD-RAM

This is a rewritable device just as a RAM memory. It can support up to 100,000 rewrites. Current disk capacity is 2.6GB per side. Higher density of the pit size and track achieve 4.7GB per side. The data is recorded in the grooves formed on the disk and on the lands between the grooves. The data format is similar with the HDD format.

DVD-RW

The DVD-RW drive format is similar to the DVD-R format, but offers rewritability using a phase-change recording layer that is comparable to the CD-RW format.

Blue Laser

Blue laser technology offers the potential for substantial data density improvements in optical storage technology during the next years. The wavelength of infrared (780nm) and red (650nm) lasers in use today limits reducing the size of data pits. The blue laser has a shorter wavelength (405nm) that could read and write smaller data pits and provide the means to produce a next-generation 27GB per side DVD disc, which is suitable for high-definition television (HDTV). In February 2002, nine leading companies announced that they jointly established the basic specifications for the new optical disc video recording format, called “Blue-ray Disc”.

4. HYPER CD-ROM TECHNOLOGY

All present storage technologies store data within a thin layer near the surface of the media. This fact represents a major limitation for storage growth. The Hyper CD-ROM technology realizes a three-dimensional multilayer optical memory, based on a proprietary glass compound which is a fluorescent photosensitive glass. The data are stored on virtual multiple levels of the storage medium. The focal point positioning determines the layer to be recorded and read. There are two multilayer concepts: reflective and fluorescent. Single- layer reflective concept is used by the CD and DVD5 devices. The probing laser emits light and a light sensor reads the reflected beam from the medium. The concept of multilayer optical discs has been proposed by Philips and IBM, and has been demonstrated up to several layers. The DVD9 and DVD18 is an implementation of this concept with two layers. Beyond two layers, the coherent nature of the probing laser beam causes interference, scatter and intra-layer crosstalk which results in a signal degraded to unacceptable levels. The fluorescent multilayer approach solves the signal degradation by using an active medium– fluorescent photosensitive glass.Because the emitted light has a different wavelength, stray light can be filtered. When the laser beam hits the desired recording level, fluorescent light is emitted. This light has a different wavelength from the incident laser light. The emitted light is not affected by data pits and transverses adjacent layers undisturbed. The reading signal is filtered so only information-bearing fluorescent light is detected, thus reducing the effect of stray light interference.

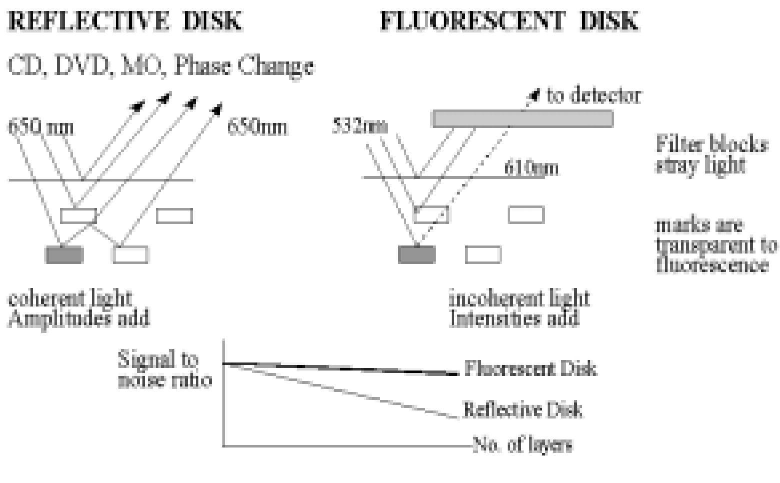

Fig.3 – Reflective and fluorescent multilayer discs.

Theoretical studies, confirmed by experimental results, have shown that in conventional reflection systems the signal quality degrades rapidly with the number of layers. In fluorescent read systems, the signal quality degrades much more slowly with each additional layer (fig.3). A complete read/write system control blocks is presented in fig. 4. This is a Write Once Read Many (WORM) technology similar with writeable CD/DVDs. The laser in the system has a dual function. During writing/recording the laser must be capable of delivering a relative high pulsed power necessary to change the fluorescence in the medium at the point of focus. The second function, the read, requires a relative low power laser similar with the ones presently used in commercial CD/DVDs. The purpose of the confocal system (illuminator pinhole, detector pinhole, lens) is to focus the incident light generated by the laser to the desired spot with improved resolution. The rejection filter is used in order to separate the fluorescence radiation from the laser light.

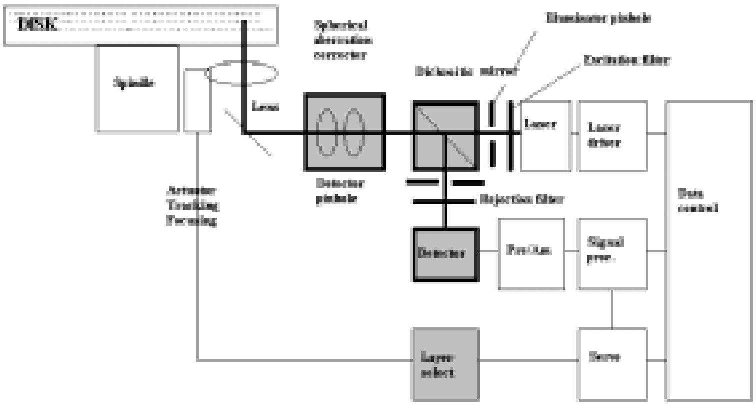

Fig.4 – 3-D optical memory drive.

5. CONCLUSIONS

With fluorescent photosensitive glasses, multiple planes can be developed which address the density issue and because of this, terabyte capacities can be offered on a single multilayer platter. In addition, high data rates and low power consumption are features that make Hyper CD-ROM technology very interesting for future mobile computing applications in notebooks, cellular phones and handheld devices.

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