Fluorescent Multi-layer Disc (FMD)
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1. Introduction to FMD

1.1 Fluorescent Multi-layered Disc

Fluorescent Multi-layer Disc (FMD) is a new data storage format currently being developed by a company called Constellation 3D (C3D). FMD is an optical format, similar in size and appearance to regular CD-ROMs and DVDs. However, the real advantage that FMD technology promises over it's rivals is that although a CDR may hold 700 MB of data, and a DVD-ROM 4.7 GB, initial reports from C3D claim that it may be possible to produce FMD discs with up to 140 GB of data, greatly eclipsing it's nearest rival.

C3D claim that existing CD-ROM and DVD-ROM disc production methods can easily be modified to incorporate fluorescent multi-layer technology. Furthermore, the cost of producing FMD discs will still remain relatively cheap, meaning data storage on unparalleled levels may become increasingly accessible to the consuming public.

1.2 Fluorescent Multi-layered Card

Fluorescent Multi-layered Card (FMC) is a further addition to the technology from C3D, providing high-capacity storage cards that are much cheaper than the current Compact Flash and MicroDrive card-type storage devices, which are in use with digital cameras, portable storage for laptops, E-books, smart cards for holding personal data for use in buildings, airports, etc.

Dubbed "ClearCard" by C3D, the FMC format could easily overtake it's rivals by being much cheaper than existing formats, while the card readers may require fewer moving parts making them durable for transport proposes.

2. FMD/C Technology

With FMD/C technology, data is recorded on multiply layers located inside a disc or card, as opposed to the single or double layer method used by existing CD and DVD formats. The recording, reading and storing of the information is achieved through the use of fluorescent materials embedded in pits and groves in each of the layers. The fluorescent material emits radiation when excited by an external light source, which allows the information to be decoded by the changes in the intensity and colour of the emitted radiation.

It has long been accepted by the research community that 2D storage methods are insufficient for the future long term application of data storage devices. Research efforts have focused on ways of using a 3D storage technology, including holographic and multi-layer storage as employed by FMD/C.

With FMD/C technology, each storage layer is coated with a transparent fluorescent material rather than the reflective metallic layer of CD and DVD. When the laser beam hits a mark on a layer, fluorescent light is emitted.

The light emitted by fluorescent light is incoherent, unlike the coherent reflected light in current CD and DVD devices. Incoherent light is not affected by data pits or other marks in the media, and passes through adjacent data layers unaltered. In FMD/C devices, emitted light is filtered before it reaches the drive's detector, which reduces the effect of stray light and interference - only data-conveying fluorescent light is detected.

The signal quality of conventional optical reflection systems degrades rapidly when additional data layers are added. Current research indicates that only a few layers are possible. DVD's two layer data format is an implementation of this research. The filtered, incoherent light of FMD and FMC technology offers the potential for storage mediums with up to 100 data layers.

3. Other Optical Formats

Optical data storage has been around for many years, and has passed through many change and continual improvements. Here is an overview of current optical technologies; those that C3D may hope that it's multi-layered devices will soon replace.

3.1 CD-ROM

The CD-ROM standard was introduced in 1984 when the CD-audio standard was modified to give PC's access to the format. CD-ROM drives quickly evolved into low-cost digital storage devices, and soon became the standard format for the production and distribution of PC games and application software titles.

With a 650-700 MB storage capacity, one CD-ROM disc can store the same amount of data as 450+ floppy discs. Data access speeds are good, with a maximum data rate of approximately 5 MB/sec.

CD-ROM drives are distinguished by disc rotation speeds measured relative to the speed of an

audio CD player. A 1X CD-ROM accesses data at approximately 150 kilobytes per second (KB/sec), the same as an audio player. A 32X CD-ROM reads data thirty-two times faster. In general, faster speeds increase data access time, but vibration and noise problems limit maximum speeds to approximately 48X.

3.2 CD-R

CD-R systems, which first appeared in the early 1990's, provided a recordable optical format for the first time. CD-R drives are an advancement of the write once/read many (WORM) storage technology that appeared in the late 1980's. CD-R drives permit multiple writing sessions to different sections of a disc, and the medium is standardised. However, CD-ROM drives must be multi-session compatible to read such discs, although most modern drive units meet this requirement. With discs available in 650 MB and 700 MB format, CD-R technology provides a valuable archiving tool.

3.3 CD-RW

A further advancement in optical data storage, CD-RW provided the means of recording data onto the same disc multiply times. Introduced in 1997, CD-RW drives used a phase-change technology to record data onto the disc. In place of the dye layer used in CD-R, CD-RW disc have 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 200oC and cooled, but also forms an amorphous or non-crystalline structure when heated even higher (500 to 700oC) and cooled. The alloy can be changed between the two states using two different laser power settings.

The crystalline state for this material reflects more light than the non-crystalline form, so it simulates the surface of a regular CD. Data bits are encoded by changing small target areas to the non-crystalline form. This writing can be repeated approximately 1,000 times per disc.

CD-RW drives write both CD-R and CD-RW discs. CD-RW drives are described by the CD-R write speed, CD-RW write speed, and CD-ROM read speed (e.g. 8/4/32x). Available in 650 MB disc format, the actual capacity per disc is about 550 MB when the disc is formatted for packet writing.

3.4 DVD-ROM

Introduced in 1995, DVD (Digital Versatile Disc) came about as the result of the DVD Consortium composed of ten founding companies. Like CD drive, DVD drives read data through the disc substrate, reducing interferences from surface dust and scratches. However, DVD-ROM technology provides seven times the storage capacity of CD-ROM, and achieves this by advancing the technology used in CD systems. The distance between the recording tracks is less than half of that of CDs, while the pit size is also less than half of that of CD-ROMs. These features alone give DVD-ROM discs four times the storage capacity of CDs.

DVD drives can also store data on both sides of the disc, which effectively doubles their capacity. A single-sided, single-layered DVD disc can hold 4.7 GB of data; a single-sided double-layered DVD can hold 8.5 GB; double-sided, single data-layered holds 9.4 GB and finally a double-sided, double-layered DVD disc can hold 17 GB of data, greatly increasing the data storage available through CD-ROM technology.

3.5 DVD-R

DVD-R drives were introduced in 1997 to provide a recordable version of the DVD-ROM format. The discs use a photo-sensitive dye technology similar to CD-R. At 3.95 GB per side, the first DVD-R discs provided less space that the original DVD-ROMs, but that capacity is expected to soon be increased to the full 4.7 GB of data storage space.

The data transfer rate is 1.4 MB/sec. Due to the high costs of DVD-R drives and media, however, their use in the mainstream of computer consumables has been limited.

3.6 DVD-RAM

DVD-RAM (rewritable) drives were introduced in 1998, and used a phase-change technology combined with some embossed land/pit features. Employing a format termed "land groove", data is recorded in the grooves formed on the disc and on the lands between the grooves. The current disc capacity is 2.6 GB per side, but a 4.7 GB version is expected that will achieve the higher density by reducing the pit size and track pitch, or distance between the recording tracks.

The 4.7 GB discs will come in cartridges that will protect the disc from handling damage, such as fingerprints and scratches. A single-sided disc is expected to be removable from the cartridge so it can also be played in a DVD-ROM drive that supports DVD-RAM. Future DVD-RAM drives, such as portable computer slim drives, will write to DVD-RAM discs without cartridges.

3.7 DVD-RW

The DVD-RW drive is very similar to the DVD-RAM device, except it uses a phase-change recording layer that is comparable to the CD-RW method. The DVD-RW is intended for non-PC use, such as providing a recording facility to existing DVD film playing systems for use with a television.

3.8 +RW

Sony and Philips were founding members of the DVD Consortium, but broke away to develop the +RW phase-change technology in 1997. There are no +RW drives in production today, but plans to introduce a 4.7 GB version of the format are currently in development.

4. FMD Compared to Other Optical Formats

4.1 The Potential for FMD-ROM Drives

The table below examines the optical systems currently available compared to the potential performance of a future FMD drive from Constellation 3D. Please be aware that these figures are based of C3D claims, and as such they may degrade in performance with the introduction of the first actual FMD drive device, which is largely dependant upon market requirements.

Drive Type	Manufacturer	Interface	Capacity	Maximum Sustained Data Transfer Rate (MB/sec)
CD-R	Several	IDE and SCSI-2	650-700 MB	1.2 (8X CD-R write) 0.6 (4X CD-RW write) 4.8 (32X CD-ROM read) MB/sec
CD-RW	Several	IDE and SCSI-2	650 MB	1.2 (8X CD-R write) 0.6 (4X CD-RW write) 4.8 (32X CD-ROM read) MB/sec
DVD-R	Several	SCSI-2	4.7 GB	1.4 MB/sec
DVD-RAM	Several	SCSI-2	2.6 GB	2.8 MB/sec

FMD-ROM potential performance figures (as claimed by C3D)

Drive Type	Manufacturer	Interface	Potential Capacity	Potential Maximum Sustained Data Transfer Rate (GB/sec)
FMD	Constellation 3D	IDE and SCSI-2?	20-140 GB	1 GB/sec plus.

4.2 C3D Plans for an FMD Drive Unit

The first generation of 120mm (CD sized) FMD discs will hold 20 to 140 Gigabytes of data on 12-30 data layers with a total thickness of under 2mm. Each data layer will hold 4.7 GB of data, as with existing DVD discs. When compared with the other optical formats from the table on the previous page, it is clear that FMD has the potential to surpass all previous optical formats.

C3D have developed a proprietary parallel reading and writing systems, that reads from several data layers simultaneously and multiply tracks at a time, which has the potential to achieve data transfer rates of over 1 GB per second.

C3D promise that FMD drives will be similar in size, design and price to CD and DVD drives and players currently on the market. Lasers and laser focussing technology will be the same and only minor modifications may be required in the signal processing unit of existing CD and DVD

Drive Type	Manufacturer	Interface	Potential Capacity	Potential Maximum Sustained Data Transfer Rate (GB/sec)

designs to allow for the reading of the incoherent light emitted by FMD discs.

5. Future Developments from Constellation 3D

Constellation 3D are working on the following storage technologies to compliment the main FMD format:

5.1 FMD-WORM Disc and Drive

Just as previous optical formats evolved into recordable technologies, fluorescent multi-layer technologies have the potential to do the same. C3D promise an FMD-WORM (Write Once Read Many) drive to give users the ability to write and record their own content for future playback. FMD-WORM media will be based on the same technology as ROM but will use fluorescent dyes capable of the phase change needed for recording. One advantage of the media will be it's ability to have both WORM and ROM on the same carrier.

5.2 ClearCard™ Disc and Drive

Fluorescent Multi-layered Card (FMC) or 'ClearCard' is in development to meet the capacity needs of the growing mobile computing market, including E-books, MP3 players, PDA's and digital photography requirements. ClearCard is a credit card sized version of the FMD technology, which will also support WORM capabilities. The first generation is likely to hold up to 10 GB of data, which gives ClearCard a massive advantage in storage capacity over the existing flash memory now in use in many mobile applications.

5.3 Future Disks & Cards

By adding layers and taking advantage of blue laser technology, second and third generation cards and discs will have the capacity of up to and exceeding 1 Terabyte (1,000 GB) of data. In addition, read/write versions of the disc and card are planned.

6. Conclusion

On April 4, 2001, Constellation 3D announced that it has reached a partnership agreement with Avica Technology to incorporate C3D's Fluorescent Multi-layer Disc technologies in Avica's FilmStore? Digital Cinema playback platform. Under the terms of the agreement, the two firms intend to jointly develop digital cinema products utilizing FMD technology.

The FMD Digital Cinema disc has the potential to provide a secure, removable, single disc distribution method. It enables both the secure delivery of an inexpensive physical disc

Drive Type	Manufacturer	Interface	Potential Capacity	Potential Maximum Sustained Data Transfer Rate (GB/sec)

containing an entire digital movie to theatres, and also provides the means for the secure return of the material following its run. FMD provides a cheaper and more durable method for cinema franchises, and as such the FMD format may see it's first real-world application is this environment.

It is important for the future of FMD technology that this first application of the technology is a success, in order to build confidence in the new format. Constellation 3D does not have the power of the DVD Consortium, for example, who had the ability to invest large amounts of capital in rolling out the DVD format in the 1990's. Consisting of Hitachi, Matsushita Electronic, Mitsubishi Electric, Toshiba, Time Warner, Pioneer Electric, Thomson Multimedia, Victor Company of Japan, Sony, and Philips Electronics, the DVD Consortium possessed the kind of venture capital that Constellation 3D can only dream about.

In my opinion, optical data storage mediums have invariably failed to live up to their full potential. Rewritable CD's often prove impractical, while rewritable DVD's are currently prohibitively expensive. It is my personal opinion that C3D may find the fiercely competitive marketplace for data storage to be a very difficult environment to survive within, with larger electronics developers benefiting from economies of scale. Unless they get the backing of such a major electronics backer, they may find the financial burdens of their undoubtedly brilliant research and development proving to be too great a burden for the fledgling start-up company.

For further information, check Constellation 3D's homepage at: http://www.c-3d.net/

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Over the last year or two since I first wrote this article, I have received many e-mails regarding the fate of Constellation 3D and their FMD technology. The link to their home site that I have provided above is now unfortunately dead, although I leave it it place for completeness sake. Regrettably, I have no further information regarding the fate of this company, except to say that it is clear that they have long-since gone out of business.

When I wrote the conclusion to this article, I did not know that my pessimistic tone would prove to be well founded. While the DVD format has reached saturation point, effectively eliminating the VHS format, and squeezing the CD format for data storage, the potentially vastly-superior FMD format seems to have succumbed to a lack of financial support, and been consigned to what might have been.

Drive Type	Manufacturer	Interface	Potential Capacity	Potential Maximum Sustained Data Transfer Rate (GB/sec)

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