An Introduction to Optical Disk Technology

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Introduction

Laser technology found its first popular commercial use in the music industry, storing digitized sound on CDs, or Compact Disks. CDs became popular very quickly, because the disks are so compact, and the sound quality far superior to tapes and records. Now, laser technology is being used in the computer industry as well.

Optical Disk Drives, which use lasers to store and retrieve data from optical disks, are one of the latest breakthroughs in mass storage technology. WORM (Write Once, Read Many) optical disks are currently available, and have a number of advantages over more traditional storage methods. Their most obvious power comes from their tremendous data capacity, which allows massive amounts of data to be stored very compactly. Since WORM media can only be written to once, they are best suited for storing information that does not change over time.

The "write-once" aspect of WORM media does create a few problems that must be addressed. WORM optical disks are more susceptible to surface defects than are other storage media, so special care must be taken to see that all errors are detected and corrected. Also, since a standard operating system computer-disk drive interface expects that an area can be written to more than once for directory maintenance, special software drivers are required for use with WORM disks.

Erasable optical disks are now in the works, and should be available commercially in the very near future. Erasable disks offer all the advantages of WORM media, as well as the flexibility of erasing and rewriting stored information. However, the erasable technology is still in the developmental phase: it has many problems to address and a long road of development ahead. Erasable disks, and future developments in the field, will add to the allure of optical technology.

This paper will introduce both technologies, but will proceed to describe the WORM technology in greater detail, as it is currently available.

Optical Recording Methods

Optical disk technology was "fathered" by Phillips Corporation. CD-ROM and WORM drives are now being developed by such companies as Sony, Toshiba and Ricoh, along with a host of smaller companies. Erasable disks are being developed in sizes of 5.25 and 3.5 inches, by Olympus, Sharp, Seiko-Epson and Kodak, to name a few.

WORM Disks

WORM optical disk drives use optical disks that can be written to only once, as the writing process causes permanent alteration of the medium. WORM disks are grooved, much like a phonograph record but with a much greater density of grooves. Writing is performed on the raised portion rather than in the groove itself. A laser beam is used to produce a "pit" on the raised portion of the medium. Figure 1 shows a vertical cross section (along tracks and sectors) of a WORM disk.

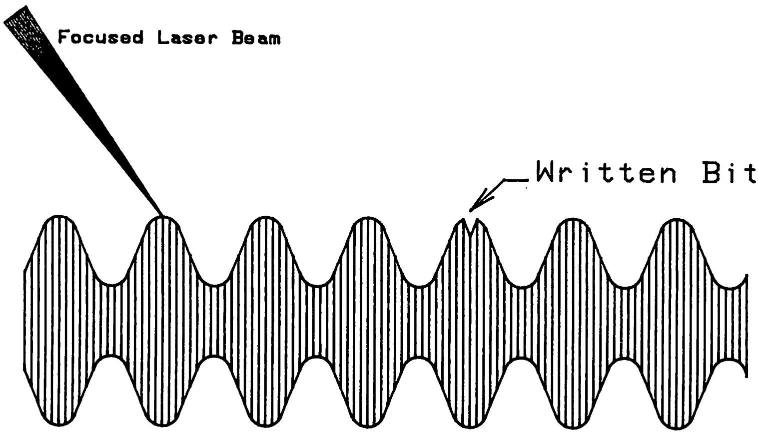

Figure 1: **WORM Optical Recording**

Each pit created on the disk represents a bit. The same laser beam that is used for writing is used to read the information that has been recorded: each pit is interpreted as a digital 1, and each "no pit" is interpreted as a digital 0. Once a pit has been created, it cannot be removed: thus information written to a WORM disk is permanent.

Erasable Disks

Optical disk drives that record on erasable disks also use lasers for reading and writing, but the technology is a bit different. On erasable disks, the recording substrate is magnetic: the value of a bit depends upon whether its orientation is "north-pole-up" (representing a 1), or "north-pole-down" (representing a 0). This is illustrated in Figure 2.

A blank erasable disk has all of its bits pointing north-pole-down (0). A magnetic coil in the drive produces a magnetic field that points north-pole-up. The strength of the magnetic field required to change the orientation of a bit varies with temperature: at room temperature, the magnetic coil is too weak to induce such a change. At temperatures above 300 degrees Fahrenheit, however, the force required to change the magnetic orientation of a bit falls to almost zero, so bits are easily "flipped" by the magnetic coil.

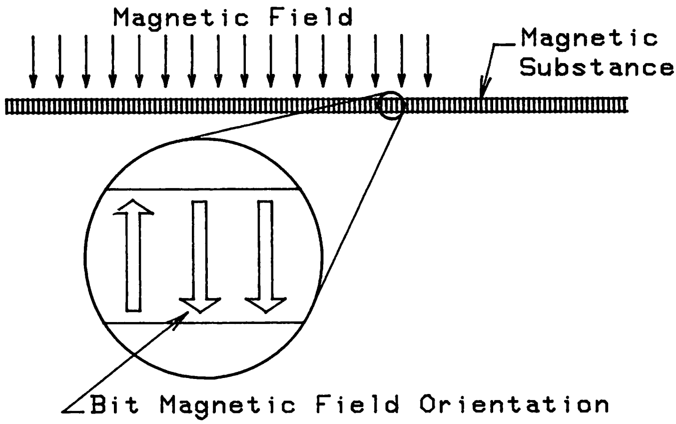

Figure 2: **Erasable Optical Recording**

To record information, a laser beam is used to heat a spot on the disk (representing a bit) to 300 degrees Fahrenheit for a few nanoseconds. In this time, the magnetic coil is able to change the orientation of the heated area to north-pole-up, recording a digital 1. Data on the disk can be erased by reversing the magnetic field of the coil (either by physically flipping the magnetic coil, or electromagnetically): with the laser on continuously, every bit that is oriented north-pole-up will be flipped to north-pole-down.

The same laser beam, at a much lower intensity, is used to read the data on the disk. When the laser beam hits the substrate and is reflected, its polarization will be rotated in either a clockwise or counter clockwise direction, depending upon the orientation of the bit being read.

Optical Advantages and Disadvantages

Advantages

WORM optical disks are rapidly becoming the medium of choice for data storage and archival, due to their numerous advantages over other data storage and archival methods. When erasable optical disks become available, the same advantages will apply. These include the relatively long archival life of optical disks, the compactness of the optical disk cartridges, high capacity, portability and ease of data access. Optical drives are also less vulnerable to problems caused by surface contamination, are not prone to head crashes, and data cannot be accidentally overwritten, or erased by magnetic fields.

Magnetic tape, for instance, has traditionally been chosen for the archival task. But magnetic tape has a relatively short life span: three years or so. Stretching or breaking of the tape and print-through (which occurs when the magnetic field from one layer of the tape migrates to an adjoining layer) contribute to the degredation of the medium, hence corrupting the stored data. Optical disks, on the other hand, have a projected archival life of 10-20 years. In addition, data access times are faster for optical disk drives which are random-access devices, than for magnetic tape which must be searched sequentially when data needs to be retrieved.

Microfilm, which has a 100 year life expectancy, is another medium commonly used for archival purposes. Microfilm's greatest disadvantage is its inconvenience: retrieving stored data is a tedious task. This characteristic makes microfilm great for storing information that is rarely (if ever) accessed, but too inaccessible for storing data that needs to be used. Optical disks offer an alternative that allows fast and easy access to any stored piece of information.

Optical disk drives also have a number of advantages over magnetic hard disk storage. Firstly, a major concern when using magnetic disk drives is the possibility of a head crash, resulting in lost data. Magnetic heads must be very close to the disk to work properly: they are typically only 8 to 10 μinches above the disk surface. When shock or vibration occurs, the possibility of a head crash is very real. Optical heads, however, may be as far as 2 millimeters away from the optical disk surface, making a head crash extremely unlikely.

Secondly, magnetic disk drives are much more sensitive to contaminants (dust particles, smoke, etc.) in the head assembly and on the disk itself. Particles on the disk or in the head can interfere with the reading and writing of data, causing the information to become corrupt. Optical heads do not focus on the disk surface, but on the substrate which is encased in glass or plastic. Because of this, contaminants have much less of an effect on the reading and writing of data to an optical disk.

Thirdly, optical disks are much less vulnerable to stray magnetic fields than are magnetic media. Once data is stored on an WORM optical disk, it cannot be erased by accidental exposure to magnetic fields. With erasable disks, the magnetic force required to corrupt the stored data at room temperature is much higher than any magnetic force that would occur in an ordinary environment.

Optical disks have additional advantages over all other storage techniques. A 5.25-inch optical disk can easily hold 200–400 MBytes of data (or more) per side. Optical disks can hold at least 400 Mbits of information per square inch, compared to 49 Mbits per square inch for magnetic media. The removable optical disk cartridges are compact, capable of storing vast amounts of data, and easy to access when you need information. And, unlike the higher capacity Winchester hard disks, the information is stored on a portable optical disk that is easily removed and transported from one machine to another. Optical disks are less expensive than other data storage methods when you take into account the overall data capacity, and with a WORM (Write Once, Read Many) drive, data cannot be accidentally (or intentionally) overwritten. No other data storage technique has this unique combination of features.

Disadvantages

Though optical disk drives have a number of advantages over other storage methods, they are not completely free from drawbacks. Speed is an important consideration in any application. Though optical disk drives are faster than sequentially accessed magnetic tape, their access times are at best comparable to magnetic hard disk. When speed is crucial, the optical disk drive may be outperformed by magnetic hard disk.

Presently, the most outstanding difference (which may or may not be regarded as a disadvantage) between optical disk drives and other storage techniques is that data written to a WORM optical disk is permanent. Once data is written to a WORM optical disk it cannot be overwritten, edited or erased. This is not the case for any other popular storage/archival techniques.

WORM Error Detection and Correction

The write-once aspect of WORM optical disks creates another problem: how to ensure data reliability in write and read operations. WORM disks, by their very nature, are more prone to surface defects than magnetic media. A typical optical disk has a bit error rate (BER) of 10^{-4} or 10^{-5}: meaning that for every 10,000 (10^4) or 100,000 (10^5) bits written, one error (on the average) occurs. A typical BER for magnetic hard disk is much closer to 10^{-12}.

On magnetic disk and tape, surface defects can be detected before the medium is ever used by writing data and then reading it back. This procedure identifies the defective sectors and tracks, which are then skipped over when the drive is used to actually store data. This greatly reduces the chance that data will be written on a defective area. This method cannot be used with WORM optical disks, since write operations destroy the disk. So, the quality of the optical disk surface cannot be ascertained before it is used. Certainly, high production standards can help to reduce surface defects, but such defects cannot be eliminated. Errror correction codes are the only way to increase the reliability of a WORM disk surface. Such techniques can reduce surface defect errors to 1 in 10^{12} bits written.

Errors can also be caused during the writing operation if the laser is poorly focused, or if the head assembly is not properly centered on the track. Optical disks are grooved, much like a phonograph record: writing is performed on the raised portion rather than in the groove itself. If the head assembly is not properly centered during the write operation, the pit representing the data will not be centered on the raised portion, and may not be read properly.

To compensate for the fact that optical disks have a relatively high BER, very effective error correction techniques must be employed. One method for detecting errors entails dividing data that is stored by a known polynomial, and storing the result on the disk. When the data is read back, the division is performed again, and the result compared to the result stored on disk. If the results differ, an error has occurred. While this method will reveal that an error has occurred, it cannot pinpoint the exact location of the error, and it does nothing to correct the error.

Another alternative is to use an error check and correction (ECC) code. With this method, errors are checked and corrected as they occur. This method is more useful since it actually corrects errors as they occur, but this method also uses a significant amount of disk space. This space is transparent to the user.

The biggest problem with any error correction method is that bad sectors of the disk cannot be forseen and compensated for. If a large area of the disk is defective, a lot of time and space can be wasted detecting and correcting error after error as it occurs. Despite these problems, errors can be found and corrected, without significantly deteriorating the performance of the WORM optical disk drive.

Applications

Optical disk drives, because of their ability to store very large quantities of data in a limited space, are especially suitable for data archival and backup puposes. In general, applications involving information that does not change over time can take advantage of WORM optical disk technology. This includes such things as testing results, seizmographical data, topological data, medical data, and knowledge bases. With the advent of erasable disks, the applications will grow to encompass any area where very large amounts of information must be stored as compactly as possible.

Meeting Military Specifications

Many military applications, such as terrain guidance systems, moving map systems, and data archival and backup, make use of unchanging data. With such a range of uses for optical disk technology, meeting military standards (not an easy task by any stretch of the imagination) is the next obstacle that must be overcome.

Different branches of the military have different specifications for the equipment they use. Standards must be met for every aspect of a drive's function, including radiation, noise, shock, vibration, temperature, humidity, and voltage. A drive that will be used on a submarine may have to fit through a hatch that is 25 inches in diameter, and be able to endure pitch and roll 30 degrees from horizontal with no loss of function. One shock test for the Navy involves dropping a hammer onto the drive during operation.

Optical disk media may well have the most trouble standing up to military guidelines. Two different substrates are considered for use: glass and plastic. Glass is usually considered a better choice as it can tolerate higher temperatures and more vibration. Most optical disks employ a sensitive material that is Tellerium based. Tellerium, however, does not tolerate humidity well, making it susceptible to corrosion. To compensate for this the medium must be sealed within an air pocket, which can cause problems if the air pressure drops. Some companies have turned to a Platinum-based disk which is not as easily corroded.

Software Support for WORMs

WORM optical disk drives do present some interesting challenges in the area of software support. As an example, consider Hewlett-Packard machines and operating systems. All HP operating systems currently in use require a storage medium that allows multiple writes to the same track or sector. Directory entries, which reside in clusters on the disk, must be updated each time a file is added or modified. WORM disks cannot be written to more than once, so the directory cannot be maintained using conventional methods.

There are two basic solutions to the WORM access problem:

1. Access can be limited to disk imaging, which allows a volume to be stored for reading access only;
2. Special drivers and software can be developed which allow a complete range of operations to the optical disk.

Disk Imaging

Creating a disk image for read-only access requires no special software tools. With this method, the user can copy an entire disk or volume onto the optical disk, using the appropriate commands from the operating system being used to access the disk. This method creates an image of the disk being archived. Once the disk or volume has been copied onto the optical disk, the copy can be accessed using the same commands that were used to access the original disk. This method can be used to make an exact duplicate of an existing volume with any type of directory system.

The drawback to this method is the fact that access to the copy is "read-only" access: new information cannot be written to the optical disk once a disk image has been made. Also, making a disk image will use up an entire optical disk volume. If the optical disk drive being used to hold the copy cannot be partitioned into smaller volumes (either through hardware or software), a lot of space may be wasted. Making a copy of a 40 MByte hard disk on a 200 MByte optical disk will use up the entire 200 MBytes, unless the disk can be partitioned into smaller volumes.

Read/Write Access

The software problems for supporting WORM optical disks are centered around the fact that a given sector of an optical disk can only be written to once. Conventional operating system support for directories requires the ability to rewrite a given sector within the directory area. To circumvent this restriction, a new directory structure must be devised which eliminates the need to rewrite sectors to support an elaborate file system.

OPTIDAM (for OPTIcal Directory Access Method), developed by IEM for use with its optical disk drives, is an example of such a directory system (see Figure 3).

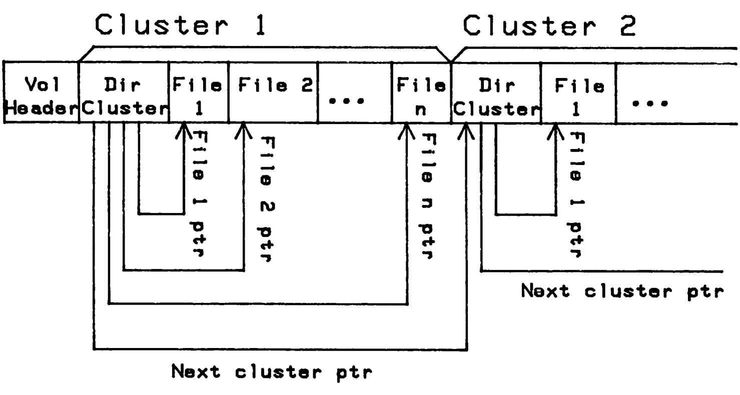

Figure 3: **OPTIDAM Directory Structure**

Each time the user writes a file or group of files (a group of files is a set of files open at the same time), information about these files is placed in a cluster of directory entries, and then written into a single sector which is located physically before the files on the optical disk. This is shown in Figure 3.

Each cluster represents a group of files that were opened at the same time by the user. The directory cluster is not written out to the disk until the last file that was open for writing is closed. This way, more than one directory entry can be written on one sector: the directory sector is not written until all the files are closed. It is conceivable to have only one file per cluster, but only if the user opens one file for writing and closes it before opening another file for writing.

Before each cluster is written out to the disk, sufficient information is written into the cluster structure to allow for finding the next cluster on the disk. This is accomplished in part by a pointer which points beyond the last file in the cluster. Each cluster contains one directory entry for each file in the cluster. This entry has information similar to any entry used by other operating system file supports such as LIF or UNIX files.

When the OPTIDAM directory structure is being used, there are two ways to support access to the optical disk: using existing operating system commands, or using archival utilities.

It may be possible to use the existing operating system commands to access the disk, with a few restrictions. Obviously, commands that violate the WORM nature of the disk (such as the BASIC commands PURGE or RENAME) cannot be used. This solution has the advantage of familiarity to the user, who is not required to learn a new language to use the disk drive. Alternately, archival utilities can be used to access the disk for reading and writing. Such utilities need to take into consideration the WORM nature of the drive, and the workings of the operating system.

In summary, access to a WORM optical disk can be supported in three basic ways:

1. **Disk Imaging.** This requires no special software tools, and allows users to make backup/archival copies of an existing volume (with any type of directory system) for reading access ONLY.
2. **Archival Utilities.** With archival utitlies, "new" commands are defined with special software, and are used to access an optical disk for reading and writing.
3. **New File Systems.** As an alternative to archival utilities, software can be written which employs a new filing system. Ideally, the new file system would allow users to access the optical disk using existing (and thus, familiar) operating system and language commands.

The Optical Future

The technology of optical disk storage is a very new field, and is expanding rapidly. As research in this field continues, there is bound to be a barrage of new developments to enhance and improve the science. Once erasable disks become widely available, users can look forward to the development of "direct overwrite" optical disks. With direct overwrite, users will be able to overwrite information on an optical disk, rather than having to erase and rewrite, as with current erasable disks. As the science grows, disk capacities will grow tremendously, data transfer rates will increase, and the drives themselves will become more compact as miniaturization reduces the size of the disk heads and other parts. With such an exciting and rapidly growing technology, the future is sure to hold much in store for those who take advantage of the optical opportunity.