WHITE PAPER

1. INTRODUCTION

The growth in demand for digital storage capacity exceeds 60% per annum. Facilities such as Storage Area Networks, data warehouses, supercomputers and e-commerce related data mining, require ever-greater capacity in order to handle the volume of data to be processed. In addition, with the advent of high bandwidth Internet and data intensive applications such as High Definition TV (HDTV) and Video & Music-On-Demand, even smaller devices such as Personal VCRs, PDAs, mobile phones, etc. will in the next couple of years demand multi-gigabyte and terabyte capacities. Not less important, is the growing demand for faster data access and reading. For instance High Definition TV and Video & Music-On-Demand applications require over terabit/sec reading speed. Such and higher speed in conjunction with huge capacity can be implemented only by means of parallel access to any part of information on the carrier. In the year 2000, one (1) ExaByte (10^18 Bytes) of information will be stored, growing to more than two (2) ExaBytes by the year 2002. Approximately 10 % of the information will be stored on magnetic disk drives (HDD), with the remainder on tapes, optical discs and paper. This increasing capacity demand has thus far, been met through steady increases in the areal density of the magnetic and optical recording media. While the limits of magnetic recording are still being debated - recently 35 Gbit/sqi has been demonstrated - the limits of conventional optical storage are well understood. Current optical storage technology is working close to the diffraction limits (5 Gbit/sqi). Future increases in density are possible by taking advantage of shorter wavelength lasers, higher lens numerical aperture (NA), or by employing Near Field techniques. Finally, optical data storage capacities have been increased by creating double sided media. Another approach to increasing the effective storage capacity is quite unique for optical memory technologies. This is three-dimensional storage. True three-dimensional optical storage opens up another dimension in which to increase the capacity of a given volume of media, with the objective of achieving a cubic storage element having the dimensions of the writing/reading laser wavelength. Even with current wavelengths of 650um, this should suffice to store up to a Terabit per cubic centimeter.

2. DIGITAL DATA STORAGE

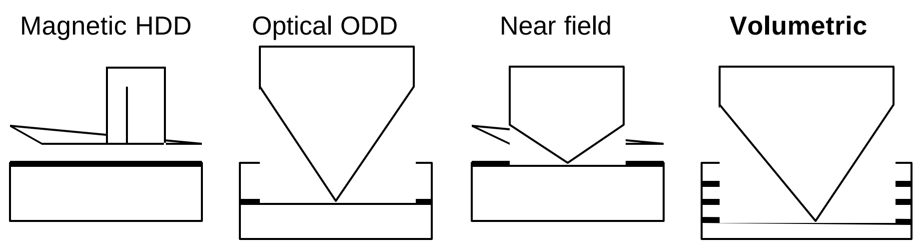
2.1 MASS STORAGE PRODUCTS

Data storage devices currently come in a variety of different capacities, access time, data transfer rate and cost per Gigabyte. The best overall performance figures are currently achieved using hard disk drives (HDD), which can be integrated into RAID systems (**R**eliable **A**rrays of

Inexpensive **D**rives) at costs of $10 per GByte (1999). Optical disc drives (ODD) and tapes can be configured in the form of jukeboxes and tape libraries, with cost of a few dollars per GByte for the removable media. However, the complex mechanical library mechanism serves to limit data access time to several seconds and effects the reliability adversely. Most information is still stored in non-electronic form, with very slow access and excessive costs (e.g., text on paper, at a cost of $ 10,000 / GByte)

2.2 TECHNOLOGIES

Figure 1, shows the basic components of different recording technologies:



Flying height	< 0.1 um	1 mm	<0.1 um	>1 mm
Density	>50 bit/um2	5 bit/um2	20 bit/um2	>100 bit/um2

Figure 1

Magnetic disk heads fly on a slider at a distance of approximately 0.1um above the surface of the storage medium. During the writing process small magnetic domains are written, the magnetic fields of these domains are detected during the read process. The information can be overwritten indefinitely. The areal density of magnetic recording has grown approximately 60% per year during the last decade. Devices with 10 Gbit/sqi are currently in production, 30Gbit/sqi have been demonstrated. However there appears to be a limit - "the super paramagnetic limit" - where the magnetic domains become unstable, thus limiting further growth in the areal density achievable.

In optical disc drives (ODD) such as CD, DVD and MO, light from a semiconductor laser is focused onto the storage layer to perform writing/reading. The storage layer is protected through the disc substrate or a thick overcoat, making this technology well suited for removable media. The achievable storage density is determined by the size of the recording spot, which in turn is determined by the wavelength of the laser light, resulting (with current 650um red lasers) in a maximum areal density of 5 bits/um2. Advances in laser technology leading to utilization of 480um blue lasers will increase this density fourfold.

Advanced optical techniques using Magneto Optic MSR, MAMMOS, HYBRID, Near Field and Super RENS technologies are expected to achieve areal densities of approximately 50 Gbit/sqi over the next ten years, making capacities of up to 100 GByte per disk possible on CD/DVD sized 120mm diameter, 1.2mm thick disks. These systems will need to use blue lasers, complex structured media and extremely sophisticated optics and mechanics. Areal density of various techniques is shown in the following Figure 2

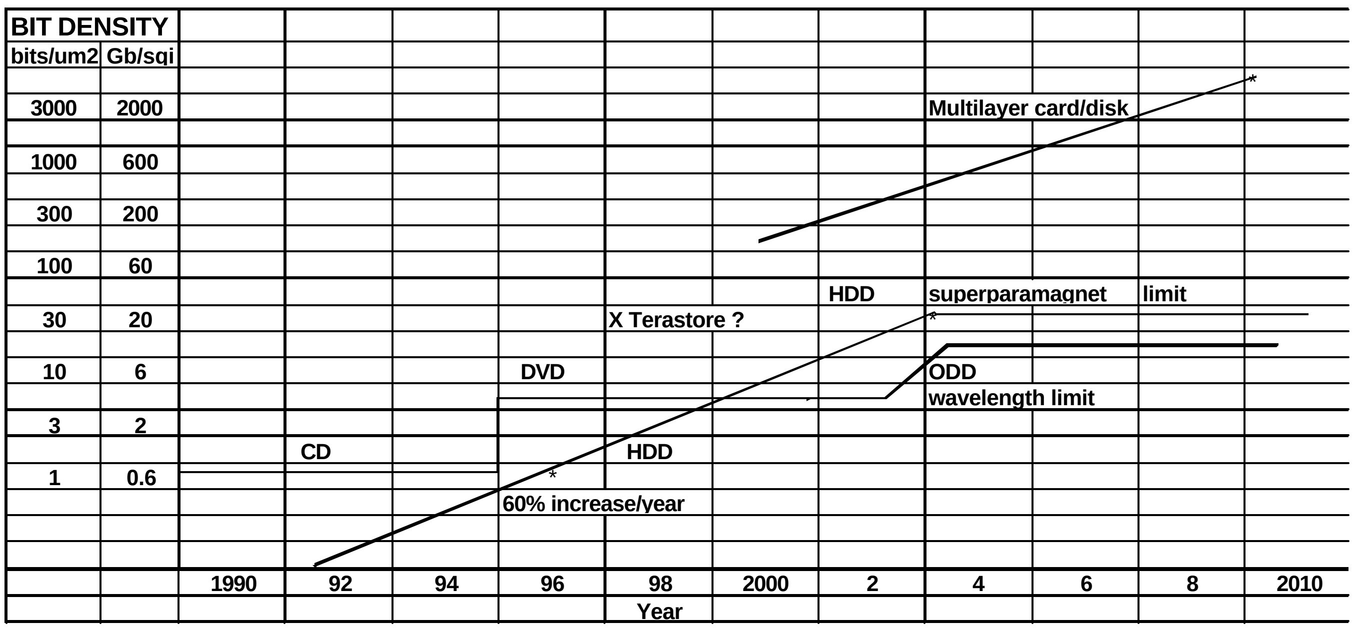


Figure 2

2.3 VOLUMETRIC RECORDING

As can be seen from the above, the storage density of media using current HDD and ODD technologies is limited due to the need to store data within a thin layer near the surface of the media

2.3.1 HOLOGRAPHIC STORAGE

With the advent of lasers in the 1960s, storage in 3D has been proposed by using holographic techniques. However, attempts at commercialization so far failed primarily due to lack of a suitable storage materials for media manufacturing

2.3.2 MULTI-LAYER STORAGE

In a multi-layer card or disc, several layers are integrated into the media, separated from each other by distances as small as 15 micro meters. A recording laser beam is focused onto one layer at a time, writing and reading the layers separately

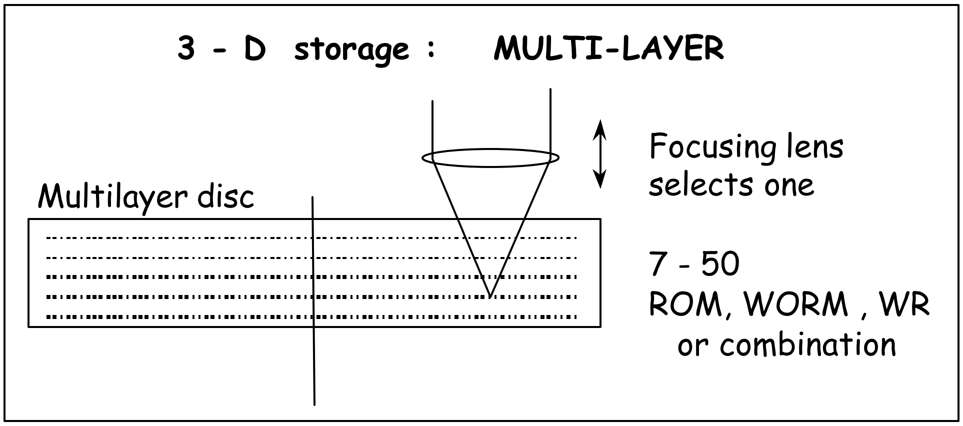


Figure 3

REFLECTIVE MULTI-LAYER

The concept of multilayer optical discs has been proposed by Philips and IBM, and has been demonstrated up to several layers. The DVD is an implementation of this concept with two layers. However, for many layers the coherent nature of the probing laser beam causes interference, scatter and intra-layer cross talk - the combination of which results in a signal that is degraded to unacceptable levels. Following its research into the feasibility of producing a 6-layer optical disc, IBM announced that it would not proceed to production of such devices due to the many difficulties involved in its implementation and thus commercialization

FLUORESCENT MULTILAYER

The concept of multi-layer, fluorescent cards/discs (FMD/C) is a unique breakthrough, solving the problems of signal degradation. Here, the storage layer is coated with a fluorescent material. When the laser beam hits the layer, fluorescent light is emitted. This emitted light has a different wavelength from the incident laser light - slightly shifted towards the red end of the light spectrum - and is incoherent in nature, in contrast to the reflected light in current optical devices. The emitted light is not affected by data or other marks, and transverses adjacent layers undisturbed. In the read out system of the drive the light is filtered, so that only the information-bearing fluorescent light is detected, thus reducing the effect of stray light and interference.
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 out

systems, on the other hand, the signal quality degrades much more slowly with each additional layer (see below). Research has shown that media containing up to a hundred layers are currently feasible, thereby increasing the potential capacity of a single card or disk to hundreds of Gigabytes. Use of blue lasers would increase the capacities to over 1 Terabyte

2.4 FMD/C ADVANTAGES

The main advantages of multilayer fluorescent read out are:

1. The multi-layer system is optically transparent and homogeneous
2. Low absorption in each layer
3. No absorption for the emitted signal fluorescent light
4. Lower than CD/DVD sensitivity to imperfections in media and drives. The fluorescent technique does not depend on interference effects and requires less stringent manufacturing tolerances for media and drives
5. The emitted fluorescent light from any given layer is non-coherent, eliminating the problem of parasite interference
6. The limited lateral spatial resolution for this system is twice that for coherent light based systems (e.g. current CD/DVD reflective systems). In the case of FMD/C, this two-fold improvement over three (3) dimensions, results in an eight-fold improvement in achievable data density
7. FMD technology is compatible with current CD and DVD formats, having the capacity to handle the same data rates over each of its layers

The above qualities make FMC unique in its technological capability to facilitate production of a multilayer optical card— ClearCard™, in any form factor including postage stamp sized SmartMedia, credit card sized ClearCard™, or otherwise. The capacity and speed of reading from these cards can be enormous. For instance, with the level of existing technology ClearCard™ of 16 cm^2 of area with 50 layers can furnish consumers with 1 terabyte capacity and, through parallel access to all its layers, allow over 1 gigabit/sec speed of reading. Another major advantage, for both cards and discs using the technology, is the ability to read data on every layer of the media in parallel, thereby allowing the potential of much grater data transfer rates compared with single layer media. This can be combined with parallel reading from multiple sectors of the same layer to increase data speeds still further, producing 3-dimensional data transfer

3. STATUS OF DEVELOPMENT

A principal obstacle to the development of small portable appliances with large data storage capacity is the lack of inexpensive small size memory carriers that can store Gigabytes of information in a media allowing fast data transfer rates. Constellation 3D's Fluorescent Multilayer technology enables the production, in a wide variety of form factors, of storage media satisfying these criteria

3.1 MEDIA

The FMD/C media consist of several plastic (polycarbonate) substrates, bonded together.
The substrates contain surface structures ("pits"), that are filled with a proprietary fluorescent storage material. A major design goal in the development of CD/DVD replacements using this technology, was to allow a simple and cost effective upgrade for existing manufacturers of optical devices. FMD technology enables the use, with only relatively minor changes (such as impregnation with fluorescent materials), of existing components and processes from high volume products such as CDs/DVDs, and avoids the need for new infrastructure for media and drive production. The number of process steps per layer is actually reduced, because a reflective metallic layer is not required. For the individual layer of a multilayer disc, metal stampers containing the digital content are produced in a mastering process that is similar to CD or DVD processes. For FMD/C, two replication processes have been developed:

Hot-Embossing: In this process, thin sheets of polycarbonate are embossed on both sides with the metal stampers at elevated temperatures. The embossed pits are then filled with the fluorescent dye. After the dye is cured, the individual sheets are bonded together under pressure, resulting in a storage media having multiple layers. Figure 4, shows a 7-layer media

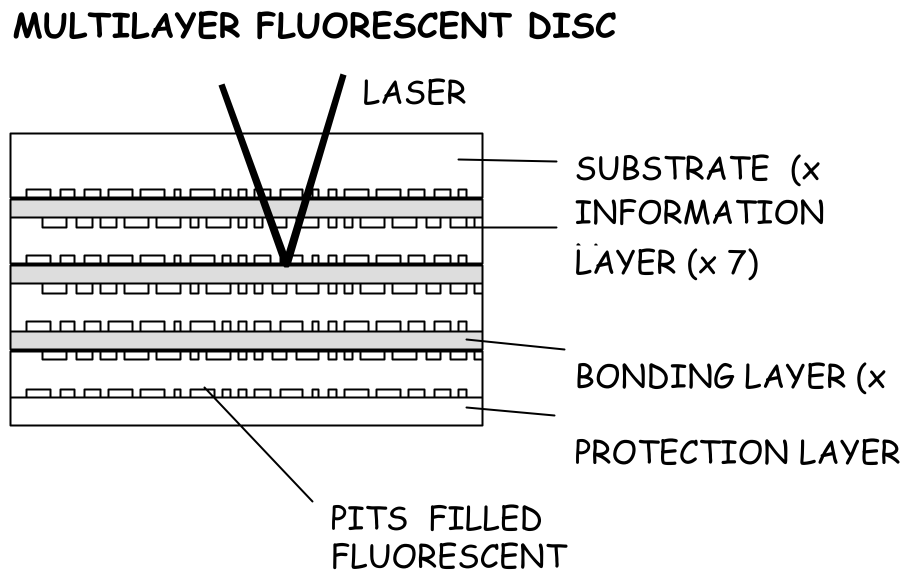


Figure 4

Photo-Polymerization (2P) Process: In this method, layers are replicated one after the other by forming of “thin replicas”. This technology has been demonstrated for up to ten layers

3.1.1 Fluorescent Material

Perhaps the most critical component of the storage media is the fluorescent material that converts the incident (incoherent) laser light into incoherent fluorescent light. The materials and associated drives for read-only cards & discs (ROM) are currently the most mature FM technology. Recordable materials and associated drives have also been developed and demonstrated, and improvement of this FM technology continues. FMD/C write/read technology based on proprietary photochromic substances has been demonstrated in Constellation 3D's laboratories during write/ read/erase/re-write experiments

3.1.2 FMD/C ROM (Read Only) Devices

There are several requirements for the fluorescent materials:

1.The fluorescent ROM material has to be compatible with the substrate material

2.The absorption wavelength should be the same wavelength as commercially available, low cost semiconductor lasers used in CD players

3.The emitted fluorescent light should be wavelength-shifted by at least 50nm, to allow easy separation of the incident and signal light

4.The material should have high conversion efficiency

5.The material should have the refraction index close to the one of the polycarbonate

6.The material should stay stable over a reasonable time

7. Fast response - 1nsec

Light-sensitive material

The photo-polymer composition (PPC) - is a mixture of monomers and oligomers with photo-initiator, which initiates polymerization process under radiation in the certain spectrum range. PPC serves as substrate for the data carrier, oxazine-1, methylene blue, methylene violet and other red dyes serve as the photo-initiator

Pit filling process

The working surface of a polycarbonate disc is a plane with pits - cavities 0,5um in size, located in a certain order. Such micro relief can be filled with liquid monomeric or oligomeric substances that turn into hard polymer substances when subjected to UV light. The substances fill the pits and overflow to form a thicker layer on the media surface. The ratio of layer thickness in pit to its thickness on the surface makes the contrast. One of the main tasks of confronting the scientists in developing the process of filling the pits, creating the overflow and choosing the material, was to find the combination of these that provided the largest such contrast.

3.1.3 FMD/C Recordable (Write Once Read Many) Devices

In addition to the requirements for ROM media, RECORDABLE media require the following:

- A writing process where the writing light is able to turn on or off the fluorescence
- A threshold level above which the fluorescent material is changed by the power level of the write, and below which the material is unchanged during any subsequent read-out

Currently 2 techniques have been developed:

Thermal Bleaching

In this technique the material is initially fluorescent. The incident write light heats the material, destroying the fluorescence. The write parameters are similar to CD/R recording and the standard optical writing 15mW laser is well suited for providing CD-R equivalent data writing rates. Materials suitable for applying this technique for use with red, green and blue laser wavelengths have been developed

Photochemical Reaction

Materials of this class are initially not fluorescent, and the write light initiates photo-chemical reactions, thereby creating fluorescence. The highly non-linear process associated with this reaction causes an effective threshold. Because no heating is involved, the required write power is low, allowing even light emitting diodes (LED arrays) to be used. With LED arrays, pages of information can be written simultaneously, thereby additionally enabling card applications. Current materials are sensitive to green and violet wavelengths. Constellation 3D is currently applying for further patents in respect of its FMD/C RECORDABLE devices, and further details on this technology will be published thereafter

3.1.4 RESULTS

10 layer discs with CD type density have been demonstrated (650 Mbyte per layer).

The above mentioned requirements have been fulfilled:

- 650 nm laser, 680 nm peak of the fluorescent light
- Stable media, no degradation during read-out
- The conversion efficiency is more than 90%
- The time response is approximately one nanosecond
- The saturation level is with 1MW/cm2, above the read power intensity

Note: In a disc player device demonstrated in Israel on 4 October 1999, digital audio was played using different content from each of the layers. 10 layer and 20 layer ClearCard^{TM} was demonstrated as well

3.2 FMC "CLEARCARD" READER

Figure 5, shows the device for retrieving data from Fluorescent Multilayer Card (FMC)

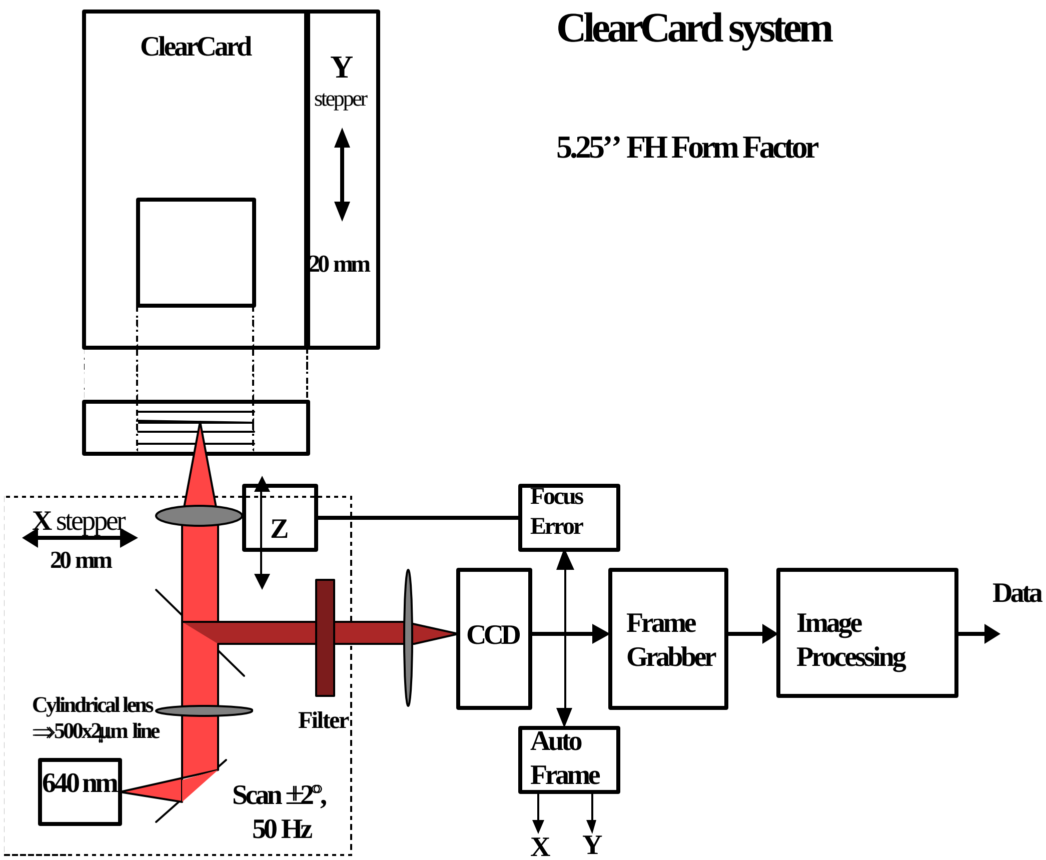


Figure 5

The block diagram above shows the device for reading data from a Fluorescent Multi-Layer Card (FMC)— "ClearCard"(TM). A semiconductor laser produces a beam, which is then focused on a selected layer of the card. A cylindrical lens forms a 500x2um line, which by means of a scanning mirror scans across a page area of the card. The induced fluorescent light is imaged to a CCD array. A “frame grabber” receives data from the CCD. In the subsequent image processing step the image is aligned, distortions are corrected, the image is "thresholded" and digital data is generated. See below in Fig. 6 magnified fragment of a page during the decoding process

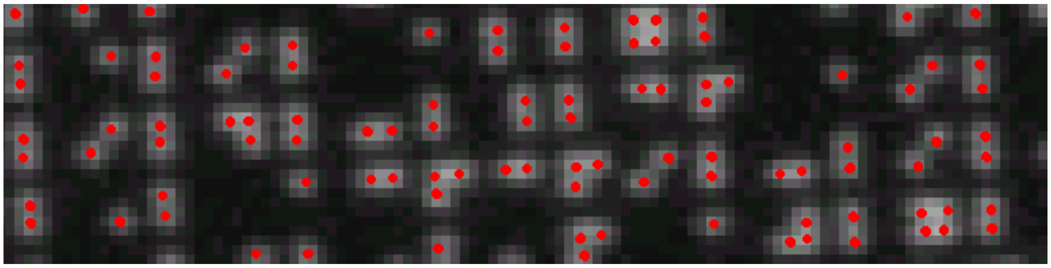


Figure 6

3.3 FMD DISC DRIVE

A schematic diagram of a FMD drive is shown in Figure 7

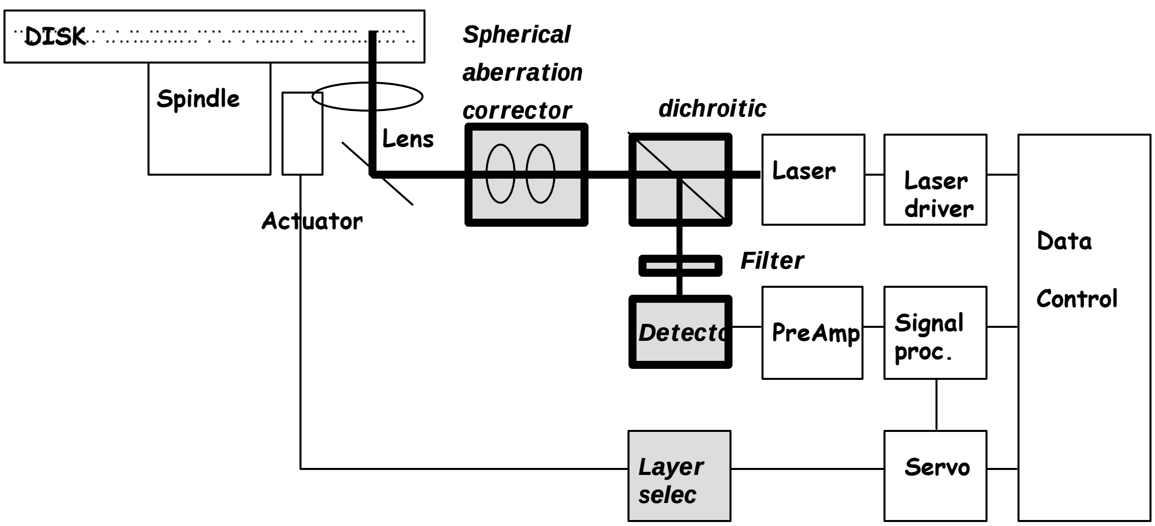


Figure 7

The drives have most components in common with CD/DVD systems: Laser, beam-forming optics, spindle, tracking / focusing actuators, control electronics, data channel, data interface. The only additional components are filters to separate the fluorescent light from laser light, and an optical element to correct for different optical path length in the storage medium, depending on the selected layer. Modification in the electronics include detector circuit with higher sensitivity and the addition of servo electronics to address different layers within the multi-layer disc

50GB Disc Project

PRINCIPLE SCHEME OF DISC AND READING SYSTEM

The principle scheme of 50GB disc is shown in Figure 8

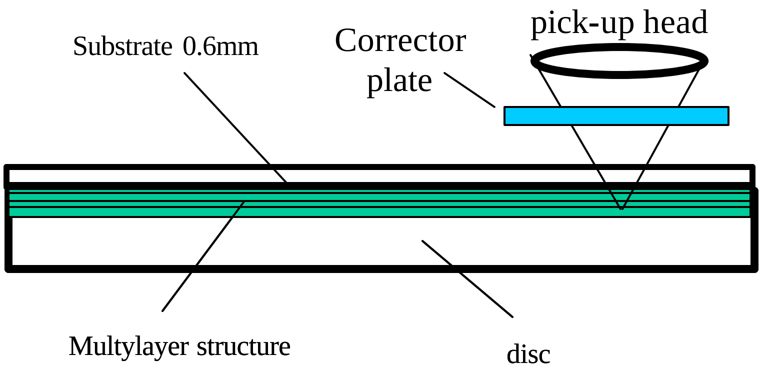


Figure 8

DISC

- Disc diameter - 130±0.3
- Substrate width from objective side – 0.6 um
- Number of layers – 12
- Distance between layers – 25 ±5 um
- Total width of information area – 275 um
- Format – modified DVD
- Distance between tracks– 0.8 um
- Channel bit length – 5/4 of that of DVD
- Pit width – 0.5 um
- Pit depth – 0.5 um
- Information capacity - 50.8GB
- Amount of data reads is 10 x 7

READING SYSTEM

- Laser– single mode diode pumped CW with stabilization
- Laser power– 10 mW
- Wavelength – 532 nm
- Aspheric objective with NA=0.5

- Objective lens is designed for 810-um thickness of substrate
- Lens and compensator have wideband antireflection coatings for 500-700 nm

PRINCIPLE DIAGRAM OF READING HEAD

Principle diagram of the head is shown in Figure 9

- Single lens objective with NA = 0.5
- Parallel beam
- Spatial filtration by means of matching of pit image and photo-detector size

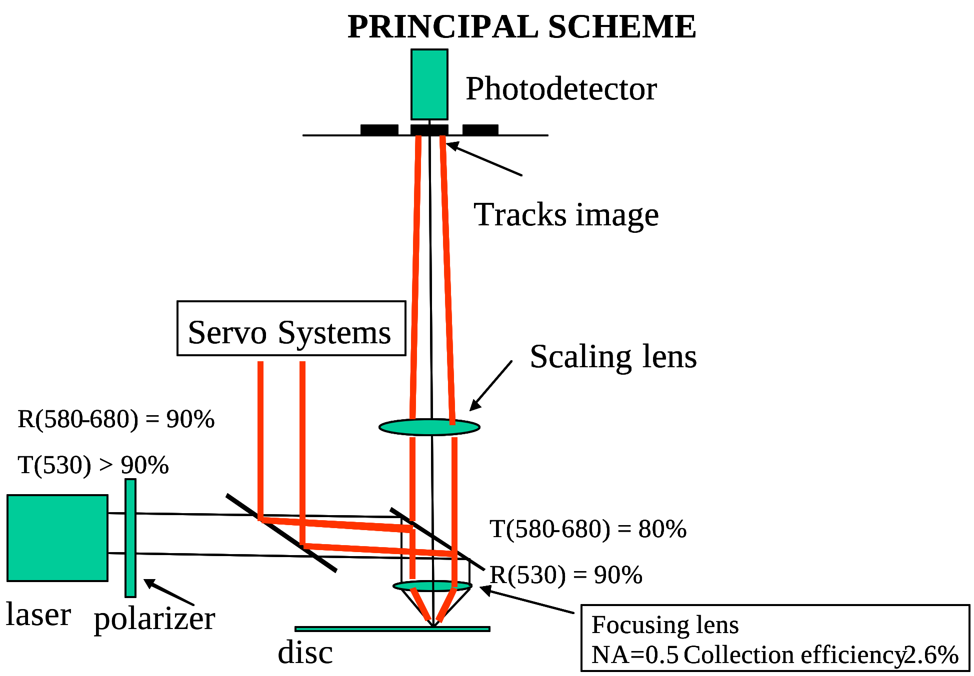


Figure 9

GEOMETRY, DISPOSITION AND ILLUMINATING OF PITS ON LAYER SURFACE

- Scaling of linear dimensions along track is carried out
- Pit depth is equal to 0.5 um independently of its length
- Distance between tracks is extended

INTER-TRACK CROSS TALK

The part of information layer image on detector surface is shown in Figure 10

- Spatial filtration is provided by matching of pits image and photo-detector sizes
- Magnification of the system – 20.
- Detector surface area serves as aperture
- Photodetector size is 20μm$\times$20μm

- Detector collection coefficient is 90% for useful fluorescent signal
- Signal to noise (from neighbor tracks) ratio is 190

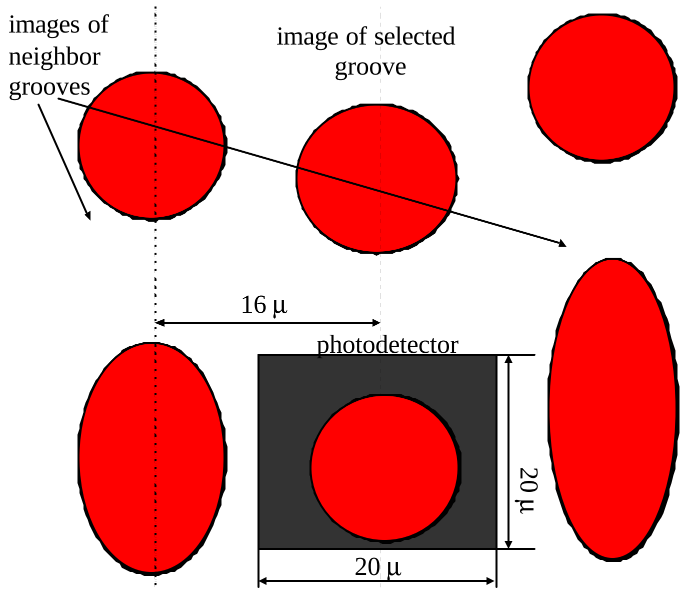


Fig. 10

INTERLAYER CROSS-TALKS

HF component of interlayer cross-talk is negligibly small. Even integral photo-detector illumination by all neighbour layers is small. Spatial filtration system described above with distance between layers equal to 25um leads to integral background illumination less than 40 dB

PARALLEL READ OUT

Using CCD arrays as a photosensitive element, opens new opportunities for parallel reading with high data rate. Mega-pixel CCD arrays with frame rate of several KHz provides the data rate up to Gbit/s. The CCD array based on time delay integration (TDI) technology is capable to read low intensity signal with data rate of about of several tens MHz. For average data density the corresponding data rate is 10 Mb/s. Note, that mechanical velocity is 450 times less than in DVD player. Standard demand for reading in DVD format SNR > 20 dB is satisfied even for velocity 100 mm/s with corresponding data rate 0.1 Gbit/s. The imaging of fluorescent marks provides the spatial resolution twice higher than for reflected signal because of non-coherent nature of fluorescence

THE SNR ANALYSIS

- The individual fluorescent marks can provide the signal of about 1 μW. This level of signal is acceptable for reading by PIN diode with data rate corresponding to 1X DVD format
- For data rate corresponding to 2X, 4X DVD and higher data rates the electronics noise is dominant. The application of ADP photo-sensor with amplification 10-40 times is highly advantageous
- Parallel and sequential-parallel reading by using CCD matrices of different types provides the high data rate and higher spatial resolution as compared with reflective technology. For parallel and sequential-parallel reading the dominant part of the noise is so-called shot noise. Generally and practically the data rate transfer for parallel reading can be much higher. The relatively simple extension to parallel and sequential-parallel reading (and writing) is one of the main advantages of fluorescent memory

The principle of the device with sequential-parallel reading is shown in Figures 11 -13

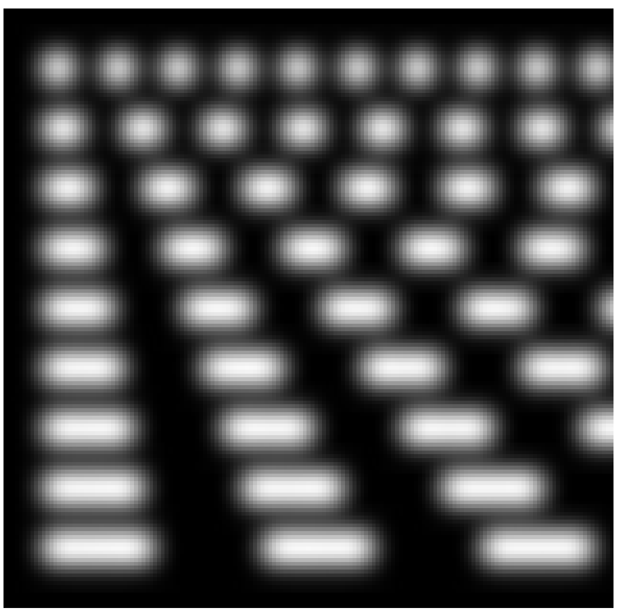


Figure 11

Image of DVD-encoded fragment of FMD/FMC

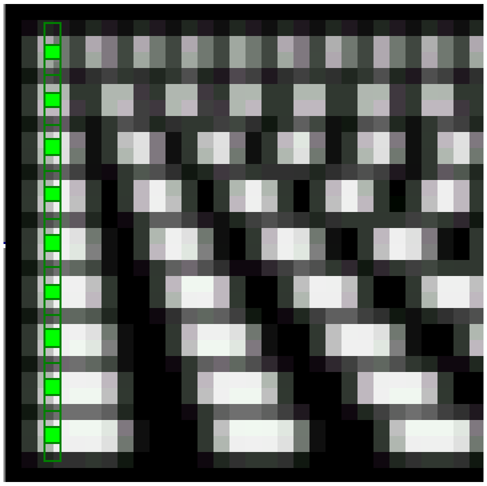


Figure 12

Twenty times magnified image of fluorescent pits with DVD-encoding imaged by CCD-camera

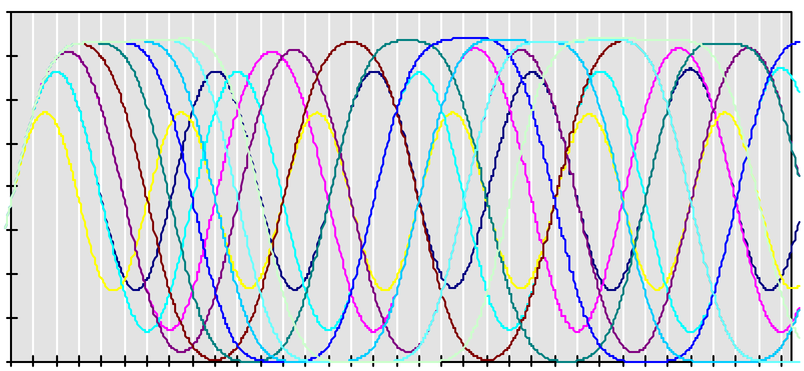


Figure 13

Eye-pattern of HF-signal from each element of photo-array

4. INDUSTRIAL PRODUCTION PROTOTYPES

Constellation 3D, Inc. has developed and proven the basic technology and will continue to develop fully functional prototypes of end-user products. With respect to each of the following products, the company will seek and establish joint ventures with strategic partners having an established market share and manufacturing capability in the relevant product market

FMC ClearCard™ ROM

The planned initial production model is a credit card-sized ClearCard™ -ROM with up to 20 layers, 400 MB/cm^2 data density and up to 10GB capacity* - twice current single-sided DVD disc, but at a fraction of the cost and size. The design of the reader will be simple, with virtually no moving parts, making them resilient to all kinds of shocks. The potential number of applications for which these cards could be used are almost limitless - from e-books and home entertainment systems to e-books and archival and navigational systems. The ClearCard™ could also be used in many applications where a CD/DVD discs are currently used. The cost of production of these cards is less than $10

Note: Constellation 3D has recently confirmed in its labs the feasibility of production of a 50-layer ClearCard™ ROM with a storage capacity of 1 Terabyte and data transfer speeds of up to 1 Gigabit/second. The card would be intended for use in HDTV, Video & Music-on-demand and other multimedia applications

FMC ClearCard™ RECORDABLE

The card is a compact version of the FMC ClearCard™ that enables the user to record the initial information to be stored. The planned initial production model is a credit card sized 10-layer disk with a 1 Gigabyte capacity. It is designed to fit into devices such as laptop and hand-held computers, digital cameras, cellular phones and video recorders and players, for which it will offer light weight, high capacity storage and quick access to data. Next generations of recordable cards will have nearly as much capacity read only cards. For cameras and video players, the ClearCard™—RECORDABLE will not only offer the same gains as for laptop and hand-held computers but also offer higher quality video. This technology will be ideal for downloading information from the Internet

FMD ROM

This disc takes the CD-ROM & DVD-ROM concept to the next level. The planned initial production model is a 120mm 10-layer disk with 140 Gigabyte capacity - vs. less than 18 Gigabytes for a maximum capacity DVD - giving it the capacity to store up to 20 hours of compressed HDTV film viewing. As mentioned above, existing CD & DVD 120mm disc and drive manufacturing equipment will be adaptable with minimal re-tooling to accommodate the new technology. The new FMD drives will also be backward compatible with (i.e., capable of reading) existing CD & DVD media. However, it is anticipated that the majority of users will at an early stage decide to take advantage of the much larger capacities and superior performance characteristics of the new FMD discs and make it their media of choice for future data storage applications

FMD/C Re-Writable

Re-Writable optical memory carriers have been recently been gaining attention within the optical memory community and provides the maximum amount of flexibility in the determination of data stored at any given time - it is a fundamental requirement of hard disk drives in PCs. In between the two extreme approaches to storing memory, ROM and Re-Writable, are data storage applications where the user requires the flexibility of deciding the initial data to be stored on the media and then the certainty that the data will not later be erased or amended. The initial solution to the most effective data management is FMD/C RECORDABLE storage carriers of very significant capacity. In particular Constellation 3D intends to produce a credit card sized ClearCard™ -RECORDABLE with 4.7 GBytes capacity and costing under $10, thereby providing users of hand held devices with a cost effective solution to their Internet downloading and other data write-once needs. The next generation products will include genuinely re-writable layers based on most recent development carried out by Constellation 3D.

MEDIA MANUFACTURING TECHNOLOGY

Fluorescent media manufacturing process described here, utilizes many processes that are typical for CD and/or DVD manufacturing. However, fluorescent media requires many proprietary polymers and compositions that were exclusively developed by Constellation 3D Inc. Company intends to make these materials available to media manufacturers through it's selected industry affiliated partners. Media manufacturing process described in this document, relies on well known optical disc replication process. Further developments related to increase of data storage capacity to the level of multi-hundreds of gigabytes per disc, will require adoption of other disc manufacturing technologies currently under internal development

- **Pre-mastering and mastering process**

Pre-mastering and mastering processes are very similar to those utilized by CD/DVD industry. However, certain modifications of mastering process will be required (namely glass master and stamper preparation). These modifications are mainly related to pit geometries that are designed to facilitate reliable pit replication and pit filling

- **Replica manufacturing**

Replica manufacturing involves preparation of circular substrates made of low birefringence plastic film (polycarbonate, PMMA or other films with appropriate optical characteristics). Film thickness is between 25 to 30 microns. Prior to usage, substrates are die or laser cut to appropriate diameter (media dependent, see above). Prepared substrate is placed over radial bead of photo-polymer deposited onto nickel matrix top surface (stamper). During spinning process photo-polymer evenly spreads between stamper surface and plastic substrate. Subsequently, UV curing hardens photo-polymer and now substrate can be separated from top surface of stamper. Substrate contains precise pit geometry. Precision of pit replication exceeds quality of injection-molded substrates (such as CDs or DVDs)

- **Pit filling**

During pit filling, fluorescent dye-polymer evenly spreads over entire replica's informational side by utilizing of spin-coating process (similarly to CD-R dye application). After dye-polymer is UV cured, certain chemical bleaching process is applied to achieve the desired signal contrast ratio of pits and lands

- **Replica inspection**

Each replica is optically inspected to verify proper dye-polymer filling of pits. Such inspection is achieved by observing of emitted light from entire area of data pits by utilizing of CCD camera. At this stage replica is optically inspected for various physical defects such scratches, inclusions and alike

- **Layer bonding**

Layers or replicas are centrally bonded onto optical spacer (0.6 mm thick polycarbonate or PMMA substrate), by utilizing capillary bonding method well known to DVD industry. Since replicas are thin and thus more pliable, formation of air bubbles in the bonding layer is minimized. Requirements to centricity of informational layers is similar to DVD discs (or +/- 25 micron)

- **Disc decoration**

After multiple replicas are bonded on the top of optical spacer (see above), additional support/protection substrate is bonded on the stack top. These decorated elsewhere substrates are made of solid color inexpensive plastic materials

- **Edge sealing**

In order to prevent layer separation by physical contact, disc outer edge is sealed with UV curable photo-polymers typically used for protection of CDs and DVDs

5. Conclusion

Constellation 3D's fluorescent multilayer optical data storage technology can be utlized to produce compact, removable, inexpensive, rugged, ultra-high capacity data storage devices, having data transfer speeds in excess of 1Gbit/sec. The company wishes to maintain its focus on research and development in the field of fluorescent multilayer optical storage, with the intention of continually expanding the limits and capabilities of this technology. Having successfully demonstrated prototype multilayer cards and discs incorporating FMC/D technology, the way is now open - through joint ventures with industry leaders to commence industrial production of these devices and take them into the mainstream