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Digital Mass Storage Technologies and Devices

Contents

Abstract

Several various technologies and devices have been created over the past few decades to address the need to store information digitally. Every year this demand grows, fueling the development of new technologies. One of the earliest storage devices, paper punch cards, was first used to control silk weaving looms in the 1800s and then later used to program computers in the mid 1900s. Since then, magnetic storage of binary information has dominated the market. These devices include tape drives, hard drives and floppy drives, as well as others. During the 1980s, laser technology began providing another way to store this information. The compact disc (CD) was developed and could store large amounts of binary data, from music to encyclopedias. These discs were initially read-only, meaning that once data was written to a CD it could never be removed or changed. This shortcoming was eliminated during the 1990s when re-writable CDs were introduced. These operated similarly to hard drives in that data could be written and changed multiple times. The latest offering in laser storage devices is the digital versatile disc (DVD). A DVD is capable of storing over seven times the amount of data that a CD can hold. Still newer technologies, and improvements to existing ones, are being developed to meet the ever-growing demand for more storage capacity at reduced costs. This paper does not attempt to cover every technology in use or in development today, but instead focuses on the more popular ones, with a look at the historical progression of electronic data storage. It is intended for anyone who wants to know about past, current, or future data storage technologies.

Glossary

Analog	Information in a sinusoidal (wave) form.
Binary	A number system that has just two unique digits.
Bit	Short for *binary digit*, the smallest unit of information on a machine. A single bit can hold only one of two values: 0 or 1.
Byte	An abbreviation for *binary term*, a unit of storage capable of holding a single character. On almost all modern computers, a byte is equal to 8 bits.
CAV	*Constant Angular Velocity* uses a constant rotational drive speed and a buffer to deal with the differences in data readout speed.
CLV	*Constant Linear Velocity* uses a varying rotational drive speed. The drive spins the disc more slowly when reading near the outside, where there is more physical surface in each track.
Compact Disc	Known by its abbreviation, *CD*, a compact disc is a polished layered platter made primarily of plastic and capable of storing digital information.
Computer	A programmable machine. The two principal characteristics of a computer are (1) it responds to a specific set of instructions in a well-defined manner, and (2) it can execute a prerecorded list of instructions (a program).
Density	How tightly information is packed together on a storage medium. A higher density means that data is closer together, so the medium can hold more information.
Digital	Any system based on discontinuous data or events. Computers are digital machines because at their most basic level they can distinguish between just two values, 0 and 1, or off and on.
Disk / Disc	A round plate on which data can be encoded. There are two basic types of disks: magnetic disks and optical discs.
Disk Drive	A device that reads and writes data to a disk. A disk drive resembles a stereo turntable in that it rotates the disk very fast. It has one or more heads that read and write data.
DVD	Short for *Digital Versatile Disc* or *Digital Video Disc*, a newer type of CD-ROM that holds a minimum of 4.7 gigabytes.
EEPROM	*Electrically Erasable Programmable Read-Only Memory*
Exabyte	A billion gigabytes (10^{18} bytes.)

File Server	A computer or device on a network that manages network resources.
Gigabyte	1,000,000,000 bytes.
Head	The mechanism that reads or writes data to a magnetic disk or tape.
Head Crash	A serious disk drive malfunction. A head crash usually means that the head has scratched or burned the disk.
Helical Scan	First used in VCRs, data is read and written to tape using a spinning head and diagonal tracks.
IC	*Integrated Circuit*
Kerr Effect	A change in rotation of light reflected off a magnetic field. The polarity of a magneto-optic bit causes the laser to shift one degree clockwise or counterclockwise.
Kilobyte	1,000 bytes.
Laptop	A small, portable computer—small enough that it can sit on your lap. Nowadays, laptop computers are more frequently called notebook computers.
Mainframe	A very large and expensive computer capable of serving thousands of users simultaneously.
Mass Storage	Refers to various techniques and devices for storing large amounts of data.
Megabyte	1,000,000 bytes.
Minicomputer	A computer whose capability falls somewhere between PCs and mainframes.
Optical (or Compact) Disc	A storage medium from which data is read and written to using lasers.
PC	Short for *Personal Computer*, a small, relatively inexpensive computer designed for an individual user.
Platter	A round magnetic plate that constitutes part of a hard disk.
RAM	Acronym for *Random Access Memory*, a type of computer storage that can be accessed randomly; that is, any byte of memory can be accessed without touching the preceding bytes.
ROM	Acronym for *Read-Only Memory*, computer storage on which data has been prerecorded and normally cannot be changed.

Tape Drive	A storage device that uses magnetized tape wrapped around spindles, usually contained within cartridges or cassettes.
TCP/IP	*Transmission Control Protocol/Internet Protocol*, the two most important protocols on the Internet.
Terabyte	1,000,000,000,000 bytes.
WORM	Short for *Write Once*, *Read Many*, a technology that allows you to write data onto media just once. After that, the data is permanent and can be read any number of times.

1.0 Introduction

1.1 The Demand for Data Storage

The need to store data probably existed soon after mankind first learned to communicate. About 200 years ago, the first storage device for machines was created: punched paper cards. First used in 1804 to control silk weaving looms ("Mass Storage"), paper punch cards were later used in early computers to store programs. Today, large amounts of data are frequently converted to binary code and stored electronically. Thanks in part to cheaper electronics and the wide use of electronic devices, the amount of digital data is continually increasing. One needs only to look at the Internet and its exponential growth to realize this. Based on one study, the world produces between 1 and 2 exabytes of unique information per year, which is roughly 250 megabytes for every man, woman, and child on earth. Printed documents of all kinds comprise only .003% of this total ("Executive Summary").

Table 1: Worldwide production of original content, stored digitally using standard compression methods, in terabytes circa 1999.				
Storage Medium	**Type of Content**	**Terabytes/Year, Upper Estimate**	**Terabytes/Year, Lower Estimate**	**Growth Rate, %**
Paper	Books	8	1	2
	Newspapers	25	2	-2
	Periodicals	12	1	2
	Office documents	195	19	2
	Subtotal:	**240**	**23**	**2**
Film	Photographs	410,000	41,000	5
	Cinema	16	16	3
	X-Rays	17,200	17,200	2
	Subtotal:	**427,216**	**58,216**	**4**
Optical	Music CDs	58	6	3
	Data CDs	3	3	2
	DVDs	22	22	100
	Subtotal:	**83**	**31**	**70**
Magnetic	Camcorder Tape	300,000	300,000	5
	PC Disk Drives	766,000	7,660	100
	Departmental Servers	460,000	161,000	100
	Enterprise Servers	167,000	108,550	100
	Subtotal:	**1,693,000**	**577,210**	**55**
TOTAL:		**2,120,539**	**635,480**	**50**

(Source: "Executive Summary")

1.2 Storage for Personal Computers

The growth in the number of personal computers during the 1980s and 1990s helped to fuel the demand for cheap devices capable of storing large amounts of information. The technologies behind these devices are expanding and new devices with greater capabilities are introduced frequently. In addition to the amount of information being stored, the speed at which it can be stored and retrieved (data transfer rate) is also significant and continues to be increased. Magnetic tapes were the first popular computer storage technology, and although they could store large amounts of data, their data transfer rate was very slow. The introduction of floppy and hard drives helped solve this problem. Magnetic tapes are still used today (see section 3.1.1) but usually for archival purposes where retrieval speeds don't need to be as fast, and the data can be (or should be) stored off-site.

1.3 How Information Was Obtained for this Report

The information gathered for this report was primarily obtained from books, the Internet, and the author's own knowledge of the subject, coming from twenty years of computing and electronics experience using various technologies. A glossary is provided at the beginning of the report that defines technical terms used within the report.

2.0 Early Storage Technologies

2.1 The First Hard Drive

Punch cards were used to store computer programs until the 1950s. Magnetic tape drives began replacing the punch card systems at about this time. Soon after, magnetic drums were developed and in 1957, the first hard drive was introduced as a component of IBM's RAMAC. It required 50 24-inch disks to store 5 megabytes of data and cost roughly $35,000 a year to lease ("Hard Disk Drive History").

2.2 Introduction of the Personal Computer

For years, hard drives were confined to expensive mainframe and minicomputer systems. They were large devices, filling an entire air-conditioned room. The first personal computers used magnetic audio cassette tapes to record digital data. Since many people owned cassette recorders, this was a convenient and inexpensive way to store information. Unfortunately, the time required to store or read data off an audio tape was excessive. Errors in the data transfer were frequent and required the operator to start the transfer over from the beginning. By the early 1980s, personal computers were being sold with 5.25-inch floppy drives (see next section) that typically held 360 kilobytes of data. A few years later, hard drives were beginning to be offered as optional storage components. Capable of storing between five and 20 megabytes of data, they were fast but expensive. At the time, this was considered more than ample storage.

2.3 Floppy Drives

Floppy drives operate much like hard disk drives but use removable disks. They are also slower and hold less information, with early models storing 360 kilobytes on each side of a 5.25-inch disk (these disks were semi-flexible, hence the term "floppy.") They have an advantage over fixed hard disks in that data stored on removable disks can be moved from one computer to another. A rigid "floppy" was later introduced that is smaller (3.5 inches) and can hold nearly 2 megabytes of data, utilizing both sides of the disk. These newer 3.5-inch drives are very popular and still found in most computer systems today.

2.4 Bernoulli Disk Drives

Named after a Swiss scientist who discovered the principle of aerodynamic lift, the Bernoulli disk drive was a special type of floppy disk drive that was faster and had greater storage capacity than traditional floppy drives. It was essentially a cross between a floppy drive and a hard drive. Like a floppy, its disks were flexible and could be removed. Like a hard drive, the read/write head inside the drive never touched the surface of the disk. These devices are no longer being produced (“Bernoulli Disk Drive”).

2.5 Falling Prices and Smaller Drives with Higher Storage Capacities

The price and physical size of hard drives have been declining rapidly since the 1980s, while their storage capacities and speeds have increased dramatically. During the mid 1980s, the typical storage capacity of a hard drive was around 20 megabytes and its average physical size was 5.25 inches or larger. This later decreased to 3.5 inches and less, which was crucial towards the development of portable PCs. A 20-megabyte hard drive cost as much as $1,000 in 1985, or $50 per *megabyte*. By the year 2000, a *gigabyte* of storage cost less than $10 and it is expected that this cost will drop to $1 by 2005 (“Executive Summary”). Drives capable of storing over 200 gigabytes are already available at prices less than $300.

3.0 Today’s Storage Technologies

3.1 Magnetic Storage

Magnetic storage, one of the earliest digital storage technologies, is still in abundant use today. It continues to remain one of the cheapest and most convenient ways to store large amounts of data.

3.1.1 Magnetic Tape

Although one of the slowest technologies in use, the low cost, portability, and compact size of magnetic tapes makes them ideal for data archival where access is infrequent. Because the data is stored on the tape sequentially, moving to a particular section of tape often requires a considerable amount of time when compared to other storage technologies. This is similar to playing an audio tape on a stereo and attempting to jump ahead to a later song on the tape. Tape storage is normally not used where data has to be accessed quickly or randomly.

Digital Audio Tape (DAT) is a popular type of magnetic tape that uses an ingenious scheme called helical scan to record data. A DAT cartridge is slightly larger than a credit card and contains magnetic tape that can hold from 2 to 24 gigabytes of data (“DAT”). As with most tape technologies, their most practical application is backing up data for offline storage.

Other types of magnetic tape technologies exist, such as Digital Linear Tape (DLT), that allow 200 gigabytes or more on one tape cartridge and higher data transfer rates (“LTO Ultrium Tape Drive”).

3.1.2 Hard Drives

Hard drives are still the most common storage device used in computers today. Their low cost and ability to quickly and reliably store and retrieve data has yet to be improved upon by other technologies. The demand for hard drives is continuing to increase steadily along with their capacities and speeds, while their prices continue to drop.

The industry shipped 144.9 million hard disk drives in 1998 with a forecast for 2002 set at 252.9 million drives ("Disk/Trend News").

SHIPMENT SUMMARY BY DISK DIAMETER

Worldwide Unit shipments (000)	1998 Shipments	Forecast 1999	2000	2001	2002
5.25 INCH	4,073.9	2,175.0	1,095.0	400.0	--
3.5 INCH	123,047.1	145,188.8	168,385.0	193,330.0	220,330.0
2.5 INCH	17,729.9	20,817.0	24,090.0	27,740.0	31,850.0
1.8 INCH OR LESS	115.9	173.0	250.0	475.0	750.0
TOTAL, ALL GROUPS	144,966.8	168,353.8	193,820.0	221,945.0	252,930.0
	+11.1%	+16.1%	+15.1%	+14.5%	+14.0%

SUMMARY BY DRIVE CAPACITY

Sales revenues in millions of U.S. Dollars	1998 Revenues	Forecast 1999	2000	2001	2002
Disk cartridge drives	271.1	180.6	187.9	210.5	242.5
FIXED DISK DRIVES					
Less than 2 Gigabytes	372.1	84.7	58.1	80.2	96.7
2 – 3 Gigabytes	3,906.5	1,237.2	338.6	106.2	--
3 – 5 Gigabytes	12,339.6	6,116.3	1,568.5	470.0	148.6
5 – 10 Gigabytes	9,229.5	12,149.4	7,691.6	2,253.4	737.5
10 – 20 Gigabytes	3,736.5	10,604.7	14,171.7	8,771.1	2,926.3
20 – 40 Gigabytes	62.4	1,757.7	10,053.5	15,968.7	10,247.6
40 – 80 Gigabytes	159.1	269.6	2,044.8	11,681.1	18,577.2
More than 80 Gigabytes	--	--	170.2	3,419.0	17,341.9
TOTAL REVENUES	30,076.8	32,400.2	36,284.9	42,960.2	50,318.3

3.1.3 Floppy Drives

Although floppy drives haven't changed much over the years, they are still a common component in most computers and other devices, such as electronic music keyboards and some digital cameras. Unlike the floppy drives of a decade ago that were only able to hold 360 kilobytes of data on a single flexible 5.25 inch disk, today's floppies can hold nearly 2 megabytes of data on a rigid 3.5 inch disk (in reality, only the protective plastic cover is rigid—the internal disk it protects is still very much flexible and easily damaged.) Their low price, popularity, and portability allows them to exist as a convenient storage device for smaller amounts of data. Many people use them to back up important files, such as word processing documents. Some software companies still distribute their applications on floppy disks, but CD-ROMs are mostly used for this now since they can hold over 300 times more data and are equally as popular and inexpensive.

Floppy disks are not an ideal solution for long-term data storage, however. They are susceptible to external magnetic fields, which can cause data loss. Since the read/write head makes physical contact with the surface of the disk, they are also prone to wear.

3.1.4 Zip and Jaz Drives

Iomega Corporation has developed several very successful removable-disk drives. The Zip drive is a portable drive capable of storing between 100 to 750 megabytes of data on removable media, depending on the model (some models are also non-portable.) The Jaz drive, although no longer being produced, is capable of storing 2 gigabytes of information on one of its removable cartridges. The quick access speeds and low costs of these drives make them a popular portable mass storage device. However, with the introduction and wide acceptance of CD-RW drives, which are capable of storing over 600 megabytes of data and also able to copy other CDs, the Zip and Jaz drives have failed to become a standard component of most computer systems. Still, the Zip drive remains popular and is generally faster than a CD-RW drive ("Iomega Drives").

3.2 Optical Storage

Using laser technology, CD and DVD drives have become a cheap and popular storage alternative to magnetic storage. They are fast, reliable, durable, portable, and have gained worldwide adoption in a variety of applications, replacing everything from cassette tape players to VCRs. CDs and DVDs also last longer since there is no physical contact with the media. The technology involved in making all forms of compact discs a viable proposition dates back to the development of the 12 inch laserdisc by Philips in the 1970s.

3.2.1 CD-ROM and DVD-ROM

Compact Disc-Read Only Memory (CD-ROM or simply CD) is a type of optical disc capable of storing large amounts of data—up to 1 gigabyte, although the most common capacity is around 650 megabytes. Unlike magnetic drives, information stored on a CD or DVD cannot be altered. Once data is written, it is forever there.

Short for Digital Versatile Disc or Digital Video Disc, DVD is a new type of disc that can hold up to a maximum of 15.9 gigabytes. Many experts believe that DVDs will eventually replace CDs, as well as VHS video cassettes and laserdiscs, just like how CDs replaced music albums and cassette tapes. Evidence of this already happening can be seen with the large availability of movies on DVD. One of the best features of DVD drives is that they are backwards compatible with CDs. This means that DVD drives and players can read existing CDs, and usually CD-Rs and CD-RWs. Most players are also able to read a variety of different data formats, including Video CD, Picture CD, MP3, WMA, and others ("DVD FAQ").

Because CDs and DVDs are relatively cheap to produce and can permanently hold a considerable amount of information, software companies find them ideal for distributing their products. Most computers built within the past few years have CD drives, and many are now being sold with CD-RW or even DVD drives. The speeds of these drives have also been increasing steadily, especially with the rewritables, which use different speeds for reading, writing, and rewriting.

3.2.2 CD-R

Short for Compact Disc-Recordable, a CD-R is a type of disc drive that can read and create CD-ROMs and audio CDs. This is one way information can be permanently recorded onto a CD-ROM disc. They're also known as WORM drives (Write Once, Read Many.) Because of the low cost and rewritability of CD-RW drives, CD-R drives are no longer being produced, but CD-R discs still are (CD-RW drives can write to CD-R discs.)

3.2.3 CD-RW

Short for CD-ReWritable, CD-RW is a newer type of CD that can be written to multiple times, unlike a CD-R. This makes them an ideal choice for removable and portable storage solutions. These drives first became available in 1997 and prices have fallen considerably since then, for both the drives and discs. The ability to copy other CDs is perhaps their most attractive feature.

3.2.4 DVD-R and DVD+R

Similar to CD-R drives, DVD-R and DVD+R drives can only record data once. But these two technologies are not compatible with each other. A DVD-R drive cannot write a DVD+R disc and vice-versa, due to the way the data is written. Capacity for both formats is 4.7 gigabytes. ("DVD FAQ").

3.2.5 DVD-RW and DVD+RW

Similar to CD-RW drives, DVD-RW and DVD+RW are rewritable drives that use competing technologies and are not compatible with each other. Discs can be rewritten about 1,000 times and hold 4.7 gigabytes ("DVD FAQ").

3.2.6 DVD-RAM

DVD-RAM uses a completely different technology that implements lasers and magneto-optic features, along with defect management. Discs are expected to last at least 30 years and can be rewritten over 100,000 times, making them ideal for data archival and backup. In addition, these drives utilize random access technology that enables them to find data on the disc more quickly than other rewritable DVD drives (Taylor, 114).

3.3 Magneto-Optical (MO)

A Magneto-Optical (MO) drive combines magnetic disk technologies with laser technology. Like magnetic disks, MO disks can be read and written to (over one million times), and are also removable like a CD. Their storage capacity can be more than 2 gigabytes, much greater than magnetic floppies ("Products"). In terms of data access speed, they are faster than floppies and CD-ROMs, but not as fast as hard disk drives ("MO").

3.4 Solid State Devices

A new technology called "flash memory" has gained popularity over the past few years. This type of storage has no moving parts; storage takes place using internal transistors. Similar in operation to Electrically Erasable Programmable Read-Only Memory (EEPROM), flash memory is much faster because instead of erasing one byte at a time, it erases a block or the entire chip (Tyson, 8). Flash memory can store up to 1 gigabyte (soon to be 4 gigabytes) of data in a very small, portable package, and is commonly used in smaller devices like digital cameras and media players.

4.0 How They Work

Many of the devices in use today work in similar ways. Their primary function is to store and retrieve data quickly, quietly, and reliably. They also have to be rugged, capable of surviving drops, jolts, and vibrations.

4.1 Tape Drives

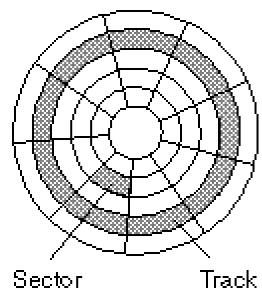
Similar to audio cassette tapes that store music in an analog format, Digital Audio Tape (DAT) and Digital Linear Tape (DLT) use magnetic tape to store data in a digital format. A read/write head is used to access or change data on the tape.

4.2 Hard Disk Drives

In many ways, a hard disk drive operates similarly to a record player. Inside a hard drive, there are usually several aluminum-alloy platters, stacked one on top of another with a small space in-between each platter. These platters are constantly spinning, often at 7,200 revolutions per minute or higher. Data is stored and retrieved from the platters by an actuator arm holding a read/write head, much like the arm holding the needle on a record player. Unlike a record player, hard drives are capable of reading and writing information on both sides of a platter. This is accomplished by having two actuator arms per platter, one for the top side and another for the bottom.

Although hard drives are similar to record players in their mechanical operation, the way they store and retrieve information is more similar to how a tape recorder works. Each side of the platter in a hard drive is coated with magnetic material a few millionths of an inch thick. To read or write information, a read/write device called a *head* is used. The head is simply a small electronic device that contains a coil of wire. This coil is capable of reading and creating positive and negative magnetic fields, which is how the binary data is stored and retrieved. During a read process, the coil passes over magnetically charged particles on the platter. These charged particles produce a small amount of current in the coil, which is then read by the electronics within the hard drive and passed onto the computer as a binary one or zero. During a write process, the procedure is reversed. The coil creates an electronic field that is induced into the magnetic particles on the platter, changing their polarity. The difference in polarity indicates whether the information is either a one or a zero (positive or negative charge.)

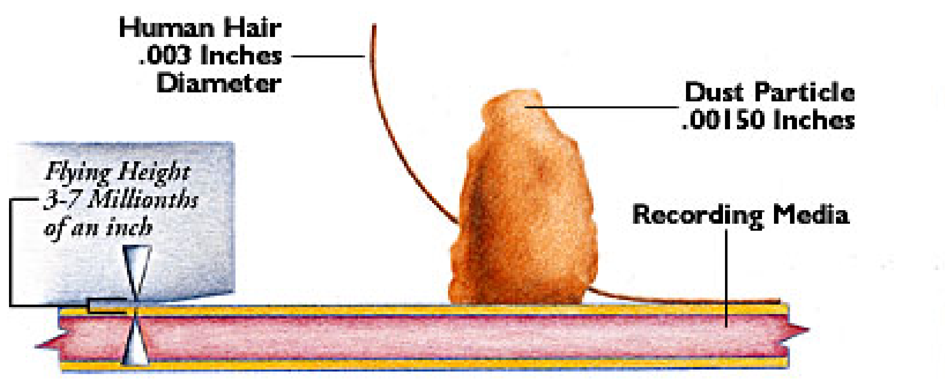
The magnetic information stored on a platter is arranged in tracks, which are concentric circles like the rings of a tree. Each track is divided into sections called sectors. Each sector usually contains 512 bytes of data, but can vary depending on the capacity of the hard drive.



Graphic showing tracks and sectors on a platter.

Information is recorded on the outermost track of all platters first. Once the outside track is filled up with data, the heads move to the next free track and begin writing information there. This recording strategy greatly boosts performance since the read/write heads can record more data at one position before having to move to the next track. Over time, however, the data on the platter can become fragmented. This happens most frequently when data is erased and a free block of space becomes available for the next write operation. Because the block of space may or may not be large enough to accommodate all of the new data, it is often broken up and stored in fragments across the drive platters. All the platters are used together like one large, single platter. Fragmentation can degrade performance, increasing read and write times, and there are software utilities available that can "defragment" a drive.

A remarkable fact about a hard drive is how the heads are designed to fly just a few microinches above the surface of the platters. They float on a cushion of air only 3 to 7 millionths of an inch thick, never making contact with the platter.



Hard disk drive head floating over the platter surface.

When the hard drive is turned off, the platters stop spinning and the heads touch down in a designated landing zone, separate from the area on the platters where data is stored. If the heads were to touch the surface of the platter in a data area, the head or platter surface may be damaged. Known as a *head crash*, this can result in data loss, and even complete destruction of the drive. In today's advanced drives, head crashes are rare because the drives are tightly sealed to keep out contaminants and built to withstands shocks, usually in the range of 60 to 100 times the force of gravity while in operation (higher g-forces are sustainable when the drive is powered off because the heads are moved to a designated "safe" spot.)

4.3 Floppy Drives

Floppy disk drives work in essentially the same way as a hard disk drive with some important differences. Data is stored magnetically in tracks and sectors just like a hard drive, but floppy drives only contain one disk, or platter. Unlike a hard drive where the platters are constantly spinning, a floppy disk only spins when data is being read or written. The disk also spins at a reduced speed because the read/write heads actually touch the surface of the disk, resulting in slower data transfer. This also makes them more vulnerable to debris and surface wear, especially since they are not sealed from the outside environment like hard drives.

4.4 Zip and Jaz Drives

These drives work similarly to a floppy drive. Data is written on removable disks made of magnetic material using a read/write head.

4.5 CD-ROM and DVD-ROM

Optical storage technology works by reading the bumps and low spots, or *pits* and *lands*, on a disc. A pit is a low spot on the CD while a land is material that hasn't been changed from its initial condition. When reading information from the disc, the laser is able to distinguish between these two conditions that represent binary data.

A CD is a 12-centimeter plastic disc that contains three layers. The first layer consists of an injection-molded piece of clear polycarbonate plastic that is impressed with microscopic bumps arranged as a single, continuous, extremely long spiral track of data. A thin, reflective aluminum layer is then placed over the bumps and topped by a thin acrylic layer that is sprayed over the aluminum to protect it. A laser is used to read the data on the disc by detecting the light being reflected back from the aluminum layer. The bumps reflect light differently than the lands, and an opto-electronic sensor detects the change in reflectivity (Brain, 3). This design makes compact discs one of the most rugged types of removable storage available today.

DVDs are made and work in a similar fashion, but they contain more tracks packed closer together. In addition, the bumps are also smaller, nearly half the size of those on a CD, allowing more data to be stored per track. DVDs also contain less error correction information whereas CDs use an older, less efficient error correction scheme. Double-layer DVDs can also be produced, effectively doubling their storage capacity to 7.95 gigabytes per side (or 15.9 gigabytes per disc.) ("DVD FAQ").

As stated earlier, CD-ROM and DVD-ROM drives are read-only devices. Once data has been recorded on them, it will remain there permanently

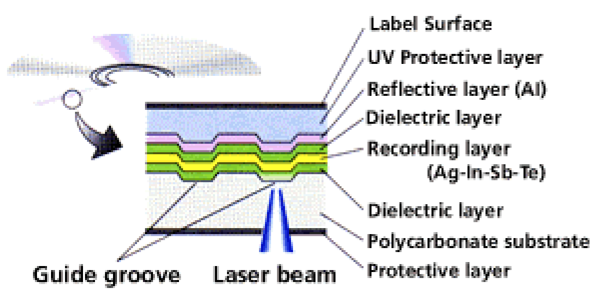
Unlike hard drives, most CD-ROM and DVD-ROM drives use a technology called Constant Linear Velocity (CLV). This means that the motor in the drive doesn't spin at a constant speed. Instead, it varies its speed depending on what track the head is accessing. This is done to ensure that the same amount of data always goes past the head in a given period of time. This technology was first used in audio CD players and was carried over to CD-ROM and DVD-ROM drives for compatibility reasons.

4.6 CD-R

CD-R discs contain an extra greenish-dye layer that can be modified with a write laser. This allows them to be written to once. On a new CD-R disc, the entire surface of the disc is reflective -- the laser can shine through the dye and reflect off the gold layer. During the write process, a write laser heats up the dye layer and changes its transparency. This produces a non-reflective area that the laser detects as a bump during the read process.

4.7 CD-RW

Like a CD-R, a CD-RW disc contains an extra dye layer that can be changed with a write laser. Unlike a CD-R, this dye can change states multiple times using phase change technology. The material has a property that allows it to change its transparency depending on temperature. Heated to one temperature, the material cools to a transparent state; heated to another temperature, it cools to a cloudy state. By changing the power (and therefore the temperature) of the writing laser, the data on the CD can be changed, or "rewritten." (Tyson, 8).



Layers of a CD-RW disc ("Phase Change Technology").

4.8 DVD-R and DVD+R

Similar to a CD-R, DVD-R and DVD+R discs contain a dye layer that can be written to once.

4.9 DVD-RW and DVD+RW

DVD-RW discs also use phase change technology for reading, writing, and erasing information. The recording layer is similar to that used in CD-RW discs. DVD-RW uses groove recording with address info on land areas for synchronization at write time ("An Introduction to DVD-RW").

DVD+RW discs work in essentially the same way as DVD-RW ("DVD+RW Technology"). The differences between the two technologies lie in how the data is written on the disc. DVD+RW format uses a high-frequency wobbled groove that allows it to eliminate linking sectors. The two technologies are backed by different sets of companies.

Both types of discs can be rewritten around 1,000 times and are expected to last about 30 years.

4.10 DVD-RAM

DVD-RAM uses phase-change dual (PD) technology with some magneto-optic (MO) features mixed in. It is the best suited of the writable DVD formats for use in computers, because of its defect management and zoned CLV format for rapid access. A wobbled groove is used to provide clocking data, with marks written in both the groove and the land between grooves. The grooves and pre-embossed sector headers are molded into the disc during manufacturing ("DVD FAQ"). The data layers in a DVD-RAM disc are made of very thin metal film that can change state over 100,000 times, allowing the disc to be rewritten more times than the other rewritable DVD formats.

4.11 Magneto-Optical (MO)

MO devices combine magnetic storage technologies with optical disc technologies.

Early MO disks used a laser and a read/write magnetic head to record data. A laser heated up the disk surface to its curie point, a temperature that allows the magnetic particles on the disk surface to be aligned to the magnetic field created by the read/write head. Because a laser was used to write to precise areas of the disk, MO disks had very high data density as compared to hard drives. This allowed them to store more data in a comparable surface area, but at much slower speeds.

In 1997, a new technology called LIMDOW (Light Intensity Modulated Direct OverWrite) was introduced that did away with the read/write head. Instead, magnets were built into the disk itself. The LIMDOW disk has two magnetic layers just behind the reflective writing surface. When it has been heated up to one temperature, it takes its polarity from the first magnetic layer; but if it has been heated up further, it will take its polarity from the other magnetic layer. This also had the added benefit of increasing write speeds to the disk, making them nearly as fast as hard drives ("Removable Storage").

Like CD and DVD drives, MO drives also use a laser to read information off the disk. This is done using a less powerful laser, making use of the Kerr Effect, where the polarity of the reflected light is altered depending on the orientation of the magnetic particles. Where the laser/magnetic head hasn't touched the disk, the spot represents a zero, and the spots where the disk has been heated up and magnetically written will be seen as a one.

4.12 Solid State Devices

Unlike other storage technologies that involve moving parts, solid state devices have none. Also known as Flash Memory, these devices use a chip that contains a grid with a two-transistor cell at each intersecting point on the grid. Using various electrical processes, the cell value can be changed between a zero and one, representing a binary bit. This type of memory is similar to EEPROM memory but is much faster because instead of erasing one byte at a time, it erases a block or the entire chip.

Currently, two storage devices are most common: CompactFlash and SmartMedia. CompactFlash consists of a small circuit board with Flash Memory chips and a dedicated controller chip, all encased in a rugged shell that is several times thicker than a SmartMedia card.

The increased thickness of the card allows for greater storage capacity, up to 1 gigabyte with 4 gigabyte cards available soon.

In contrast, SmartMedia cards are compact (about twice the surface area of a quarter) with the components integrated into a single package without the need for soldering. They can store between 2 and 128 megabytes (Tyson, 10).

5.0 A Look Towards the Future

It seems clear that digital storage technologies will continue to develop at a feverish pace for the foreseeable future. Several new technologies are in development today; many will make their way into production, while others will never make it out of the research lab. Driving factors including cost, complexity, capability, advertisement, and popularity will play a role in the survivability of these new technologies. This section discusses some of the more promising ones.

5.1 Optical Super Density

Optical Super Density (OSD) technology's design goals were to develop a high capacity (40GB or more) removable MO drive which retained the ruggedness and reliability offered by existing ISO-standard MO solutions, achieve data transfer rates competitive with hard disk and tape products (30 MBps), and provide the user a significantly lower cost per megabyte than other optical and tape products. In 1999, the first working prototype device was introduced ("Removable Storage"). These devices will be targeted to long-term storage needs, providing 10 million overwrites and a 50-year shelf life.

5.2 Multilevel Recording

Expanding on the idea of pits and lands used with CDs and DVDs, Multilevel Recording implements gray-scale disc encoding, with 3 bits per spot giving eight shades of gray. Under a microscope, the disc surface appears as a continuous blending of light to dark shading, versus the traditional disc appearance of either dark or bright spots. The technology depends on the ability to detect the smallest changes in reflectivity in a continuously changing pattern (Mannion).

Storage capacity will be up to 2 gigabytes per disc, and existing CD and DVD players need only an IC upgrade to read the new format; the rest of the hardware remains the same.

5.3 Blu-ray Disc

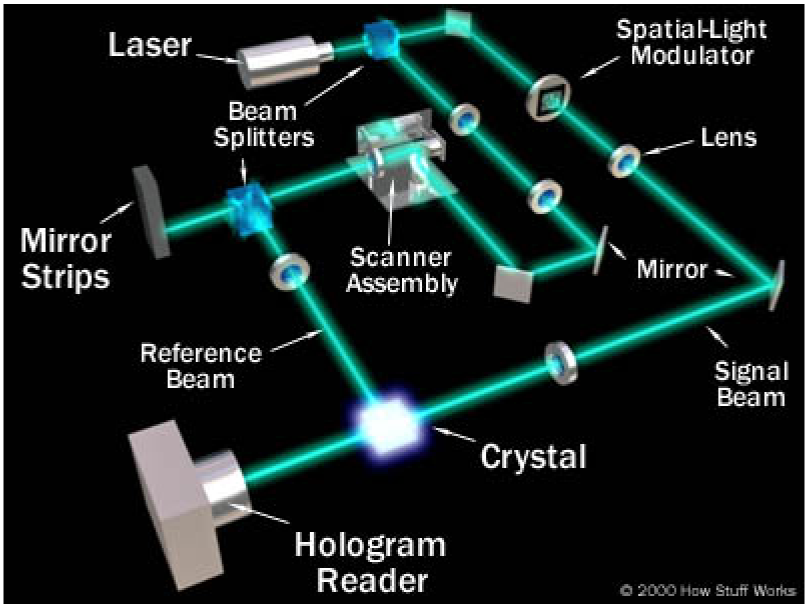
The Blu-ray Disc is capable of storing 27 gigabytes or more of data on a single disc. The primary difference between these discs and those of traditional DVDs and CDs is the use of a blue laser as opposed to a red laser. Blue lasers have a shorter wavelength, which means the laser beam can be focused onto a smaller area of the disc surface. The result is that less real estate is needed to store one bit of data, enabling more data to be stored on a disc (Williams).

5.4 Fluorescent Disc Technology

Fluorescent Disc Technology will attempt to increase the number of recording layers in a disc by using the so-called "stable photochrome", discovered by physicists and engineers in Russia. This is a transparent organic substance whose fluorescence can be triggered by a laser beam with sufficient time for it to be detected by a standard photoreceiver. The ability to concurrently read data off multiple layers exists, greatly increasing retrieval speeds. Storage capacity has the potential to reach over 1 terabyte using a $16cm^2$ area and 50 layers. The first production devices will likely store much less than this, in the range of 5 to 100 gigabytes ("Removable Storage").

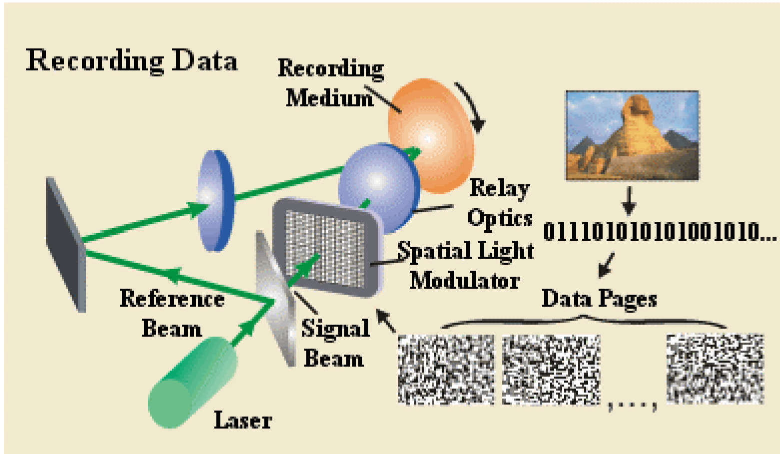
5.5 Holographic Memory

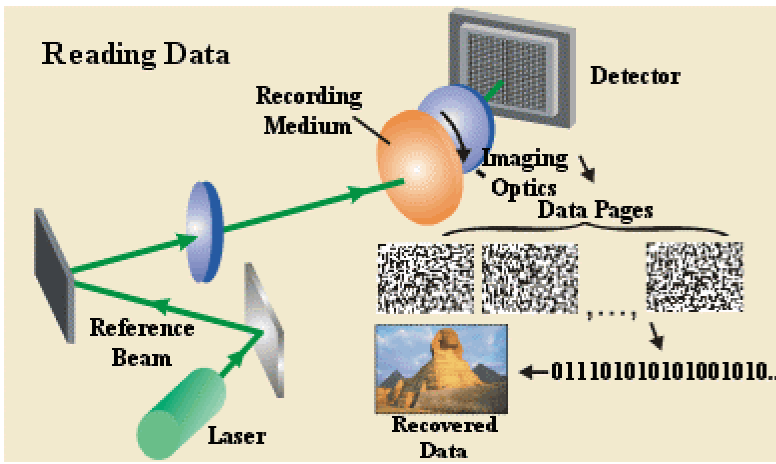
A new twist on using laser technology, holographic memory is a storage technology that records information in the form of 3-D holograms. Similar to Fluorescent Disc Technology, it can achieve much higher storage densities than convention methods by using multiple layers for storage, with the potential of storing 1 terabyte of data in a sugar-cube-sized crystal. Data retrieval speeds are also significantly increased, since an entire page of data can be read instantly.



Components of a holographic storage device (Bonsor).

When the blue-green argon laser is fired, a beam splitter creates two beams. One beam, called the object or signal beam, will go straight, bounce off one mirror and travel through a spatial-light modulator (SLM). An SLM is a liquid crystal display (LCD) that shows pages of raw binary data as clear and dark boxes. The information from the page of binary code is carried by the signal beam around to the light-sensitive lithium-niobate crystal. Some systems use a photopolymer in place of the crystal. A second beam, called the reference beam, shoots out the side of the beam splitter and takes a separate path to the crystal. When the two beams meet, the interference pattern that is created stores the data carried by the signal beam in a specific area in the crystal – the data is stored as a hologram.





Holographic recording and reading processes (Bonsor).

In order to retrieve and reconstruct the holographic page of data stored in the crystal, the reference beam is shined into the crystal at exactly the same angle at which it entered to store that page of data. Each page of data is stored in a different area of the crystal, based on the angle at which the reference beam strikes it. During reconstruction, the beam will be diffracted by the crystal to allow the recreation of the original page that was stored. This reconstructed page is then projected onto the charge-coupled device (CCD) camera, which interprets and forwards the digital information to a computer (Bonsor, 3).

Holographic memory is already being used in fingerprint identification systems (Drake).

5.6 Probe Storage

History repeats itself. Probe Storage relates back to the punch card, designed over a century ago. But instead of using a paper card for storage, this technology is based on atomic force microscopy. Researchers have been able to pack bits together at a density of one trillion per square inch, more than 20 times denser than today's disk drives. Using an array of 1,024 probes, they've been able to read, write, and erase data on a plastic medium. A competing technology uses phase change instead of probes, much like a rewritable optical disc.

Potential uses of this technology include portable memory cards, able to store 1,000 times more data than Flash Memory technology (Leo).

6.0 Summary

As the demand for digital storage of information continues to grow, the need for new technologies to support this demand also grows. New storage devices are being introduced every year, and each device is capable of storing more information than ever before at ever increasing speeds and reduced costs.

6.1 Introduction of Inexpensive Hard Drives

After the floppy drive, the introduction of inexpensive hard drives in the 1980s launched a new era for digital mass storage. They eventually became standard components of personal computers. And as the number of personal computers began to grow, so did the sales of hard drives. These demands eventually lead to the use of laser technologies, capable of writing data to smaller areas of space.

6.2 Portability

Hard drives fulfilled the requirement for large data storage, but lacked one desirable feature—portability. Unlike floppy disk drives, hard drives were meant to be a permanent fixture within a computer system. If a user wanted to transfer information from one computer to another, they would most likely have to use several floppy disks, making it a time consuming task. It became obvious that consumers needed devices that were portable, allowing large amounts of information to be easily transferred from one computer to another.

Several devices have been introduced over the years to meet the demand for portability. CD-ROM drives, although read-only, allowed software companies to distribute huge amounts of data to customers with minimal expense. Just like what happened with hard drives in the 1980s, CD-ROM drives became a standard component in most computer systems during the 1990s. By the late 1990s, rewritable CD-RW drives came down far enough in price to become a popular optional storage device, especially since they had the added benefit of being able to copy music CDs. They are now starting to replace CD-ROM drives as a standard computing system component.

DVD-ROM drives are also experiencing rapid growth, due in part to the digitization of movies. Instead of CD-ROM or CD-RW drives, many new computers are instead being shipped with DVD-ROM versions. Rewritable DVDs are the next advancement, and they will no doubt replace CD-RW drives at some point in the future when their price falls to more affordable levels.

Magneto-optical devices have also been somewhat popular, especially in the area of data archival. Zip drives continue to remain popular, with newer models still being sold. They never did reach mass proliferation like the floppy drive, as many people predicted. It's likely their higher cost prevented this from happening.

Although not technically a storage device, computing networks, and especially the Internet, are also contributing to the portability of data. Software and files can now be transferred electronically via TCP/IP to anywhere in the world. One might think of the Internet as a gigantic shared storage device by itself, accessible to any system that is able to connect to it.

6.3 Demand Continues

Digital data storage requirements will continue to grow in the years to come, especially as more data continues to be digitally encoded (books, magazines, movies, photographs, microfiche, music, etc.) The trend appears to be focusing primarily on optical solutions, although great strides are being made in the solid state technologies as well. Many newer technologies are being developed, ranging from radical new ideas to improvements on existing ones. In the end, reliability, convenience, capability, availability, and costs will determine which technologies make it out of the lab and onto the store shelves.

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