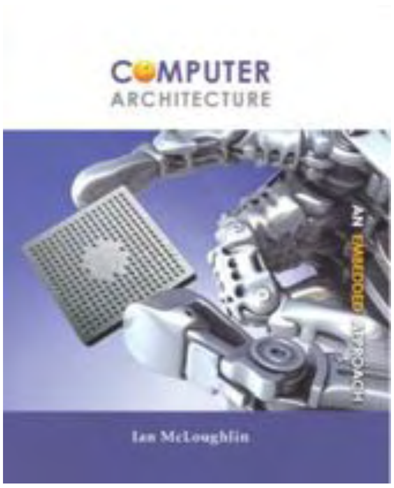
Computer Peripherals

School of Computer Engineering
Nanyang Technological University
Singapore

These notes are part of a 3rd year undergraduate course called "Computer Peripherals", taught at Nanyang Technological University School of Computer Engineering in Singapore, and developed by Associate Professor Kwoh Chee Keong. The course covered various topics relevant to modern computers (at that time), such as displays, buses, printers, keyboards, storage devices etc... The course is no longer running, but these notes have been provided courtesy of him although the material has been compiled from various sources and various people. I do not claim any copyright or ownership of this work; third parties downloading the material agree to not assert any copyright on the material. If you use this for any commercial purpose, I hope you would remember where you found it.

Further reading is suggested at the end of each chapter, however you are recommended to consider a much more modern alternative reference text as follows:



Computer Architecture: ***an embedded approach***
Ian McLoughlin
McGraw-Hill 2011

Chapter 12. Optical Disks

After the human memory, optical storage is perhaps the oldest storage technology in use. When cavemen started making scratches on the walls of their caves, we have not only an application of write-once ready-many (WORM) technology, but a data encoding method as well! However the modern optical storage devices have a relatively short history as the first laser disk was only demonstrated in 1972. This was the 12-inch *Laservision,* a video disk in which the video signal was stored in an analog form similar to the present video cassette recorders. Later in 1975, Philips together with Sony defined the standard for the 5-in audio CD (compact disc). This is a read-only device, but the audio information is stored digitally. The EFM (eight-to-fourteen modulation) coding scheme invented by Philips continues to generate income by way of license and royalty fees that contributes a significant proportion to the total budget of their R&D activities. Optimem demonstrated in 1977 the first 12-inch writeable (once) disk (WORM). So far the devices developed were targeted at the consumer audio-visual market.

In 1980, Philips and Sony introduced a version of the CD that is used for storing digital data for computer applications. As this acts as a memory device, it was called the CD-ROM. Finally in 1987, Sony demonstrated the erasable and rewritable 5.25-inch optical disk drive. Recently products became available enabling the user to create his own CD-ROM using a write-once disk.

12.1. Types of Optical Disk

Although there are many different types of optical disks, they can be grouped into three main categories.

1. *Read-only memory (ROM) disks,* like the audio CD, are used for the distribution of standard program and data files. These are mass-produced by mechanical pressing from a master die. The information is actually stored as physical indentations on the surface of the CD. Recently low-cost equipment has been introduced in the market to make one-off CD-ROMs, putting them into the next category.
2. *Write-once read-many (WORM) disks:* Some optical disks can be recorded once. The information stored on the disk cannot be changed or erased. Generally the disk has a thin reflective film deposited on the surface. A strong laser beam is focused on selected spots on the surface and pulsed. The energy melts the film at that point, producing a non-reflective void. In the read mode, a low power laser is directed at the disk. and the bit information is recovered by sensing the presence or absence of a reflected beam from the disk.
3. *Re-writeable, write-many read-many (WMRM) disks,* just like the magnetic storage disks, allows information to be recorded and erased many times. Usually, there is a separate erase cycle although this may be transparent to the user. Some

modern devices have this accomplished with one over-write cycle. These devices are also called direct-read-after-write (DRAW) disks.

12.2. Read-Only Storage

The CD-ROM, together with the audio compact disk are examples of technologically advanced products that have been mass-produced and made readily available to the general public. For the computer industry, the read-only CD-ROM is gaining importance as a delivery medium for software. The large storage capacity and low cost of manufacture makes it a very attractive means of distributing software which is getting larger all the time. Also machine-readable documentation can be included on the same disk or on a separate disk. Software available on CD-ROMs now include many games which have large graphics and audio files, graphics software with clip-art, and operating systems like Unix and OS/2.

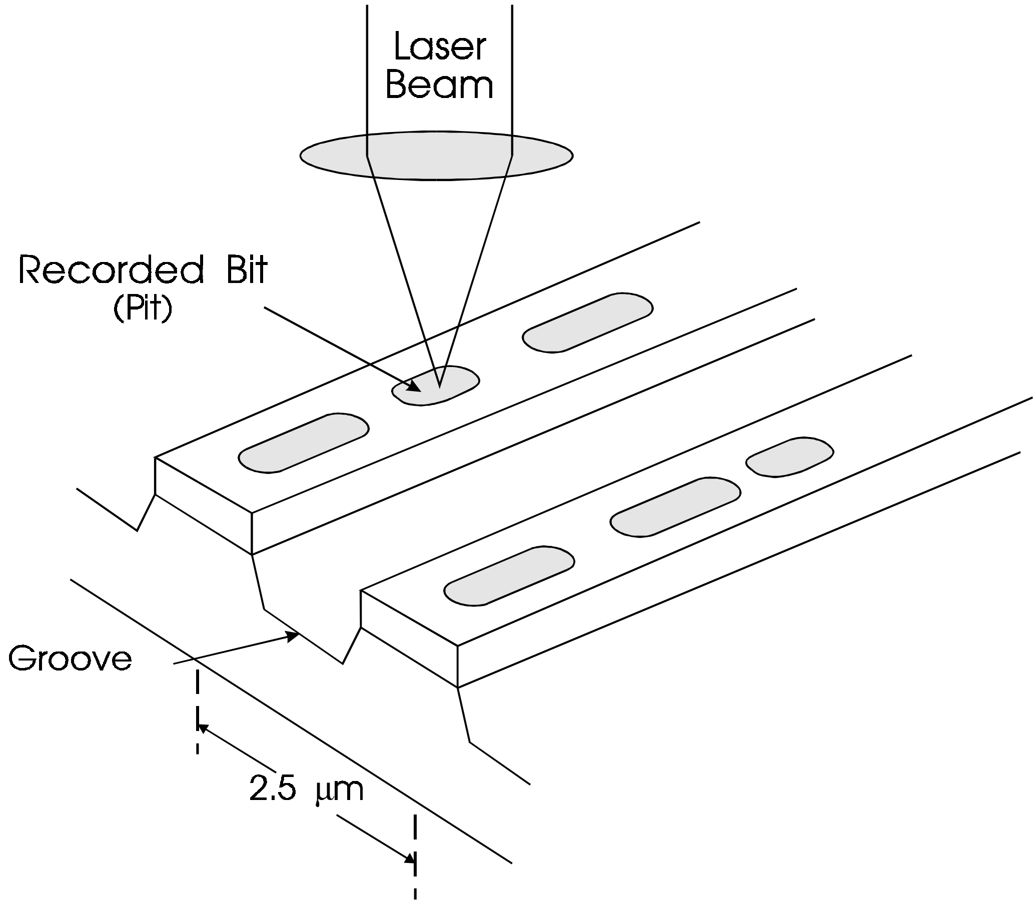


Figure 12.1. Pits and land representing data bits in a CD-ROM.

The CD is a 120-mm diameter polycarbonate disk with a thickness of 1.2 mm. The disk is coated with a reflective aluminium layer on which a sequence of 'pits' are placed in a spiral track. To prevent corrosion and physical damage, a protective layer covers the reflective surface. In operation, as shown in Figure 12.1, a low power laser beam is focused through the transparent protective layer and the reflected beam is detected. Everywhere there is a pit, the beam is not reflected so that binary information can be represented as a series of pits and lands along the track.

The basic performance of CDs and CD-ROMs are given in Table 12.1. As it is an adaptation of the audio CD, the CD-ROM can be reproduced at very low cost, and can be read and re-read without any degradation. There are however some limitations and inefficiencies.

<<The standard audio CD block contains 672 data bytes. Computers normally work with some multiple of 512 bytes per block. In the CD-ROM, blocks of 2048 data bytes are used and some 588 bytes are 'wasted' This decreases the data capacity and the data transfer rate. >> to be replaced by p 216 of cunningham.

Calculating Data Capacity

Blank recordable CD-R and CD-RW discs are available in two capacities: 74 minutes (both CD-R and CD-RW) and 80 minutes (CD-R only at this time).

So, if we do the math:

74 min x (60 sec) x (75 sectors) x (2 kbytes) = 666,000 kilobytes

= 650 megabytes

80 min x (60 sec) x (75 sectors) x (2 kbytes) = 720,000 kilobytes

= 703 megabytes

Factory-recorded CDs can be made to hold a little more data.

The actual capacities of blank discs can vary slightly; some 74-minute discs can hold up to two minutes more than their stated capacity. However, this is not likely to be evident on the packaging; you will have to find it out by direct experience, or by asking other CD-R users.

Constant linear velocity (CLV) format

The constant linear velocity (CLV) format requires the rotational speed to be changed as the radial position of the read head changes. This can take up to a second for full stroke movement. Still, the market has readily accepted the CD-ROM as a very convenient and secure way for delivering software.

Standard	ECMA/TC15/86/16 [1986]
Disk diameter	120 mm, single-sided.
Data capacity	650 Mbytes of data plus overhead, 170,000 equivalent pages
Format	Constant linear velocity, embedded servo.
Scanning velocity	1.2 m/s, with up to 25,000 spiral tracks.
Rotational speed	approx. 200 rpm @ OD, 500 rpm @ ID.
Access time	600 ms, average.
Data rate	2 Mbits/s.

EDAC strategy	CIRC (cross-interleaved Reed-Solomon code) ECC.

Table 12.1. Characteristics of the CD-ROM.

12.3. Write-Once Systems

The photographic process is an obvious write-once only optical recording system. However, such methods, including the use of photographic films, photoresists and photopolymers require development or some other similar form of post-processing. Other non-erasable technologies make use of ablative thin films and phase-change media. The recording mechanism is permanent and cannot be reversed.

In *ablative recording*, spots on a thin film of metal, bonded to the disk substrate, is melted to form a hole. Metal films like tellurium, bismuth, selenium and other alloys with low melting points are used. In high speed recording, the energy of the laser beam is sufficient to vaporize the metal, hence the term ablative. Whether melted or vaporized, the hole size must be large enough so that surface tension and reflow does not cause the void to be unstable.

Dye/polymer recording, uses ablation to form marks in light-absorbing organic films by heat. Apart from the vaporization of material, the pressurized vapor also pushes the soft polymer away to form a clearly defined pit.

Phase-change media can exist in two or more stable structural states. The material is manufactured in a metastable state. When a mark is required, heat is applied at the required bit cell with the laser. This heats the region up and the material is allowed to anneal into a more stable state. For example the material may be deposited in the amorphous state. The heat cycle causes the material to anneal into the crystalline state. Usually the crystalline state is more reflective and this property is used in reading out the stored data. The material properties have to be carefully selected so that the states remains stable even at all expected storage temperatures. Unlike the rewritable systems, this phase-change cannot be reversed.

Write-once systems are particularly suitable for archival storage. Recently low-cost systems have been introduced into the market which enable users to create their own CD-ROMs.

Apart from disk systems, write-once storage devices are appearing in the form of smart cards and stored value debit cards where a complete and non-erasable history of all transactions can be kept for audit purposes.

12.4. Rewritable Optical Storage

With the development of the erasable/rewritable optical disk, the most obvious limitation of optical storage systems is removed. Optical disks can now functionally replace other recording storage media. In applications where large amounts of data have to be stored, but read/write access times are not stringent, this is in fact beginning to take place. At this point, it should be noted that the 'floptical' (floppy-optical) drives, which is also known as SuperDrive or LS120, do not use optical storage techniques. The optical portion of the name comes from the fact that optical tracking is used in the positioning of the head, enabling a much higher track density and total storage. Magnetic recording is still used for data storage.

At present the magneto-optical recording is the main technology used in WMRM (write-many read-many) disks. Other methods have been demonstrated and one making use of reversible phase-change media appears quite promising.

12.4.1. Thermomagneto-optics

When a magnetized piece of iron is heated, a temperature is reached above which the magnetization is lost. Some materials have the property that at normal room temperature they are very resistant to any changes in the magnetic domain structure, i.e. the material exhibits a high coercivity. A high applied field is needed to change its magnetic pattern. However when the temperature is raised above a certain characteristic value, called the *Curie temperature* T_{curie}, the magnetic structure becomes disoriented and the coercivity disappears.

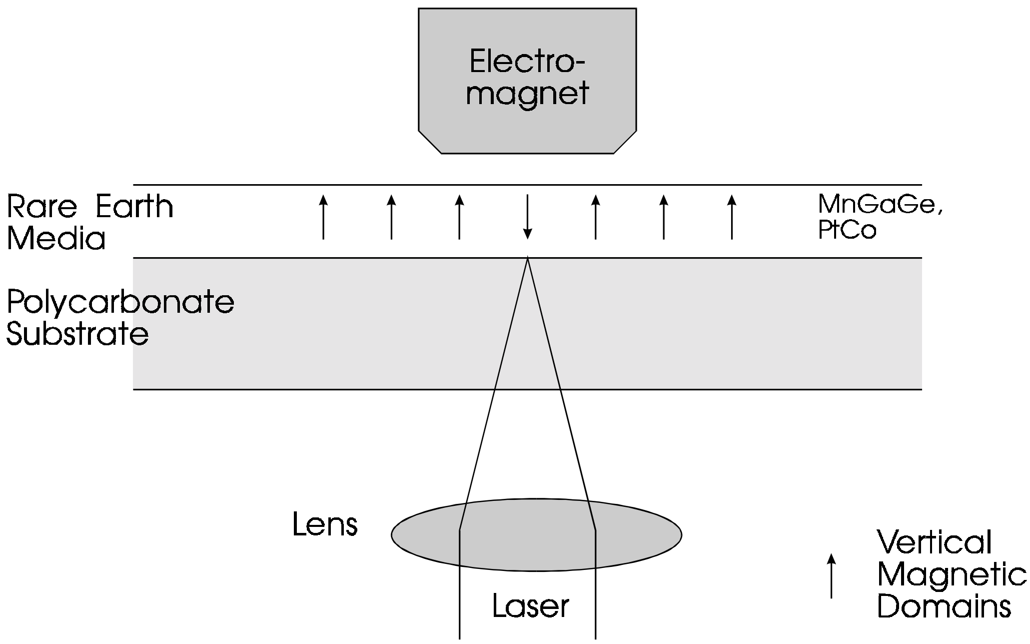


Figure 12.2. Thermomagneto-optical recording.

In the magneto-optical (M-O) storage device, the disk is coated with a layer of M-O material, with a Curie temperature of about 200°C. In the 'blank' state the material has an initial magnetization, say downwards, representng all zeroes. During the *write* cycle, a magnetic field in the upwards direction is applied to the region and a high power laser is focused onto the spot where the '1' bit data is to be written. This spot is quickly raised above T_{curie}, lowering the coercivity. As the material cools, the magnetic domains are realigned according to the externally applied field. Figure 12.2 illustrates the arrangement of the laser and externally applied magnetic field.

The written information can be *erased* by repeating the write process with the external field reversed. At the present most systems uses a separate erase cycle. Compared with normal magnetic recording techniques this is a disadvantage as it means that each re-write operation requires at least two revolutions of the disk. Intensive efforts are under way to develop a reliable over-write materials and technology.

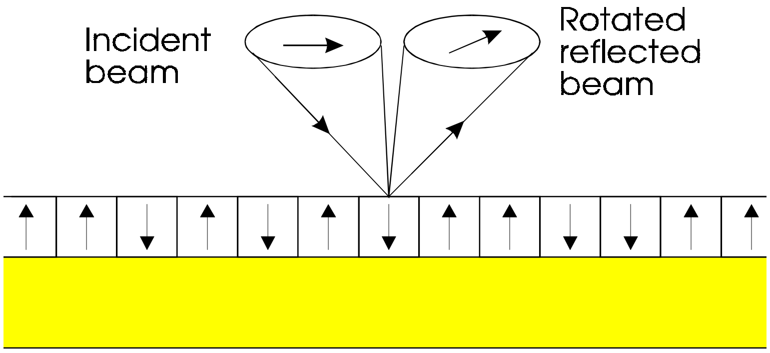


Figure 12.3. Kerr rotation from vertical magnetization..

To *read* the stored information from the optical disk, we make use of the *Kerr effect*. This is shown in Figure 12.3. A plane polarized beam is directed at the M-O layer and the reflected beam is detected. Comparison of the plane of polarization between the incident and reflected beam shows that the reflected beam has undergone a small angle of rotation. The direction of rotation depends on the direction of the vertical magnetization of the spot the beam is focused on. For example, if initially the direction of magnetization is downwards, representing binary '0', the polarization is rotated 20° anti-clockwise. When a '1' is written, the direction of polarization is reversed to point upwards. The beam reflected from this region will have the plane of polarization rotated 20° in the clockwise direction. In this way, the direction of magnetization, which is a representation of the stored information can be detected.

12.4.2. Magneto-optical systems

Figure 12.4 illustrates the essential features of a M-O disk drive. The laser diode has two power levels, high power to raise the temperature of the M-O layer above the Curie temperature, and a lower power beam for reading. The laser beam is passed through a diffraction grating and collimator lens into the polarizing beam splitter cube (PBSC). From this direction most of the beam is transmitted to the movable mirror which directs it onto the selected track on the disk. The polarized beam passes through a variable-phase plate in both directions. When the plane-polarized incident beam interacts with the M-O material, a component normal the plane of polarization is produced. The variable-phase takes this elliptically polarized reflected beam and converts it in two linearly-polarized beams, aligned with the parallel and perpendicular axes. This is reflected back to the first PBSC which now reflects the composite beam down to the second PBSC where the two beams are split, one being transmitted and the other reflected. The intensities of these two beams are detected differentially to give the direction of rotation, hence the direction of magnetization and the bit information.

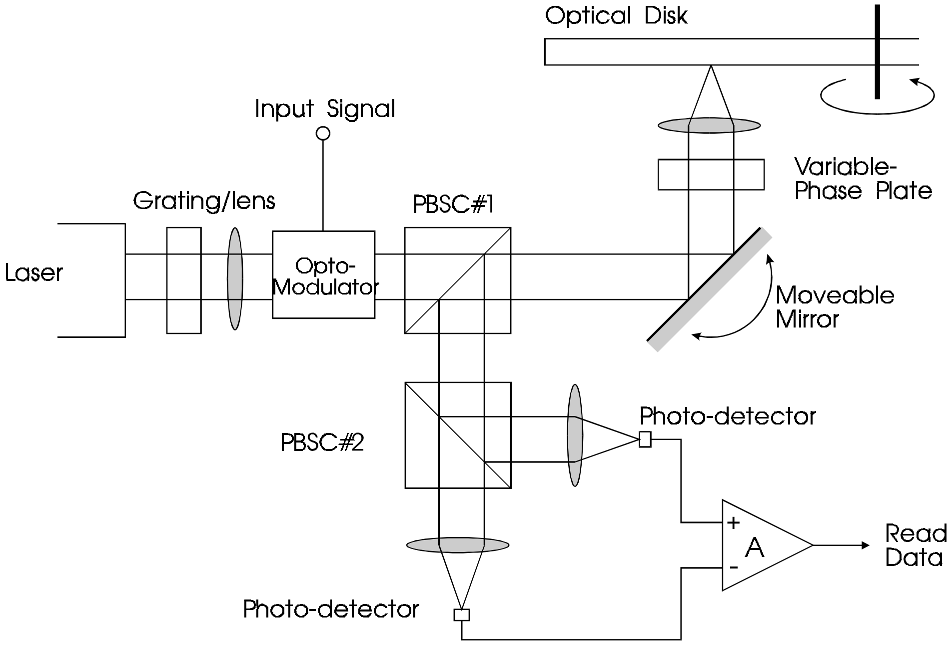


Figure 12.4. M-O disk drive.

In the write mode, the input signal is applied to the opto-modulator which controls the intensity of the laser beam directed at the disk. For a write of a '1', the intensity is sufficient to raise the temperature of the M-O material above T_{curie}.

12.4.3. Phase-change recording

Phase-change recording makes use of the discovery that many materials can exist in several crystalline phases. Generally the most common phase has the lowest energy state, but the other phases can occur at a local activation energy minima. The change in phase often causes changes in some optical characteristics such as refractive index or colour. These changes are exploited in phase-change recording. The laser beam is used to rapidly heat a small region which is then quenched quickly into its new state. For erasure, the region is heated and allowed to cool slowly, annealing the material back into the original state. To read the data, a much lower power laser beam is used. A typical phase diagram is shown in Figure 12.5, and Table 12.2 lists the basic requirements for erasable phase-change materials.

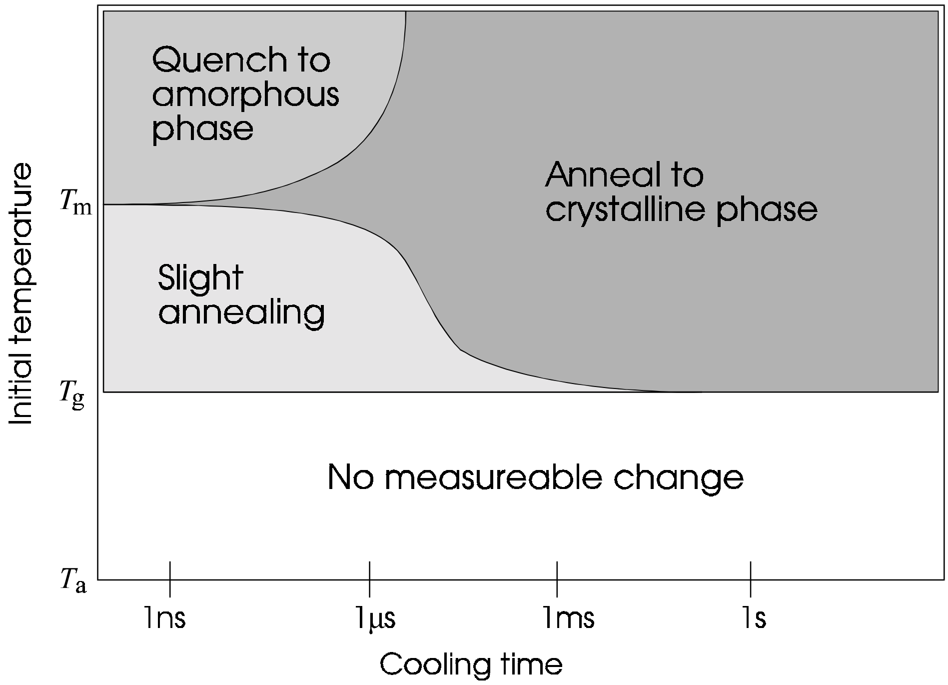


Figure 12.5. Phase diagram of phase-change material.

Characteristics	Function
Refractive index change	Optical contrast between crystalline and amorphous regions
Moderate thermal conductivity	Enables rapid cooling and quenching
Low melting point T_{melt}	High sensitivity
Rapid annealing below T_{melt}	Easy erasure
High activation energy for annealing	Stable data storage
Density compatibility	Low physical stress

Table 12.2. Erasable phase-change material requirements.

12.5. Data Storage Formats

Like the magnetic disks, three different formats are used to organise data on the optical disk. These are shown in Figure 12.6.

The *constant linear velocity* (CLV) format optimizes utilisation of the usable recording area by having an uniform recording density throughout the disk. By maintaining the linear velocity constant, the recording density is kept constant. Data are stored in one continuous track that spirals from the circumference inwards to the centre. As the tracks moves inwards, the radius decreases and to maintain the same linear velocity the disk must spin faster. CLV is best suited for sequential access applications such as in the CD audio disk and as a replacement for magnetic tape in for archive and backups. In most applications of CD-ROM, this is generally acceptable, where the information contained are usually programs which have to be installed or loaded sequentially. Trying to directly access a specific block of information is slow as apart from the movement of the read head mechanism, the rotational speed of the disk has to change also. CD-ROMs and some WORM devices use the CLV format.

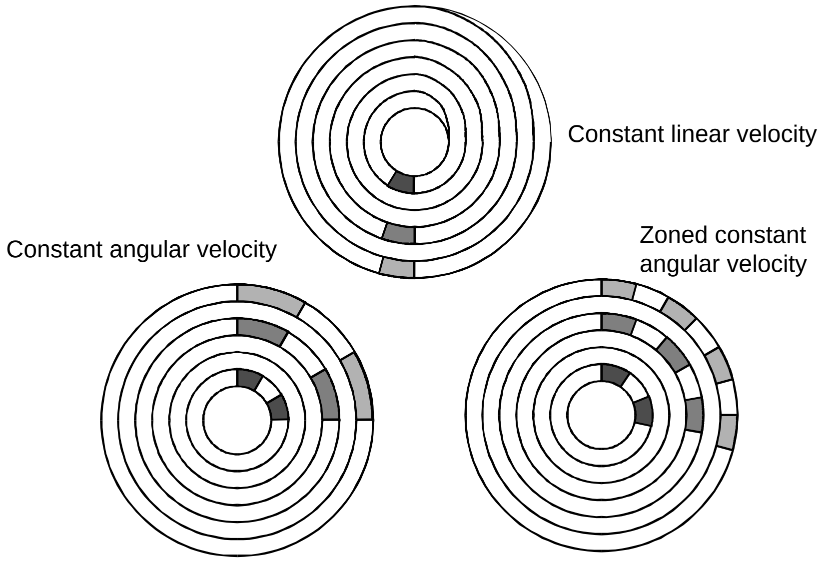


Figure 12.6. Disk recording layouts.

Magnetic hard and floppy disks normally use the *constant angular velocity* (CAV) format for the layout of the tracks and sectors. With concentric tracks and a fixed number of sectors per track, direct access to any specific sectors depends only on the seek delay. The rotation of the disk is at a high constant speed, which also keeps the latency time down. An ANSI/ISO standard has been defined for rewritable optical disks using this format.

Performance characteristics	Philips LaserDrive	Maxtor Tahiti
Disk, 20sided	12 cm M-O, ISO	12 cm M-O
Capacity, per side	327 MB	298 MB, CAV 466 MB, ZCAV
Bytes/Sector	512	512/1024
Typical bit density		25,000 bpi.
Track/pitch density	1.6 mm	17,000 tpi.
Encoding method:	RLL (4,15)	RLL, (2,7)
Average access time:	70 msec incl latency	35 msec seek
Spindle speed:	1800 rpm CAV	2200 rpm CAV, ZCAV
Error rate with ECC	10^{-12} bytes	

Table 12.3. Typical performance of M-O disks.

Zoned constant angular velocity (ZCAV) reduces the inefficiencies of the CAV format by dividing the disk into typically five zones. The maximum recording density is used at the inner radius of each zone, resulting in a different number of sectors per track between the zones. The increased complexity of the controller is justified by the improvement of over 40% in storage capacity. Presently no industry standard has been defined for ZCAV formats. In the advanced magnetic disks where the platters are fixed, this is not a problem, but with removable optical disk cartridges, interchangeability amongst M-O drives has not been realized. For example, the Maxtor Tahiti M-O drive supports both CAV and ZCAV. 327 Mbytes of data can be stored in the ANSI CAV format, whereas using the Maxtor proprietary ZCAV format, the same disk can hold as much as 500 Mbytes. Brief specifications of two M-O drives are reproduced in Table 12.3 as examples.

12.6. Focus and Tracking

In the magnetic disk, sophisticated servo systems are used to keep the head aligned with the track being read or written. The flying height of the head above the media surface is determined by the aerodynamic design, springs and the surface velocity. In optical disks, servos are required to position accurately the head on the selected track and also to ensure that the laser beam is properly focused on the reflective film.

The tolerances in optical disks are typically ±0.1 mm for tracking and ±0.5 mm for the focusing of the optical read / write head. Usually the same laser beam that is used for the read/write operation is used to accurately sense the head position. The tracking and focusing errors are processed by complex electro-mechanical servo systems, often incorporating digital signal processors.

12.6.1. Focus sensors

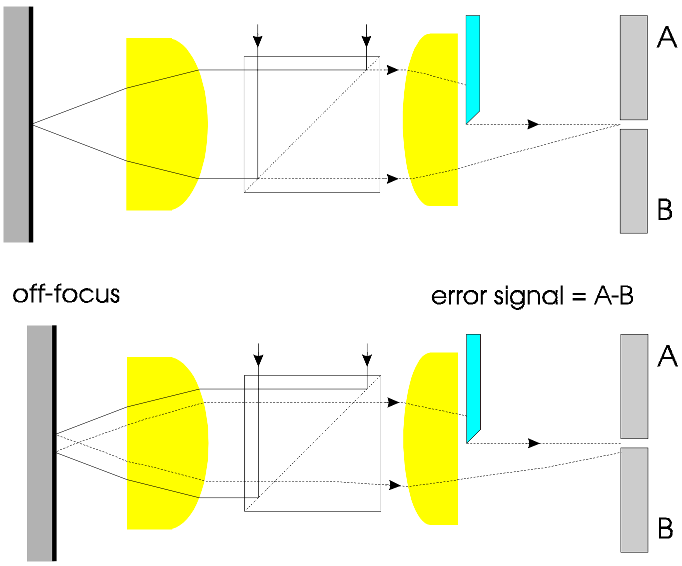


Figure 12.7. Focusing error sensing using the Foucault knife-edge.

Referring to Figure 12.7, it will be seen that when the focus is perfect, sensors A and B will detect equal amounts of light, but when the media is slightly out of focus, there will be a difference in the amount of light falling on sensors A or B. This error signal can be used as the input to the servo system for focusing the laser beam. Other focus sensors that operate with collimated beams are the half-aperture sensors and the astigmatic focus sensors. Although the above discussion depends on the use of a collimated (parallel) beam, the same effect is observed even when there is some divergence in the beam.

12.6.2. Tracking sensors

The audio LP record uses the groove to constrain the pick-up stylus to stay in the track. In optical disks, there is no physical contact between the optical stylus and the disk, but one important method of tracking makes use of tracking grooves on the disk.

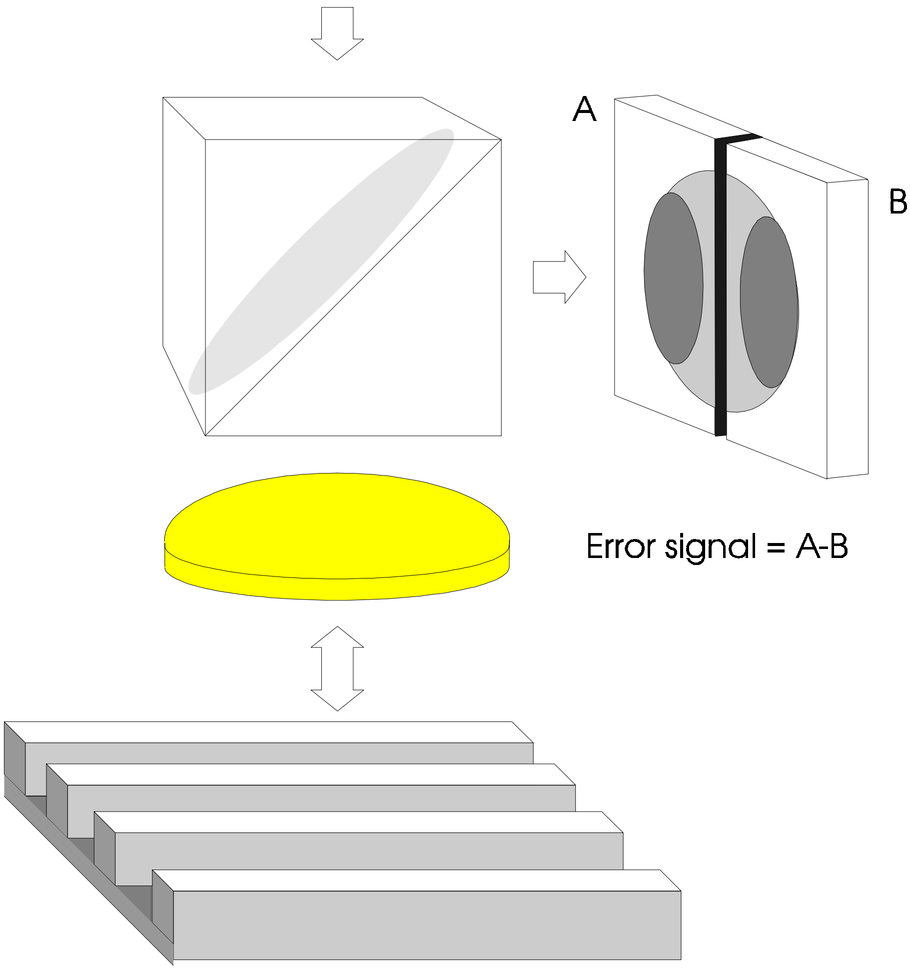


Figure 12.8. Track positioning sensor.

As shown in Figure 12.8 the tracks on the disk form grooves on the surface. The wavelength of the lasers used on optical disk is about 0.8 µm, and the grooves are spaced 1.6 µm apart. When the incident beam is directed at the surface, apart from the primary reflected beam located at the angle of reflection, the grooves cause the beam to be diffracted, with components reinforcing the primary reflected beam. A diffraction pattern is produced which is symmetrical when the beam is exactly aligned on the groove. If there is a small deviation from the track, the pattern changes, and the intensity of the light detected at a split sensor becomes unbalanced. This is used as the error signal input to the tracking servo system.

12.7. Defect Management

Error detection and correction techniques used in optical storage systems are essentially the same as those used for magnetic disks. However, because of the much higher density of recording, the optical marks are smaller. The laser is working at just a slightly longer wavelength than white light and it is not possible to see the marks made by the laser beam using an ordinary optical microscope. Defects like dust, scratches, voids, which may not cause any problems in magnetic media are now relatively two orders of magnitude larger in optical media. Bit error rates (BER) of 10^{-8} are readily achieved with magnetic media and certified defect-free diskettes, tapes and disk are normal. With optical media, current manufacturing processes can only achieve a BER of 10^{-6}.

Error management strategies have already been discussed in Chapter 8. With erasable disks the same defect management procedures can be used. The media is formatted, and a defect map maintained to identify defective sectors which are re-vectored. A complication arises with WORM disks where the medium can only be written once. It is not possible to perform a verification of the medium, and the presence of defects is detected only during the actual write operation.

During the operation of WORM drives, a direct read after write is performed, and if the a block of data could not be verified, it is re-written in the next block. This strategy is somewhat similar to that used in QIC tapes, except that to conserve media, and because of the direct access capability of the disk drive no additional successive blocks need to be written. The verification stage requires a second pass of the sector under the read, slowing down the whole process. In some WORM drives a complex optical system is used where verification is made during the same pass as the write operation by interleaving a second low power laser pulse to read the bit immediately.

12.8 CD versus DVD

Feature	CD format	DVD format
Disk diameter	120 mm (5 in)	120 mm (5 in)
Basic structure	One 1.2-mm substrate	Two 0.6-mm substrates DVD-5: 4.7 GB (single-sided, single layer) DVD-9: 8.5 GB (single-sided, two layers) DVD-18: 17 GB (double-sided, single layer)

Minimum pit Length	0.83 µm	0.4 µm
Laser wavelength	780 nm	635 to 650 nm
Numerical aperture (n sinθ)	0.45	0.6
Areal data density	0.68 Gbit/in^2	3.28 Gbit/in^2
Track density	16,000 tpi	34,000 tpi
Linear bit density	43,000 bit/in	96,000 bit/in
Data rate (for same rpm)	Variable, 4.8 Mbit/s max	Variable, 11 Mbit/s max

Refer to "*DVD technology: The new paradigm in optical storage*." by Micheal Elphick in Data Storage, January 1997.

12.9. Conclusions

CD-ROM, WORM and rewritable optical disk are effective devices for the storage of large programs and data files. With the increasing use of multimedia applications where sound, graphics and video are used, the data files used are often several Mbytes in size. The challenge is to be able to deliver these large amounts of data to the computing elements at a rate capable of supporting real-time audio, video and animation graphics.

Development is proceeding rapidly in several fronts. There is a constant search for improvements in media that have faster response, are more stable and can reliably undergo many cycles of erasures. To increase the storage density, researchers are experimenting with shorter wavelength lasers in the blue range. Compared to the magnetic Winchester disks, access times are much longer and developments in servo systems using DSP techniques are needed for the focusing and tracking systems.

The lack of a standard M-O format for 5.25 in. disks presents an obstacle to the growth of the market. Some of the newer drives, particularly those using the 3.5 in. format are being developed with the capability to handle CD-ROM, WORM, WMRM and P-ROM (Partial ROM), where some space at the end of each block is available for user written data on a compatible CD-ROM.

The PCMCIA is now well accepted as an interface and peripheral device standard. There are opportunities for new product development of optical storage products that will conform to this standard. These devices could use either rotating disks or stationary cards. There could be demand for 'smart cards' that would hold many Mbytes of data, for example, the contents of a book complete with illustrations.