

# **Fluorescent Multilayer Technology: A Breakthrough in Optical Data Storage**

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## INTRODUCTION [\(↑\)](#)

Hashmi Technical Consultants, Inc. has completed an in-depth analysis of fluorescent multilayer (FM) technology. This introduction describes the scope of research and the format for this report.

### SCOPE OF RESEARCH [\(↑\)](#)

The purpose of this report was to determine whether investment in companies supporting FM technology is – or will be – a sensible decision. To accomplish this goal, a complete technical analysis of the technology was conducted, as were format-to-format comparisons. Also examined were cooperative agreements and partnerships among companies supporting FM technology.

The subjects of the technical analysis were as follows:

- Fluorescent Multilayer Technology
- Media Development
- Security
- FMD Hardware

FM technology was compared to the following data-storage formats:

- Optical: DVD and CD
- Magnetic: Hard-Disk Drives
- Solid-State: Flash memory cards

Cooperative agreements between Constellation 3D and the following partners were examined:

- Warner Advanced Media Operations
- Sonic Solutions
- Avica Technology
- International Partners: Ricoh, Zeon, Toolex, etc.

### REPORT FORMAT [\(↑\)](#)

This report includes seven main sections:

1. *Demands in Data Storage*: discussion of data-storage needs in foreseeable future
2. *Introducing FMD*: brief introduction to fluorescent multilayer disc
3. *Technical Analysis*: a complete overview of FM technology
4. *Comparisons*: FM media compared with other formats

5. *Cooperative Agreements*: overview of C3D's domestic and international partners
6. *Future FM Hardware*: artist's conceptions of future FM devices
7. *Conclusions*

## DEMANDS IN DATA STORAGE [\(↑\)](#)

In the 1990s, the growth in demand for data-storage capacity exceeded 60 percent per year (Magnitskii, 2000). This new decade promises to bring even more accelerated growth. Practices such as supercomputing, e-commerce, data warehousing, and data mining need continuously expanding capacity in order to handle their huge volumes of data. In the near future, increasing use of broadband, HDTV, and portable devices such as PDAs, mobile phones and digital cameras will require multi-gigabyte and terabyte capacities. Professional HDTV applications, for example, require reading speeds over one terabit per second; hence, the storage medium must be capable of enormous capacity. By the end of this year, two exabytes ( $10^{18}$  bytes) of information will be stored worldwide, up from one exabyte only two years ago. Approximately 10 percent of the information will be stored on magnetic hard-disk drives (HDDs); the remainder will be on tapes, optical discs and paper (Magnitskii, 2000). Thus far, the supply of inexpensive storage solutions have kept in pace with demand by steady increases in the areal density of magnetic and optical media. Unfortunately, many of the *current* formats have or will shortly be approaching their theoretical capacity limits.

## INTRODUCING FMD [\(↑\)](#)

In the mid-1990s, a team of scientists with backgrounds in physics, chemistry, optics and electronics conducted ambitious experiments focused on designing photosensitive materials for a fundamentally new kind of optical data disc. The result was the creation of a paradigm-breaking optical medium based on fluorescent multilayer (FM) technology. This technology, unlike any other optical media before, shares enough in common with existing media to become a viable product in today's market. The scientists realized this and formed a company in New York City, Constellation 3D, Inc. (C3D), to realize their commercial invention. Upon seeking and later receiving sufficient capitalization, they created versions of FM media and drives in their laboratories. Subsequent demonstrations helped raise more capital and enabled the business to attain a NASDAQ listing (stock symbol, CDDD) in November 2000. Since then, C3D has continued to refine its technology and has achieved working demonstrations using DVD's pit density and MPEG-2 encoding. The company has over 120 allowed or pending patents on FM technology. It will seek revenue from licensing agreements with partners in every storage-related industry (C3D Web site, 2002).

## The Basics [\(↑\)](#)

A fluorescent multilayer disc (FMD) is a multi-layer, readable and re-writable disc with the same diameter and thickness as a CD or DVD. Its transparent nature is one of its most recognizable features (Fig. 1). FMD will provide an optical-storage solution for the data needs of high-performance computer and multimedia applications. This can be done using *existing* red-laser technology yielding 150 GB discs. When blue lasers become cost-effective, FMDs with nearly one terabytes of capacity and a 1 megabits per second (Mbps) data rate will be feasible (C3D Web site, 2002).



Fig. 1 (Courtesy FMD Insider)

## Advantages [\(↑\)](#)

The primary advantages of FM technology are as follows (C3D Web site, 2000):

- Optically transparent and homogeneous multilayer system
- Low light absorption in each layer
- Emitted (signal) fluorescent light not absorbed
- Less sensitive to imperfection in media and drives than CD/DVD; fluorescent technique does not depend on interference effects and requires less stringent manufacturing requirements for media and drives
- Emitted fluorescent light from any given layer is non-coherent, eliminating problems of “parasite interference”
- Limited-lateral spatial resolution system twice that for coherent light-based systems (e.g., CD/DVD using reflective layer).
- Compatible with present CD/DVD formats, having the ability to handle the same data rates over each of its layers.

## TECHNICAL ANALYSIS [\(↑\)](#)

### FLUORESCENT MULTILAYER [\(↑\)](#)

Multilayer, fluorescent discs address the problem of signal degradation by offering a unique solution. Specifically, each data layer is coated with a proprietary fluorescent material (dye). When the layer is struck by the laser beam fluorescent light is emitted. This light is different in wavelength than the incident laser light, being slightly

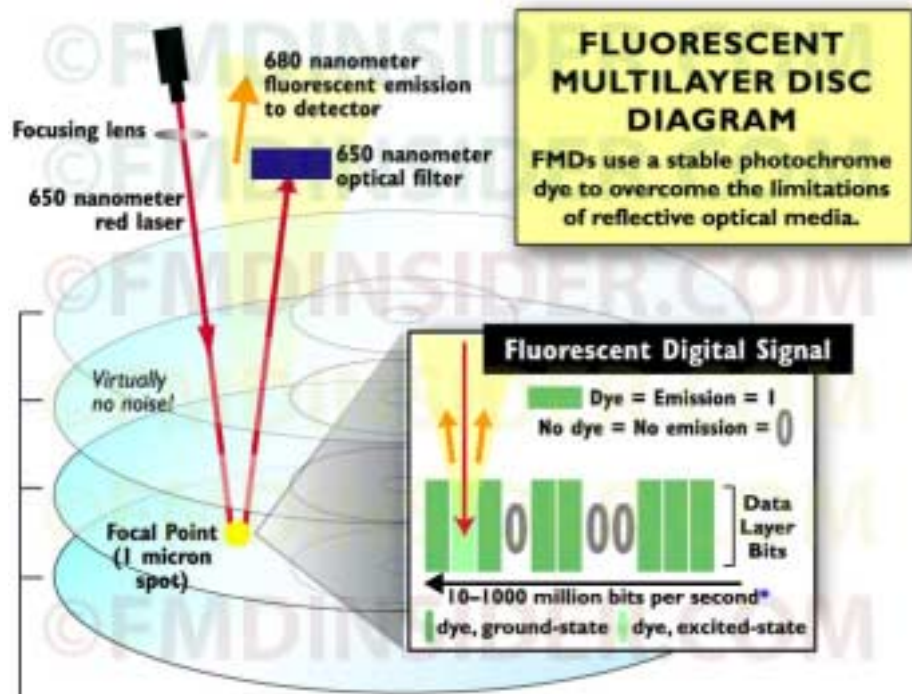


Fig. 2 (Courtesy FMD Insider)

red-shifted and incoherent in nature (Fig. 2). The emitted light is not affected by data or other marks and moves through adjacent layers without being distorted. In the *read* system of the FMD drive, the light is filtered; this allows only data-carrying fluorescent light to be received, lessening the effect of interference and stray light. Unlike reflection-based systems (DVD), the signal-to-noise ratio (SNR) degrades much more slowly with each additional layer. This remarkable ability will permit a single disc with as many as 100 layers.

## MEDIA DEVELOPMENT [\(↑\)](#)

The FMD media is composed of several bonded polycarbonate substrates. Each substrate contains surface structures (pits) that are filled with a proprietary fluorescent compound (Fig. 3). According to Ingolf Sandler of C3D, “a major design goal in the development of CD/DVD replacements using this

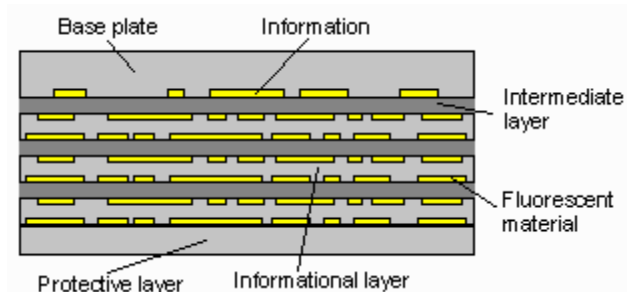


Fig. 3 (Courtesy FMD Insider)

technology, was to allow a simple and cost effective upgrade for existing manufacturers of optical devices” (1999, p.1). C3D’s FMD technology allows the use of existing facilities, with only minor changes (i.e., addition of fluorescent compound). Compared to DVD, there are fewer process steps per layer since a

reflective, metallic layer is not needed. For the mastering process, each layer of an FMD requires a data-containing metal stamper, similar to CD/DVD. Unique to FMD, two replication processes have been developed:

*Hot-Embossing:* Using hot metal stampers, thin polycarbonate sheets are embossed on both sides. After the sheets cool, the embossed pits are filled with fluorescent dye. After the dye is cured, the individual sheets are stacked and bonded together under pressure. The result is a storage media having multiple layers: a Fluorescent *Multilayer* Disc (Sandler, 1999).

*Photo-Polymerization (2P) Process:* This method, in which layers are sequentially replicated by creating “thin replicas”, will eventually allow FMD to incorporate up to 100 layers (Sandler, 1999).

### **Fluorescent Material** [\(↑\)](#)

The fluorescent material – arguably, the “main ingredient” of FMD technology – converts incident (incoherent) laser light into incoherent fluorescent light. C3D has several material formulations. The most-developed material is used in read-only discs. Writable (recordable) and re-writable formulations (and their corresponding drives) have also been demonstrated using proprietary photochromic compounds (Sandler, 1999).

### **FMD ROM (Read-Only) Technology** [\(↑\)](#)

The fluorescent material, used in FMD ROM media, must adhere to the following requirements (Magnitskii, 2000):

- Compatibility with substrate material
- Absorption wavelength must be the same wavelength found in commercially available, low-cost semiconductor lasers used in CD/DVD player
- Emitted fluorescent light must be wavelength-shifted by 50 nm (minimum) to allow easy separation of incident and signal light
- High conversion efficiency
- Refraction index close to that of the polycarbonate
- Stability over an extended period of time
- Response time  $\leq 1$  nsec

#### *Light-sensitive material*

The photo-polymer composition (PPC) consists of monomers and oligomers. With the addition of a photo-initiator, operating under a specific-range radiation, the polymerization process is initialized. PPC functions as the substrate for the

data carrier, oxazine-1, methylene blue, methylene violet while other red dyes function as the photo-initiator (Magnitskii, 2000).

### *Pit-filling process*

The “working surface” of a polycarbonate disc is a plane with billions of pits (0.5  $\mu\text{m}$  in diameter), positioned with a specific order. These pits can be filled with *liquid* monomeric or oligomeric materials that convert to *hard* polymer substances when placed under UV light. The substances fill the pits and overflow to form a thicker layer on the media surface. The greater the difference between the layer thickness in the pit to that on the surface, the better the contrast (Magnitskii, 2000).

## **FMD WORM (Write Once, Read Many) Technology [\(↑\)](#)**

In addition to the requirements for ROM media, writable (recordable) media require the following:

- A write process in which the write laser is able to turn the fluorescence on or off
- A standardized level above which the fluorescent material is changed by the power level of the write laser, and below which the material is unchanged during read-only operation

To meet these requirements, two procedures have been developed:

### *Thermal Bleaching*

In this procedure, the material is initially fluorescent. The incident write laser heats the material, destroying the fluorescence. The write parameters are similar to CD-R; thus, a standard 15mW optical-writing laser works just fine in an FMD-R drive. Also developed are materials that can be used with red, green and blue lasers (Magnitskii, 2000).

### *Photochemical Reaction*

Materials used in this class are *not* initially fluorescent. When the material is struck by the write laser, a photochemical reaction occurs creating fluorescence. Since no heat is required in this process, the write-power needs are low. This allows the possibility of using inexpensive light-emitting diodes (LEDs). Using LED *arrays*, huge quantities of data can be written in parallel, allowing smaller FM technologies (cards) to become viable. C3D has successfully demonstrated materials sensitive to green and violet wavelengths (Magnitskii, 2000).

## SECURITY [\(↑\)](#)

FMD will offer an extraordinary amount of security. In addition to complying with the newest and most sophisticated encryption technologies, FMD's unique dye chemistry will offer much greater control over access to intellectual property. In the digital cinema realm, for example, FMD's capacity allows for digital watermarking of each frame (there are 24 frames per second). Dyes can even be customized to work exclusively with FMD players used in cinemas, rendering stolen copies inaccessible to those using consumer drives. As for protection from mass-duplicating pirates, dyes can be designed to last only for a specific number of plays or limited amount of time (Cohen, 2001). One can easily see that FMD's security options will be useful beyond cinema. Governments, businesses large and small, and consumers will all benefit from them.

## FMD HARDWARE [\(↑\)](#)

FMD drives have components similar to those of CD/DVD drives: laser, beam-generating optics, spindle, tracking/focusing actuators, servo, control processors, data channel and data interface (see Fig. A1 in Appendix A). The only additional components are filters to separate the fluorescent light from the laser light and a spherical aberration unit to correct for optical path length, depending on selected layer. Electronic differences include a *high-sensitivity* detector circuit and additional servo electronics to address different layers within the multi-layer disc (Magnitskii, 2000).

## COMPARISONS [\(↑\)](#)

In order to appreciate the virtues of FM technology, comparisons must be made with other existing and soon-to-be-released formats. Today, there exist three basic storage technologies: magnetic (hard disk drives, tapes, Zips and floppies), optical (DVD, CD, FMD), and solid-state (flash memory cards).

### Optical Storage: DVD and CD [\(↑\)](#)

Compact disc (CD) and digital *versatile* disc (DVD, originally called digital *video* disc) are the two major optical formats today. 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 (Fig. 4).

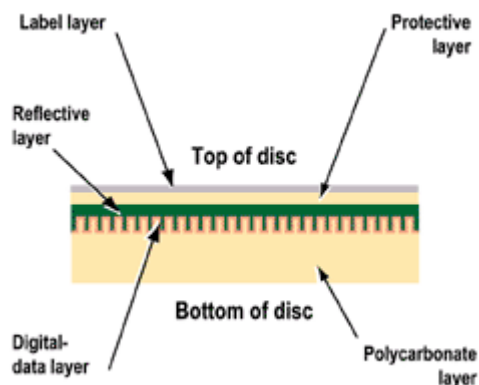


Fig. 4 (Courtesy Dell.com)

Although DVD only recently emerged as a commercial phenomenon, it is genetically similar to compact disc technology originated in the 1970s. The technical breakthrough that made that made DVD possible involved improvements in manufacturing processes that increased pit density

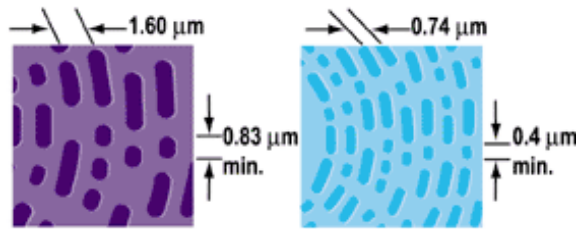


Fig. 5 (Courtesy Dell.com)

on a single disc layer – it is seven times that of CD (Fig. 5 ). Although this was no small feat, it does not constitute a departure from the reflective optical media standard. DVD is an evolutionary rather than a revolutionary advance.

CDs allow a maximum of 0.8 GB of data storage with a data rate of 1.28 Mbps. Meanwhile, DVDs allow a maximum of 18 GB of data storage in a dual-layer, dual-sided configuration with a data rate of 10 Mbps. When much-anticipated blue-laser technology becomes an economic viability – still several years distant – DVDs will be capable of nearly 40 GB of data storage with a data rate of nearly 100 Mbps (Taylor, 2001). Although this will be a welcomed advance in the evolution of the format, DVD still has some inherent limitations.

DVD technology's Achilles heal is that it is limited to *two* layers as are all reflective media. Why is the case? Simply stated, the laser in DVD drives and players is running a gauntlet during playback, its signal distorted by the effects (i.e., interference, scatter and intra-layer crosstalk) of its interactions with the medium's reflective layer. DVD's SNR becomes substantially worse once it strikes the first layer, and then again when it reaches the second layer, and still further when it passes through the first layer on its path to the detector. The resulting noise degrades the signal to such an extent that the use of three layers lies beyond DVD technology.

The [DVD Forum](#), a group responsible for creating the standards of the DVD format in the mid 1990s, imposed a "speed limit" of 10 Mbps on DVD-Video (Taylor, 2001). Although this is fine for current home video standards (e.g., NTSC in North America and Japan, PAL in Europe), HDTV requires a minimum bit rate of 20 Mbps. Encoding a *current* red-laser-based DVD with a 20-24 Mbps rate is entirely possible. However, such an increase would consume the disc's storage capacity before it could accommodate a two-hour film. DVD-ROMs also run into capacity and data rate limits when computer drives are used at multiple read or write speeds.

Finally, there is the problem of *overabundance* of DVD formats. Presently, there are the following:

1. DVD-ROM: computer applications
2. DVD-Video (DVD-V): the popular movie format
3. DVD-HD: HDTV/DTV version of DVD-V; will be released in late 2003

4. DVD-Audio (DVD-A): a new, high-resolution audio format; competitor to Super Audio CD (SACD)
5. DVD-RW: a re-writable DVD format supported by Pioneer, Panasonic and Hitachi
6. DVD+RW: a re-writable DVD format created by Sony and Philips
7. DVD-RAM: a re-writable DVD format created by Pioneer
8. DVD-R: a write once read many (WORM) format created by Pioneer

This Beta-vs.-VHS-like format war only creates public confusion. Additionally, all writable/re-writable DVD standards will be limited to *only* 4.37 GB per side in the foreseeable future (Cohen, 2001).

FMD technology overcomes every technological barrier that DVDs and CDs face, including the all-important capacity limit (see Fig. A2 in Appendix A and Table B1 in Appendix B). Further, FMDs will be less expensive to manufacture, offer better copyright protection, and will conform to only one optical standard. They will offer these benefits using *existing* red-laser technology.

### **Magnetic Storage: Hard-Disk Drive** ([↑](#))

No other digital-storage technology today is as evolved as the ubiquitous hard-disk drive (HDD). The capacity of HDDs grew about 25 to 30 percent each year in the 1980s and accelerated to an average of 60 percent in the 1990s. By the end of 1999 the annual increase had reached 130 percent. Today disk capacities are doubling every nine months, fast outpacing advances in computer chips, which obey Moore's Law (doubling every 18 months) (Toigo, 2000). Concurrently, HDD prices have plummeted. In 1988, the price per *megabyte* for an average HDD was \$11.54; today it is less than \$2 per *gigabyte* (Disk/Trend Web site, 2001).

This incredible combination of increasing capacity and decreasing price has resulted in a flourishing market. In 1998, the industry shipped 145 million HDDs; by the end of 2002, this number is expected to reach 250 million, denoting nearly \$50 billion in revenues (Disk/Trend Web site, 2001).

Despite the popularity of magnetic storage, its future remains uncertain due to a *major* obstacle: the impending super paramagnetic effect (SPE). SPE is a physical phenomenon that occurs in data storage when the energy that holds the magnetic spin in the atoms making up a bit (0 or 1) becomes comparable to the ambient thermal energy. When this occurs, bits can randomly flip between 0's and 1's, corrupting the information they represent. In an attempt to increase hard drive capacities, manufacturers have crammed smaller and smaller bits together, making the data more prone to SPE. Today, HDDs have a maximum areal density of 35 gigabits per square inch (Gb/sqi). With the current pace of

miniaturization, many experts think the industry could hit the SPE wall by 2005 or roughly 60 Gb/sqi (Toigo, 2000).

In terms of transfer rate and capacity, it may be some time before FMD surpasses the HDD (see Table B2 in Appendix B). However, as a *removable* media, FMD technology is already far ahead of magnetic antiquity. For example, current digital video recorders (DVRs), such as RePlayTV® and TiVo®, use HDDs as their storage solution. Who is actually willing to travel with a TiVo® tucked under their arms? Further, there is a limit to what one can store on a HDD before it becomes necessary to make room for more material.

HDDs have one more limitation: reliability. Although today's HDDs are far more reliable than they once were, they are still gauged by the infamous MTFB (Mean Time Before Failure) parameter. For most HDDs today, MTBF is roughly five years. FMD drives are *not* impervious to electrical or mechanical failure; nevertheless, crash recovery is a far easier task: simply remove the FMD, replace the drive, and reboot. HDD's differ so much between manufacturers and models that salvaging a defective drive is almost impossible. Often, when a HDD fails, the data on it is permanently lost.

### **Solid-State Storage: Flash Memory Cards [\(↑\)](#)**

The rising popularity of portable devices, such as PDAs, digital cameras and MP3 players, has created a niche for compact, solid-state memory modules. Such nonvolatile modules, popularly called "flash memory cards," represent a young but potentially explosive market.

Flash memory cards combine the features of read-only memory (save data when power is off) with random access memory (data can be written, altered and deleted). These qualities are advantageous for portable devices, especially when it comes to power consumption. By simply keeping data in memory, precious battery power is kept from drainage.

Another advantage of flash memory cards is their inherent durability. The solid-state device is usually encased in a hard plastic or metal shell. In addition, there are no mechanical parts. This is unlike optical and magnetic drives, which rely on mechanisms to rotate and track their respective media; the media (DVD and CD) is also subject to scratches, dust and other forms of contamination.

Despite these advantages, the format has major obstacles to overcome. One is the *overabundance* of memory card formats. Currently, there is PCMCIA, Compact Flash, SmartMedia, Multimedia Card, Secure Digital, Memory Stick, Thompson/Matrix and a new but not standardized USB memory key called EasyDisk. Unfortunately, consumers do not get to choose what memory format can be used with a particular device. For example, Sony products use only

Memory Sticks. “Universal” card readers are available for individuals who use more than one card format, but this is an expensive option.

The main obstacles facing flash memory cards are cost and relatively poor storage capacities. Today, flash memory costs five to ten times more than DRAM. Regular PC133 SDRAM costs 11 cents per megabyte, while flash memory costs 70 cents (Wong, 2001). Given the fact that today’s best memory cards allow only 256 MB of storage, they are comparatively expensive.

C3D has developed a potential alternative to flash memory cards: a fluorescent multilayer *card* (FMC) that has most of the advantages of FMDs, only in a compact, credit-card sized format. An FMC can be made just as durable as memory cards by enclosing them in a protective sleeve. FMCs are read by “FMC Readers” (Fig. 6). These units are compact and free of mechanical parts, relying instead on CCD arrays.



Fig. 6 FMC Reader (Courtesy C3D)

In 2000, C3D created an FMC prototype with up to 20 layers, 20 Mbps data rate, and 10 GB worth of storage capacity. The estimated cost of production is less than \$10 per card (C3D Web site, 2000). FMCs with even greater capacity and data rates are currently in the development stage.

## COOPERATIVE AGREEMENTS [\(↑\)](#)

### WARNER ADVANCED MEDIA OPERATIONS [\(↑\)](#)

C3D is currently a research and development organization. Therefore, it does not have the infrastructure and capital necessary to produce and market FMD on a large scale. On July 16, 2001, C3D signed a Cooperative Development and Licensing Agreement with Warner Advanced Media Operations (WAMO), a business unit of AOL Time Warner, to co-develop, cross license and manufacture FMD ROM media. Steve Haddad, Senior Vice President of C3D stated, “This is an extremely significant event in the execution of [C3D’s] partnership strategy. WAMO is the pioneer of DVD manufacturing and innovator of manufacturing processes. As the market leader in ROM media manufacturing, WAMO’s core competencies will be maximized by [C3D] to every extent possible” (July 2001, C3D Web site).

## **SONIC SOLUTIONS** ([↑](#))

The FCC and United States Congress have mandated that every television broadcasting station in the U.S. must broadcast their entire programming lineup in HDTV format by 2006. HDTV content cannot be placed on current DVDs due to insufficient capacity and data rate. Further, broadcast professionals are looking to replace their bulky digital video equipment with technology that is compact, light and ergonomic.

To address this issue C3D and Sonic Solutions, San Francisco, California, have decided to collaborate in mastering High Definition video content for FMD. According to C3D, "Using Sonic Solution's award-winning DVD authoring system, DVD Creator, 100 GB FMDs capable of storing 11 hours of HDTV content in 1080i and 720p resolution are entirely possible" (2001, C3D Web site). Special versions of FMD are also being designed for Post Production, Mastering, Broadcasting and Video/Data Archiving.

## **AVICA TECHNOLOGY** ([↑](#))

One of the most likely initial uses of FMD will be in digital cinema (d-cinema). D-cinema is perhaps the most demanding business application for a storage medium, and FMD is the first optical format up to the challenge.

On April 4, 2001, C3D reached a partnership agreement with Avica Technology, Santa Monica, California, to incorporate FMD technologies in Avica's FilmStore Digital Cinema playback platform (C3D Web site, 2001). The FMD Digital Cinema disc has the ability to provide a secure, removable, single-disc distribution method. This can result in a substantial cost savings (over \$1 billion) when the following facts about *traditional* film distribution are known (Cohen, 2001):

- Average movie consists of six reels, each holding over 2,000 feet of film
- Manufacturing/shipping a single print of film to one theater costs \$1,000 - \$3000
- Wide-release films in the U.S. require 3,000-5,000 prints be made for the same number of screens

## **INTERNATIONAL PARTNERS** ([↑](#))

In addition to an impressive list of domestic allies, C3D also maintains cooperative partnerships with several Asian and European companies (C3D Web site, 2002). These include the following:

- Ricoh (Japan): drives, players, optics
- Zeon Chemicals (Japan): elastomers, polymers and specialty chemicals
- Toolex (Netherlands): thin-layer, pit-filling and embossing technologies

- Lite On (Taiwan): drives and players
- Plasmon (UK): disc manufacturing and mass production
- Profolio Telr (Turkey): digital video recorders (DVRs) and players
- STEAG HamaTech (Germany): dye coatings

## FUTURE FM HARDWARE [\(↑\)](#)

For consumers and businesses, FMD hardware will be similar to today's CD/DVD hardware in both form and function. There will be internal and external drives and "burners" for computer applications. In addition, there will stand-alone FMD video players and recorders, similar to current DVD players and VCRs. Portable units such as FMD "discmen" and "boomboxes" are also possible. The following artist's conceptions (Fig. 7 and 8) are projected appearance of a few such units:



Fig. 7 FMD drive (Courtesy C3D)



Fig. 8 FMD Player (Courtesy C3D)

FMC hardware – used for more compact devices – may appear as shown below (Fig. 9 and 10):



Fig. 9 FMC PDA (Courtesy C3D)



Fig. 10 FMC/D laptop (Courtesy C3D)

## CONCLUSIONS [\(↑\)](#)

This report has presented a critical analysis of fluorescent multilayer technology. Based on our research, we feel it is a *revolutionary* technology – much as CD was in the early 1980s – and has enormous potential for growth. Once it is mass produced, FMD/C will not just be a niche solution – it will be a self-sustaining industry.

For computer manufacturers, FMD can revive lagging sales of recent times. If Steve Jobs, Apple Computers CEO, is correct about computers becoming “digital lifestyle hubs,” consumers will be delighted to back up hundreds of gigabytes of home video and photographs on FMD. For corporate, government and academic archivists alike, FMD offers superior speed, security and reliability over any other format – all while maintaining a much lower cost. Likewise, the consumer electronics industry will be revolutionized because, unlike previous optical media, FM technology is not limited to rotating disc implementations: credit card and postage-stamp-sized formats will allow small, portable devices to take advantage.

Hashmi Technical Consultants feels strategic investments in C3D and other companies that support FM technology will ensure its ultimate success. As Adam Cohen, creator of FMDInsider.com states, “[FM] technology embodies the gestalt of all instances of genius – the list of potential applications is as inexhaustible as imagination itself” (2001, p. 89).

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# APPENDIX A: Graphics [\(↑\)](#)

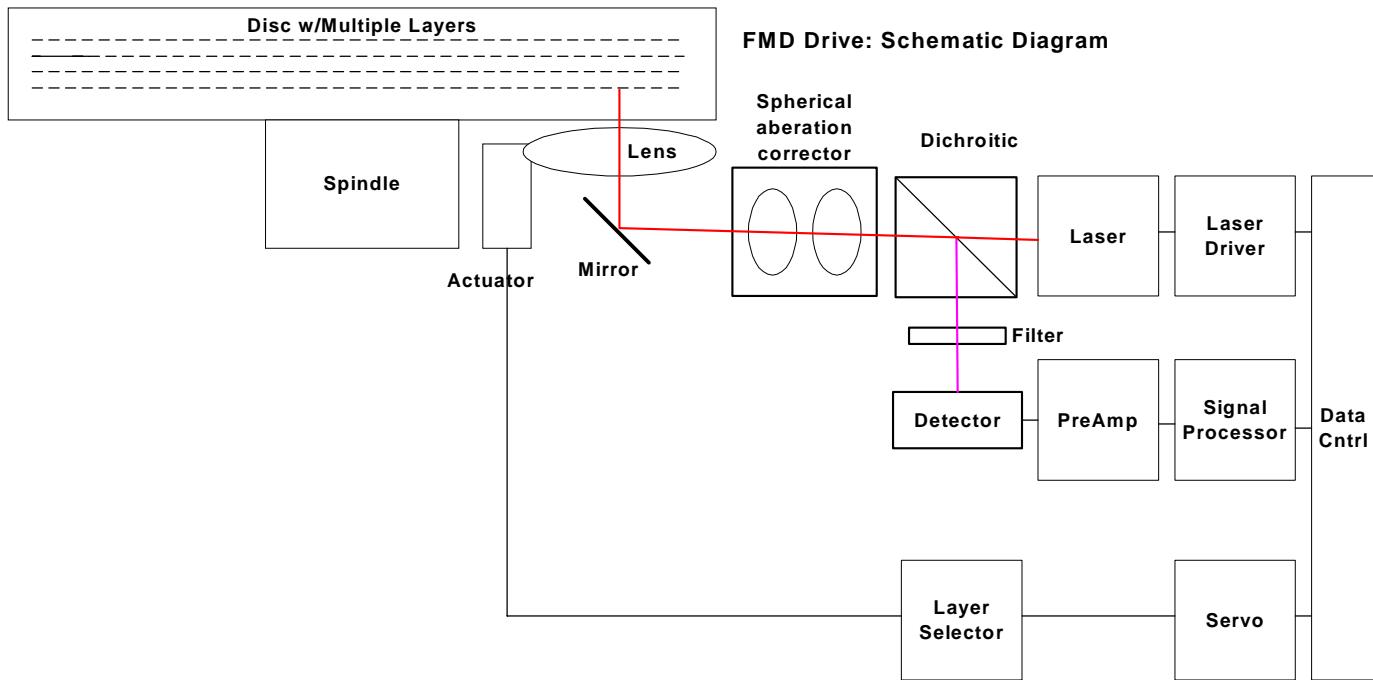


Fig. A1 (Original C3D schematic enhanced by Hashmi Technical Consultants)

# PUSHING THE OPTICAL STORAGE ENVELOPE

CD, DVD, and FMD use the same form factor and red laser configuration, with radically different results.

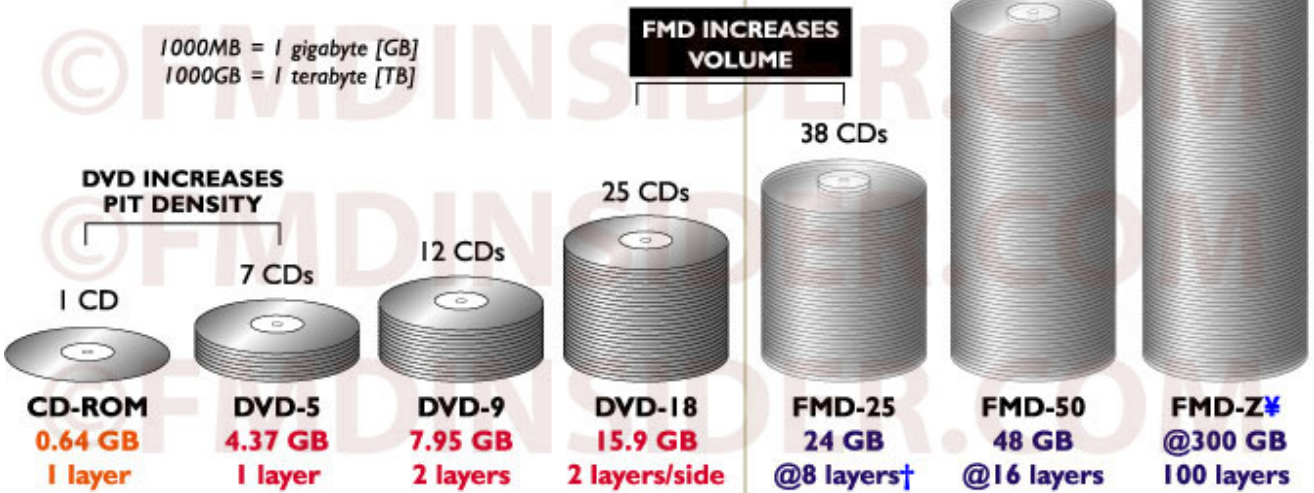
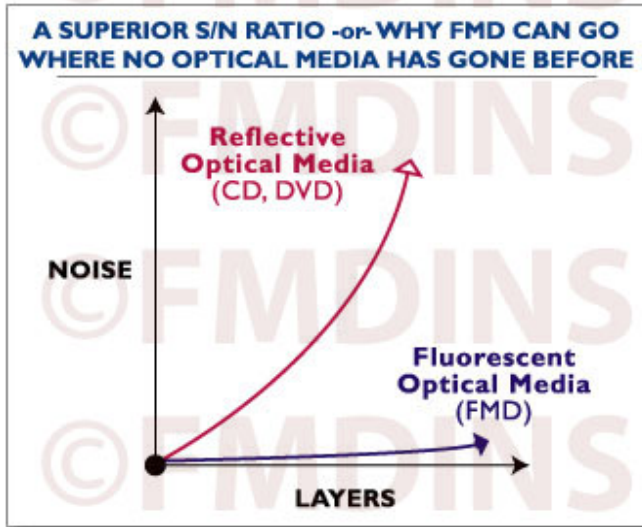


Fig. A2 (Courtesy FMDinsider.com)

## APPENDIX B: Tables [\(↑\)](#)

Optical Medium	CD	DVD	FMD (Gen1)	FMD (Gen2)	HD-DVD	FMD (BlueGenX)	FMD (BlueGenY)
<b>Disc Diameter</b>	120 mm	120 mm	120 mm	120 mm	120 mm	120 mm	120 mm
<b>Disc Thickness</b>	1.2 mm	1.2 mm	1.2 mm	1.2 mm	1.2 mm	1.2 mm	1.2 mm
<b>Disc Structure</b>	Single substrate	Two bonded 0.6 mm substr	60-600 micron thick substrate	24-600 micron thick substrate	Two bonded 0.6 mm substr	24-600 micron thick substrate	12-600 micron thick substrate
<b>Laser Wavelength</b>	780 nm (infrared)	650 and 635 nm (red)	650 and 635 nm (red)	650 and 635 nm (red)	blue or violet	blue or violet	blue or violet
<b>Numerical Aperture</b>	0.45	0.60	0.60	0.60	?	?	?
<b>Data Layers</b>	1	1 or 2	1-20	1-50	1 or 2	1-50	1-100
<b>Data Sides</b>	1	1 or 2	1 or 2	1 or 2	1 or 2	1 or 2	1 or 2
<b>Data Capacity</b>	0.64 GB	4.37-15.9 GB	~3 GB/layer	~3 GB/layer	~20 GB/layer	~13 GB/layer	~13 GB/layer
<b>User Data Rates</b>	1.2 Mbits/sec (ROM Mode 1)	10 Mbits/sec (DVD-V)	10-24 Mbits/sec	10-60 Mbits/sec	10-100 Mbits/sec	10-100+ Mbits/sec	100-1000 Mbits/sec
<b>Cost per GB</b>	~\$0.60 (CD-R)	~\$2.60 (DVD-R)	NA	NA	NA	NA	NA

Table B1 CD/DVD vs. FMD

Storage Medium	Hard Disk Drive (HDD)	DVD (Red laser)	FMD (Red laser Gen1)	FMD (Red laser Gen2)	HD-DVD (Blue laser)	FMD (Blue laser GenX)	FMD (Blue laser GenY)
<b>Disc Structure</b>	Multi platter Al/Mg or Si	Two bonded 0.6 mm substr	60-600 micron thick substrate	24-600 micron thick substrate	Two bonded 0.6 mm substr	24-600 micron thick substrate	12-600 micron thick substrate
<b>Areal Density (Gb/sqi)</b>	35.1 (as of Feb 2002)	6	100	100	12	2000	2000
<b>Data Layers</b>	1	1 or 2	1-20	1-50	1 or 2	1-50	1-100
<b>Data Sides</b>	2 per platter	1 or 2	1 or 2	1 or 2	1 or 2	1 or 2	1 or 2
<b>Data Capacity</b>	160 GB (Maxtor 5400 RPM)	4.37-15.9 GB	~3 GB/layer	~3 GB/layer	~20 GB/layer	~13 GB/layer	~13 GB/layer
<b>User Data Rates</b>	52 MB/sec (Sustained)	10 Mbits/sec (DVD-V)	10-24 Mbits/sec	10-60 Mbits/sec	10-100 Mbits/sec	10-100+ Mbits/sec	100-1000 Mbits/sec
<b>Cost per GB</b>	>\$2 (Maxtor)	~\$2.60 (DVD-R)	NA	NA	NA	NA	NA

Table B2 HDD vs. FMD

APPENDIX C: Request for Proposal and Proposal [\(↑\)](#)

**The High-Tech Mutual Funds Company**  
**PO Box 123456, Denver, Colorado 80217**

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**- Request For Proposal -**

Date: 2002/02/11

Subject: Search for new investments in data-storage market

Attn Consultants:

Our company is looking for “bankable” technologies in which to invest. In particular, we want to focus our investment strategies on data-storage formats that are or will be used in information technology and multimedia.

Please put together a proposal selecting a technology that you feel successfully competes (or will compete) in the high-technology market. You do not have to perform a business analysis on the technology. However, you must present a scientifically credible analysis that is backed by solid research.

If your proposal meets with our criteria, we will request a comprehensive report from your organization. The purpose of that report will be an in-depth study of the choice(s) you made in the proposal.

Sincerely,  
*The High-Tech Mutual Funds Company*

## Digital Data Storage and Future Markets

Prepared For: The High-Tech Mutual Funds Company

Submitted By: Hashmi Technical Consultants

Date: 13 February 2002

### Summary

Current magnetic and optical data-storage formats limit the potential of modern multimedia software. Fluorescent Multilayer Disc (FMD) -- a new high-capacity, high-speed format -- will remove most of these restrictions allowing multimedia companies to take their products to unprecedented levels. This proposal recommends FMD as the top choice among technology investments in the data-storage market.

### Introduction

Today the world seems to be saturated with data-storage formats. CD and DVD are the most common *optical* formats. Newer flash memory cards, used in digital cameras and PDAs, comprise a medium that is just beginning to take root. Finally, there are the ubiquitous magnetic formats: hard disc drives, floppies, Zips and tape. The data-storage market is highly competitive. As a result, new technologies arise or old ones quickly evolve. Storage devices and their associated media differ in data capacity and transfer rate, access time and cost per megabyte. The demand for growth in data-storage capacity is huge -- over 60 percent per year in the last decade (Toigo, 2000). Unfortunately, many of the *current* formats have or will shortly be approaching their theoretical capacity limits.

Based on our research, three-dimensional optical storage -- realized in a format called Fluorescent Multilayer Disc (FMD) -- shows the most promise. Not only is it suitable for virtually all foreseeable data needs, it is compatible with *current* optical technology.

### Magnetic Storage: Hard-Disk Drives

Magnetic storage technology -- especially the hard-disc drive (HDD) -- has evolved to a high standard. Today, HDDs serve as the *main* data-storage component of personal computers. Costing as little as \$2.00 per gigabyte, HDD storage is inexpensive and reliable (BestBuy.com Web site, 2002). Magnetic

HDD technology is supported by some of the giants of the electronic industry, such as IBM, Sony, Fujitsu, and others. To meet current demands, these companies continue to invest billions of dollars in research and development. Some of the latest demands come from application-specific devices, such as digital video recorders (DVR). Sony, Microsoft and Panasonic market popular DVRs such as TiVO, UltimateTV and RePlay.

Despite the popularity of magnetic storage, its future is uncertain due to several obstacles. One hurdle deals with the laws of magnetic physics, which limit the capacity that can ultimately be squeezed onto magnetic media. Other concerns involve durability and reliability limitations of the format.

### **Solid State Storage: Flash Memory Cards**

The explosive growth of *portable*, digital devices – PDAs, digital cameras, MP3 players, etc. – have created a demand for flash memory cards. This type of memory has many benefits other than its compact size. One of the major problems memory cards alleviate is power consumption, a vital issue for mobile devices. Keeping data stored in memory no longer drains batteries. Another advantage to memory cards is their inherent durability. Being a solid-state device eliminates the problem of mechanical wear and tear; scratches are not a problem, unlike CDs and DVDs.

The main obstacles for flash memory cards are their relatively poor storage capacities and cost. Flash memory currently costs five to ten times more than DRAM. Regular PC133 SDRAM costs 11 cents per megabyte, while flash memory costs around 70 cents (Wong, 2001). CDs cost less than a penny per megabyte. Given the fact that today's best memory cards allow only 256 MB of storage, they are an expensive option.

Another hurdle for flash memory cards is the *overabundance* of formats. There is PCMCIA, CompactFlash, SmartMedia, Multimedia Card, Secure Digital, Memory Stick, Thomson/Matrix and a new but not standardized USB flash memory "keys." "Universal" card readers are available for individuals who use more than one card format, but this is a costly option.

### **Optical Storage: DVDs**

The CD format's reign is ending despite its current popularity. DVDs are bound to take over the position as the optical format of choice. In terms of home entertainment, DVD-V has proven to be the fastest-growing format ever – surpassing even CD and VHS. DVD-ROM, used for computer software, has had a tougher time gaining acceptance. One reason may be the late arrival of writable (recordable) DVDs. Presently, leading electronic manufacturers are

marketing four *completely incompatible* formats: DVD-R, DVD+RW, DVD-RW and DVD-RAM. Despite these shortcomings, recordable DVD drives are finally becoming cost effective. Many computer manufacturers are even starting to offer such drives on their high-end models.

DVD allows a maximum of 18 GB of data storage in a dual-layer, dual-sided configuration. This is sufficient with respect to most *computer* applications. However, it is far less than the capacity needed for the latest home entertainment devices or multimedia standards. A prime example is HDTV. DVD storage can be doubled using the much-anticipated blue laser (current CDs and DVDs use a red laser). Unfortunately, using blue lasers will only double current DVD capacity; much more is needed for HDTV. To further complicate things, HDTV requires a data rate of 20-24 Mbps; current DVD technology is only capable of approximately 10 Mbps. Although it is possible to reformat DVD to this higher rate, it would consume the disc's storage capacity before it could accommodate a two-hour film.

The quest to replace *audio* CDs with a high-resolution, multi-channel, audio-only format has led to two competing (and incompatible) formats: DVD-Audio (DVD-A) and Super Audio CD (SACD). Although both have been available for over a year, sales have been poor. People seem to be content with CD. In addition, the Internet has given listeners another choice: MP3. This format has not only curtailed interest in the new high-resolution formats, it has also made a significant impact on *existing* CD sales (BBC Web site, February 2001). MP3 cannot match the sound quality of CD, much less DVD-A or SACD. To many, however, this is not an important factor – they simply want the convenience of putting hundreds of tracks onto a single CD. The potential of placing *thousands* of MP3 tracks onto a recordable DVD may further complicate the “high end” audio market.

### **Optical Storage: Fluorescent Multilayer Disc (FMD)**

FMD is a revolutionary optical disc technology pioneered by [Constellation 3D](#) (C3D). It incorporates three-dimensional optical storage allowing monumental gains in data capacity and transfer rates. If the format gains enough support, it has the capability of eclipsing every other data-storage technology mentioned in this proposal. This can be done with comparatively less cost, time and effort than competing magnetic and solid-state formats.

Briefly, an FMD is a multi-layer, readable/(re-)writable disc with the same diameter and thickness as a CD or DVD. Using current red-laser technology, it is possible to create a 300 GB disc with 100 Mbps write and 1 Gbps read speeds! Once blue lasers become economically feasible, a 1terabyte disc is possible. An FMD can be made backward compatible; that is, it can be formatted to *current* CD and DVD standards. Existing CD/DVD manufacturing plants will only require minor tooling changes to accommodate the new format. FMDs are also cheaper

to produce since they do not require the hard-to-manufacture reflective media used in CDs and DVDs; they can be made in labs that do not require stringent clean-room standards.

In terms of hardware, existing CD/DVD players and drives need only minor modifications to be compatible with the new format. In fact, one of the latest [prototypes](#) is simply an off-the-shelf Toshiba DVD player reworked for an R&D demonstration.

Although preliminary results have been very encouraging, FMDs and FMD drives exist *only* as prototypes. Nonetheless, [major electronic and multimedia companies](#) have begun to take interest in this format. One of the chief commercial interests for FMD is d-cinema. Manufacturing and distributing 2000 feet of film (*one* movie) for 30,000 US screens is a staggering expense. In an effort to reduce costs, major film studios are interested in replacing 35mm film with digital storage and playback. FMD is the only optical format that can face this challenge. This is just one of an endless list of possible applications.

## **Conclusion**

We feel FMD offers the best potential for growth in the data-storage market. Although C3D is a young, R&D organization, it is beginning to draw extensive financial support from major multimedia companies. Strategic investments in C3D and others who support FMD will ensure its success. It is one of the most promising storage formats ever conceived. We look forward to providing you with an extensive report on this technology.

APPENDIX D: Project Approval Letter ([↑](#))

**The High-Tech Mutual Funds Company**  
PO Box 123456, Denver, Colorado 80217

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Date: 2002/02/16

Subject: Request for in-depth report on fluorescent multilayer technology

Attn Hashmi Technical Consultants:

Congratulations! Your organization provided the most convincing proposal. Therefore, we are commissioning an in-depth report project on the benefits of fluorescent multilayer technology. The report should be completed no later than March 27, 2002. We would also like a mid-term progress report during the week of March 3, 2002. We recommend you complete the report in the following seven-phases:

*Phase 1:* Begin research by taking notes from reference material

*Phase 2:* Contact editors or webmasters from Internet resources for additional, technical information; obtain permission to use graphics

*Phase 3:* Create outline, then begin writing "body" of report

*Phase 4:* Complete writing body of report; add graphics; create comparison tables, Title page, Table of Contents, Introduction, Appendix and References; submit Progress Report

*Phase 5:* Assemble final report by incorporating RFP, Proposal and Progress Report; adjust page layout accordingly

*Phase 6:* Proofread document; make revisions

*Phase 7:* Submit final report

If you have any questions or comments, please feel free to contact us.

Sincerely,  
*The High-Tech Mutual Funds Company*

## APPENDIX E: Progress Report ([↑](#))

### *Hashmi Technical Consultants, Inc.*

#### MEMORANDUM

DATE: March 5, 2002  
TO: The High-Tech Mutual Funds Company  
FROM: Khurram Hashmi, Special Projects Director  
SUBJECT: Progress Report on Fluorescent Multilayer Technology Analysis

#### INTRODUCTION

On February 16, your company commissioned a research project from our organization on the topic of fluorescent multilayer (FM) technology. We agreed that the project would take six weeks and be completed in the following seven phases:

- Phase 1: Begin research by taking notes from reference material
- Phase 2: Contact editors or webmasters from Internet resources for additional information; obtain permission to use graphics
- Phase 3: Create outline, then begin writing “body” of report
- Phase 4: Complete writing body of report; add graphics; create comparison tables, Title page, Table of Contents, Introduction, Appendix and References; submit Progress Report
- Phase 5: Assemble final report by incorporating RFP, Proposal and Progress Report; adjust page layout accordingly
- Phase 6: Proofread document; make revisions
- Phase 7: Submit report to *The High-Tech Mutual Funds Company*

The project is now near the end of Phase 4. We are happy to report that our analysis of FM technology – even at this intermediate stage – continues to reflect the optimism expressed in our original proposal. This report provides an overview of the work that has been completed as well as what remains to be done.

#### WORK COMPLETED

During week one (Feb 17 – Feb 23) of this project, we began gathering extensive information from various websites, as well as books and periodicals from our own library or the library at the University of Toledo. Throughout week two (Feb 24 – Mar 2), we contacted several webmasters for additional technical information as well as to request the use of their graphics. During week two and part of week three (Mar 3 – Mar 9), we began writing the main body of the report as well as incorporating graphics and tables.

## Use of Internet

We used the Internet extensively for gathering the latest information on FM technology as well as competing formats. The following list contains sites that we felt provided the best information for our analysis:

1. *Constellation 3D* <http://www.c-3d.net>: The inventors of FM technology. This site provides the latest developments in FM technology as well as financial and market information. C3D's site is one of the primary resources for our analysis.
2. *FMD Insider* <http://www.fmdinsider.com>: A private site maintained by Adam Cohen. This site has excellent, non-biased coverage of FM technology as well as its competing formats. FMD Insider is also one of the primary resources for our analysis.
3. *Disk/Trend, Inc.* <http://www.disktrend.com>: An organization that studies the hard-disk drive (HDD) market. Their year-by-year analysis of the HDD industry, as well as their predictions of future trends, has allowed us to make a very solid case for FM technology.
4. *OnePC* <http://onepc.net>: This site provides comprehensive information about the latest trends in the PC industry. We used their evaluations of solid-state memory cards in our comparison analysis.

## Use of Periodicals and Books

In our analysis, we have used several periodicals and books to provide us with solid, scientifically credible information. Among the most valuable of these resources are the following:

- *Scientific American*. Unfortunately, the editors of this outstanding periodical have not yet devoted coverage to FM technology. However, their thorough investigations into magnetic and solid-state formats have been invaluable in our comparison analysis.
- *PC World*. This periodical provides excellent coverage of cutting-edge developments in the computer industry. We have used their product reviews, such as those comparing the latest HDDs, to “gauge” the competitiveness of a storage format.
- *DVD Demystified 2<sup>nd</sup> Edition* by Jim Taylor. This is often considered *the* textbook of DVD and CD technology. In our format-comparison tables, we have made generous use of numerical data – as well as non-trivial facts – presented throughout this textbook.

## Email Correspondences

We used email to contact various organizations. This was done for two reasons: obtain further information on a specific topic and/or request permission to use

graphics found on their website. In all of our initial correspondences, we clearly stated the *format* Hashmi Technical Consultants uses in its reports to cite borrowed graphics. The following is a summary of our correspondences:

1. Adam Cohen, creator of *FMD Insider*. We emailed Adam on February 25 to request permission for the use of various graphics he has created for <http://www.fmdinsider.com>. He promptly replied the same day, granting us permission. Adam asked that his site be given credit in the report and that a copy of our final project be sent to him for his own curiosity. We contacted Adam again on February 27 for his opinion on the recent announcement of DVD's next evolution, the Blu-Ray project. In his response, again extremely prompt, Adam asked us to read the update on his site the following day (Feb 28).
2. John Ellis, VP of Marketing, *Constellation 3D*: We emailed John on February 25 to request permission for using various graphics from the C3D website. In addition, we requested permission to display a *modified* version of their FMD drive schematic in our report. We received his response on February 27 indicating our request was approved.
3. *Dell Computer*. On February 25 we emailed the webmaster of <http://www.dell.com> requesting permission for the use of graphics presented in their [White Paper](#) on removable media storage. We received a response from Steve Williams, Assistant Web Designer, on March 1 stating we could use their graphics as long as Dell was cited for each image and that we complied with their published [terms of use](#).

## The Report

The majority of the report's "rough draft" has been written. Currently, it is composed of seven main sections:

8. *Demands in Data Storage*: discussion of data-storage needs in foreseeable future
9. *Introducing FMD*: brief introduction to fluorescent multilayer disc
10. *Technical Analysis*: a complete overview of FM technology
11. *Comparisons*: FM media compared with other formats
12. *Cooperative Agreements*: overview of C3D's domestic and international partners
13. *Future FMD Hardware*: artist's conceptions of future FMD drives/players
14. *Conclusions*

Most of the graphics and tables have also been added.

## **WORK PLANNED**

With the research completed and permissions to use images approved, we are making excellent progress towards completing this report. We predict the following schedule for the remainder of the project:

March 9: Complete Phase 4

March 10-16: Begin and complete Phase 5: assemble final report

March 17-26: Begin and complete Phase 6: proofread document and make revisions

March 27: Phase 7: Submit final copy to *The High-Tech Mutual Funds Company*

## **CONCLUSIONS**

Thus far, the project is proceeding well. The only hurdle we encountered was the announcement of the DVD Blu-Ray project last week. However, this new information only meant changing a few numerical facts in our comparison analysis – it did not affect the outcome. We are confident that a high-quality project will be delivered to your firm on schedule. If you have comments or questions, please feel free to contact us.