Architecture of Computers and Parallel Systems

Part 7: External Memories (Disks)

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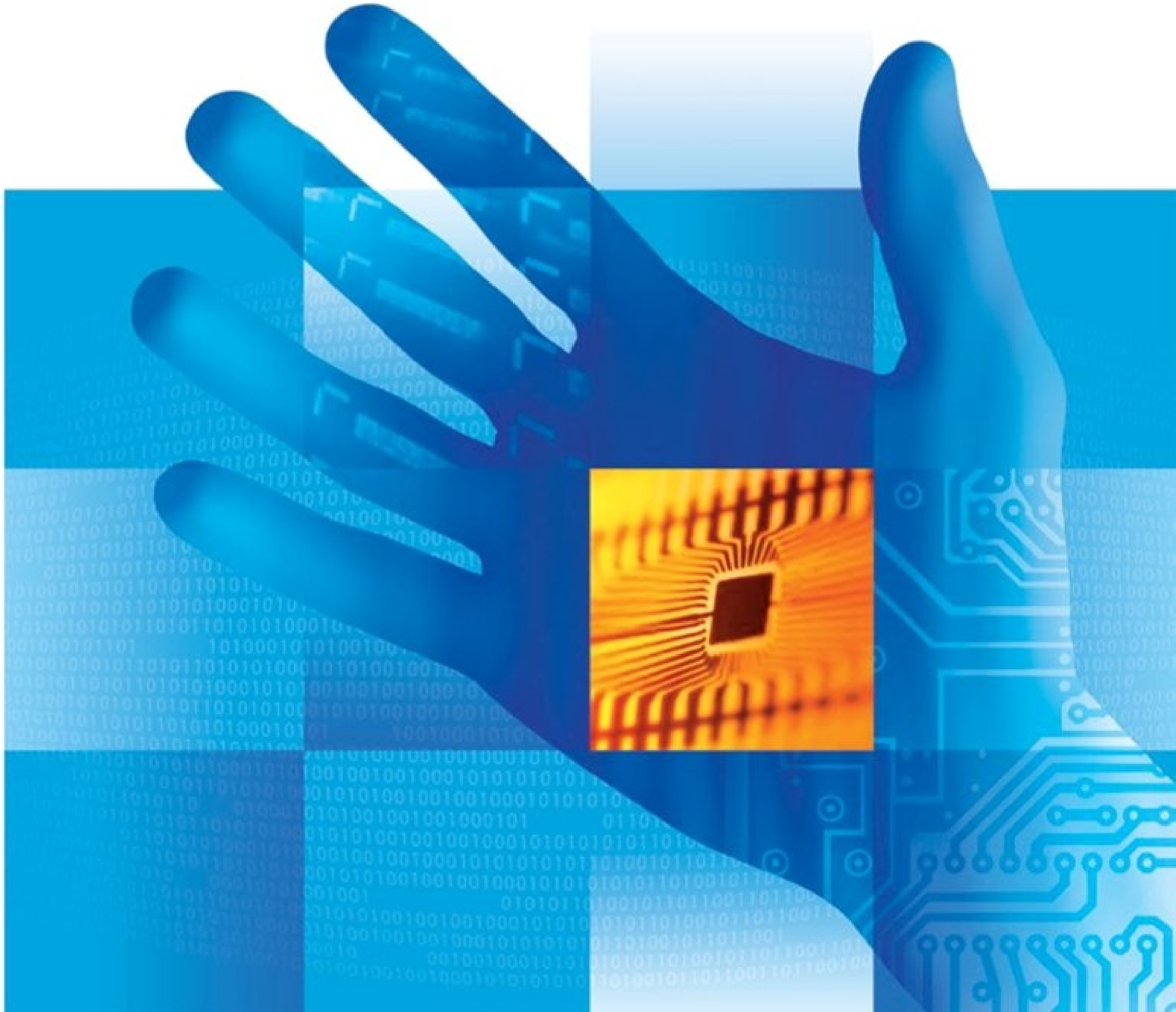

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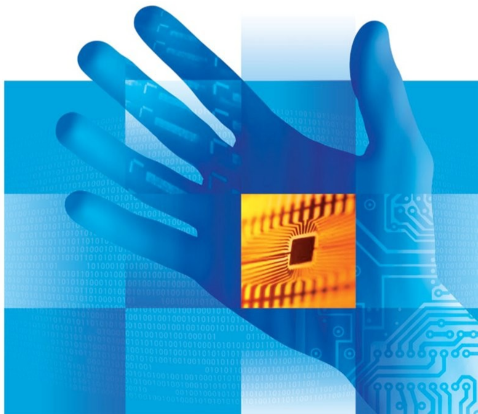

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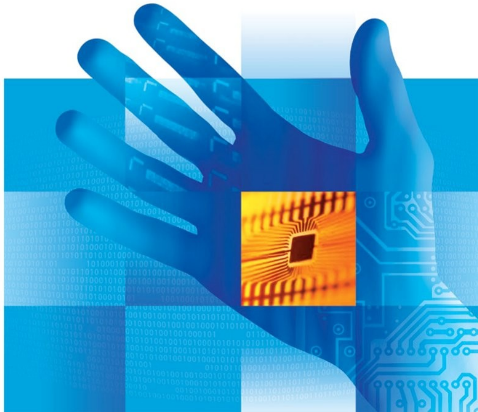


Magnetic Disk History

The disk history started about ten years after the first computer. Here is a brief overview of the hard disk history:

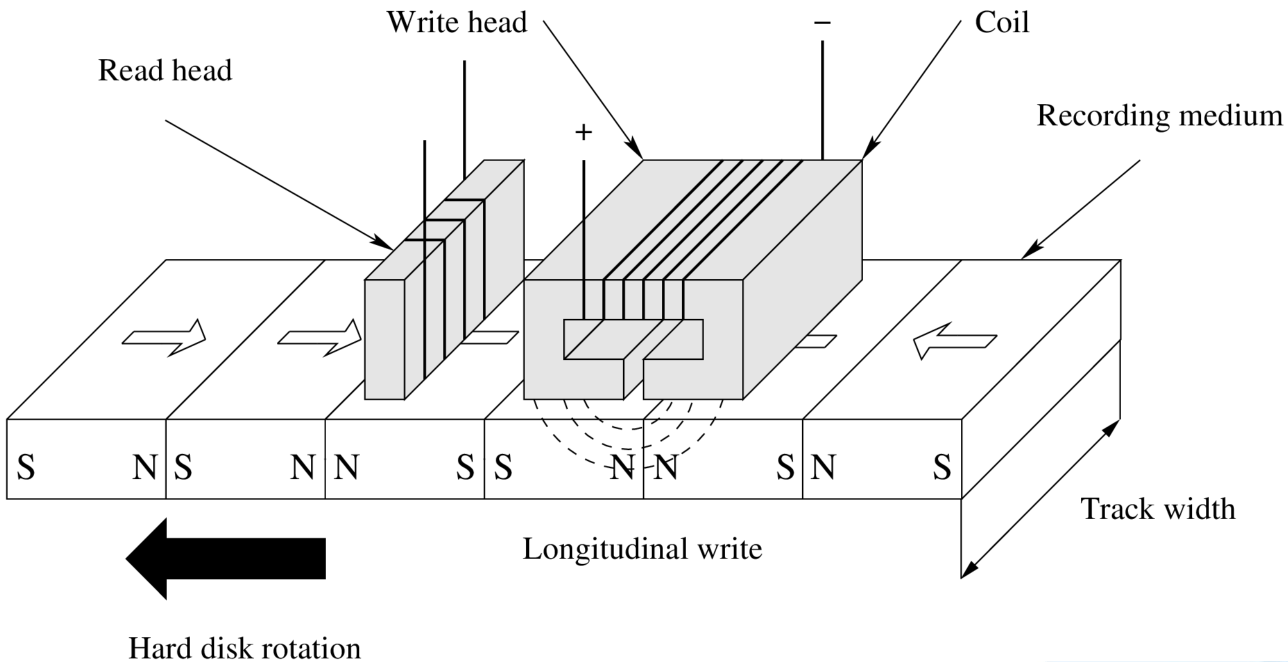
- 1953 – First hard disk RAMAC.
- 1973 – First fully integrated hard disk in one box together with reading heads – named Winchester.
- 1990 – Magneto-resistive head.
- 1997 – Giant magneto-resistive head.
- 2005 – Perpendicular recording.

Floppy disks were very popular too:

- 1971 – First floppy disk.
- 1976 – First floppy disk drive 5¼”.
- 1983 – First floppy drive 3.5” with capacity 875kB.
- 1994 – ZIP Drive 100MB (alternative LS-120).

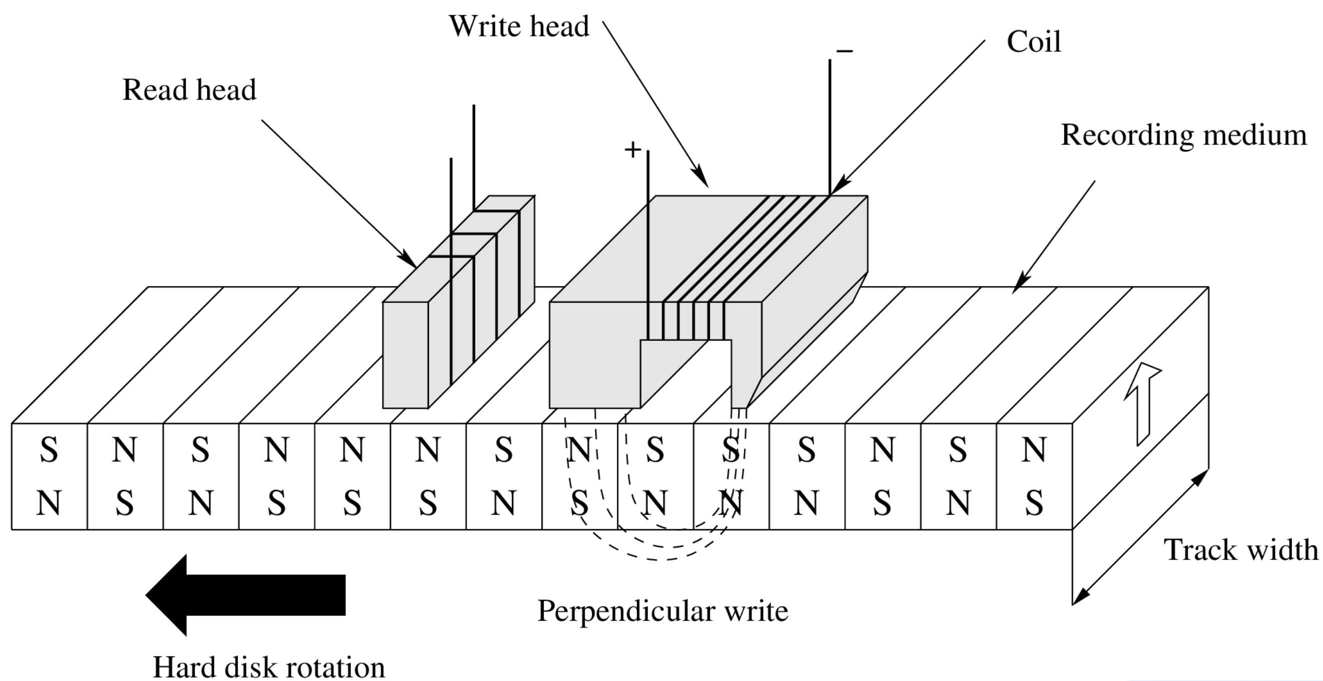
Magnetic Medium

The principle applied to all magnetic disks is similar. There is a very thin magnetic surface on the carrier and information is saved as a magnetic orientation in small magnetic elements. The longitudinal write was used for fifty years. It is shown on the next scheme. Every drive uses two heads, one for reading and one for writing.



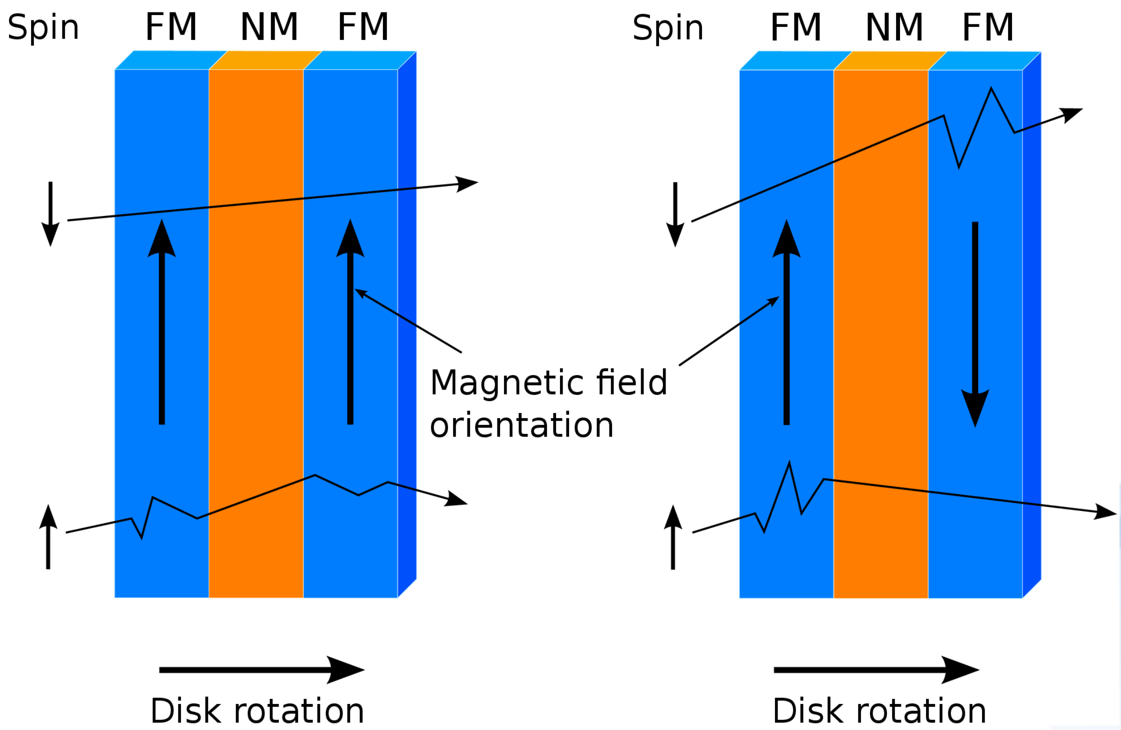
… Magnetic Medium

Modern hard disks use greater density writing with – perpendicular write – see below. This principle required a change of the writing head design in a drive. The greater density provides more than higher medium capacity. More information passes under the read head at the same time and it increases the speed of reading.



Giant Magnetic Resistance - GMR

Reading heads are using the technology invented in 1997 – Giant Magnetic Resistance. Let's take a look at this physical phenomenon closer. The resistance of material depends on the ability to pass electrons. But very thin layers are also affected by the quantum mechanics. Ferromagnetic material in magnetic field can pass only electrons with the same spin.



… Giant Magnetic Resistance - GMR

On the previous picture there are two outside thin layers from ferromagnetic material (usually cobalt). The middle layer is nonmagnetic metal (usually copper). When electrons come from the left side, the ferromagnetic material passes only those with spin that has the same direction as the magnetic field. It can pass up to 50% of electrons. Now electrons pass through middle layer to second ferromagnetic layer. If magnetic field in this layer has the same orientation as the first one, all electrons pass to the right side. Therefore all three layers have the low resistance.

If the magnetic field has different orientation in both outside layers, no electrons are possible to pass through all layers and this structure has the high resistance. The resistance is not measured directly in the hard disk read head. The voltage is connected to the head and the current passes through the GMR structure. When the resistance in the head grows, the current decreases. Thus we say that the head works as a “current valve”.

Data Encoding

One might think that since there are two magnetic polarities, N-S and S-N, they could be used directly to represent a 1 and 0 to allow the easy encoding of digital information. That would be nice, but it doesn't work that way.

The first encoding system for digital data recording on magnetic media, was frequency modulation FM. This is a simple scheme, where a 1 is recorded as two consecutive flux reversals, and a 0 is recorded as a flux reversal followed by no flux reversal.

The problem with FM is that it is wasteful. Each bit requires two flux reversal positions. FM was replaced by modified frequency modulation - MFM. The MFM reduces the number of flux reversals inserted just for the synchronization. Instead of inserting a synchronization reversal before each bit, one is inserted only between consecutive zeros.

… Data Encoding

An improvement of the MFM encoding is the Run Length Limited encoding (RLL). This is a more sophisticated coding technique. The RLL works by looking at groups of bits instead of encoding one bit at a time. The idea is to mix the synchronization and data flux reversals to allow even denser packing of encoded data to improve efficiency (up to 3 times).

The next table shows the difference between MFM and RLL:

Pattern	RLL	Pulses	MFM	Pulses
00	PNNN	1	PNPN	2
01	NPNN	1	PNNP	2
100	NNPNNN	1	PNNPNN	2
101	PNNPNN	2	NPNNNP	2
111	NNNPNN	1	NPNPNP	3

Hard Disk

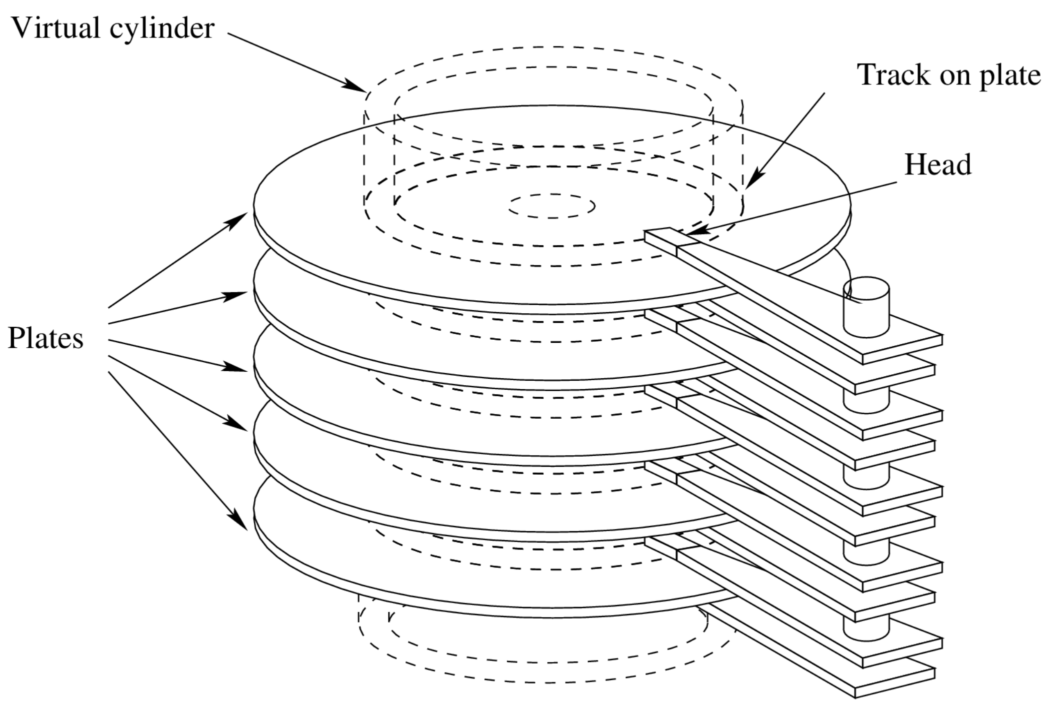
All hard disks consist of several major functional parts. Main parts are rounded plates with magnetic surface. All plates are mounted parallel on the spindle (axis). The spindle is mounted in bearing and rotation is provided by the synchronous (three phase) motor. The speed of rotation is usually in thousands of rotations per minute and it is constant.

The second most important functional parts are (read and write) heads. One head is moving above each plate surface. All heads are mounted on the pivot parallel with spindle. This pivot does not rotate, step motor only tilts them in small angle.

Both functional parts are inserted in an aluminium alloy case from where the board with the driver and controller is mounted outside. The case has to be dust-proof. The hard disk is then connected to a computer board by a cable.

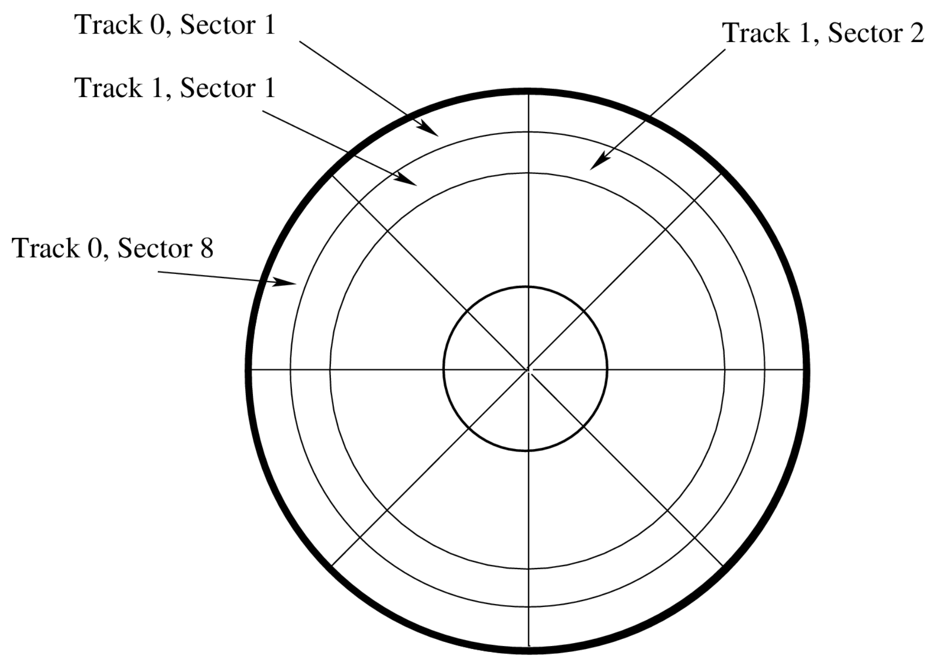
The scheme of the hard disk is on the next slide:

Hard Disk



Plates rotate with the high speed and heads move above plates surface. All heads move synchronously, because they are mounted firmly on pivot. In each step head makes a circle on a plate, called a track. Tracks with the same order number create virtual cylinders on plates.

Hard Disk Geometry



As it was already noted, the plate is divided into concentric circles called tracks. Every track is divided to circle segments, which are in short called sectors. Tracks and sectors are on both sides of plates.

From penultimate picture it can be seen, that all tracks with the same order number create virtual cylinder. This term is used when we talk about disk geometry.

… Hard Disk Geometry

From the previously mentioned information we can conclude that the hard disk geometry is given in units: *Cylinders – Heads – Sectors*.

The size of the sector is 512 bytes and the capacity of the disk can be computed as a product: *Cylinder*Heads*Sectors*512*.

The very important is the order of data writing to the disk. For the maximum speed it is necessary to minimize the head movement. Thus data are in first step written to all sectors in one track. Then the writing continues on track with the same order number under the following head. When all heads finished writing to the single cylinder, then heads are moved to the next cylinder.

The smallest addressing unit of the disk is one sector! When a program wants to read one byte, it must read the whole sector. Therefore the cache is installed on the disk controler, which speeds up the reading. Hard disk does not propagate outside its real CHS geometry. It presents some virtual geometry (LBA) and it internally converts the sector order number to internal geometry.

S.M.A.R.T.

All hard disks are equipped with standardized technology: Self-Monitoring, Analysis and Reporting Technology, in short SMART.

The purpose of SMART is to inform users about technical problem during running and warn them of impending drive failure. Early warning provides the user some time to back up data and replace the drive. Disk errors are predictable and unpredictable. Predictable errors cause more than 60% of failures and SMART can detect them in advance.

The main monitored parameters, which may cause failure are e.g. distance between heads and plates - small distance may cause head crash. The number of bad sectors – the newest disks redirect bad sectors to a backup area. But when too many sectors are redirected, the disk is marked as unreliable. The high temperature - may damage some hard disk parts of hard disk. The time required for the disk to spin up – any changes of that time indicate imminent failure of the engine.

Hard Disk Parameters

All disks have a number of technical parameters. They are used by customer to make the proper selection:

- Capacity – GB/TB, is important parameter for the most users.
- Size of disk – external dimension, usually 3.5”, 2.5” or 1.8”.
- Speed – RPM, usually thousands of rotations per minute. Higher speed can generate the noise and the disk will warm up.
- Transfer speed – how many MB/s can disk read or write.
- Interface – cable connector for one standard SATA, PATA, SAS.
- Access time – average delay before reading.
- Power consumption – disk with high consumption needs cooling.
- MTBS – mean time between failures - value indicates the reliability of the disk. Disks designed for servers and RAIDs have significantly higher MTBF, than low-end disks for desktops. computers.

Floppy Drives

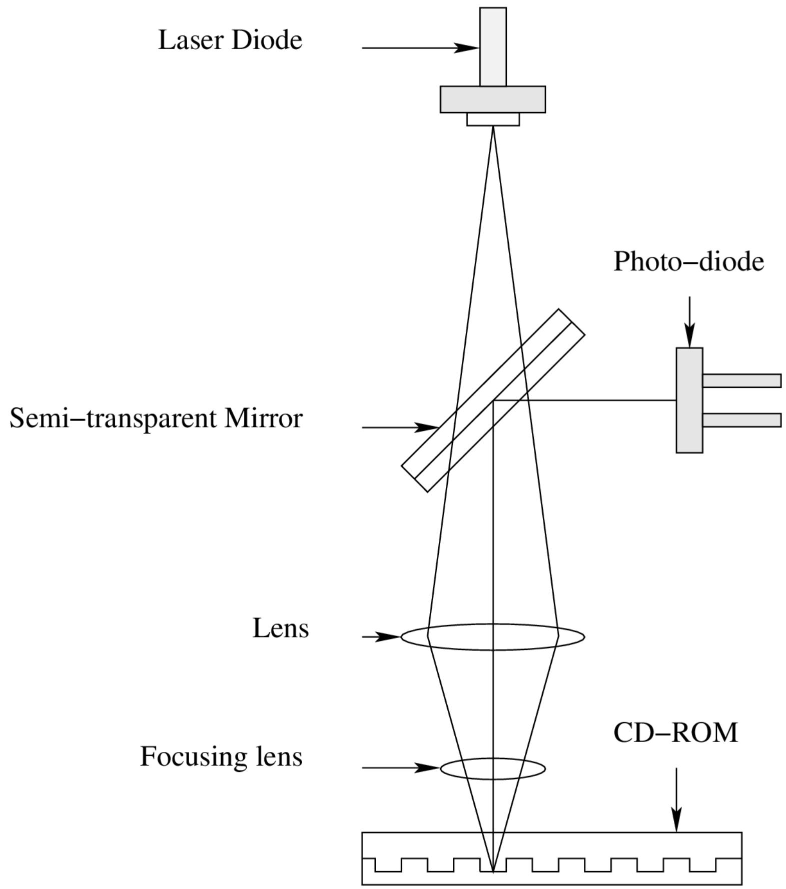
Until recent past, floppy disks were in wide use. Now they have become quite rare. There were several types of floppy drives used in personal computers:

- 5¼” with capacity of 360kB, 720kB (both sides) and 1.2MB
- 3½” with capacity of 720kB, 1.44MB and 2.88MB.
- LS-120 – Superdisk with capacity of 120MB.
- ZIP – external or internal floppy drive with capacity 100MB.

Floppy disks were always manufactured in self-closing disk cartridges, apart from old 5¼” floppy disks. The floppy drive and the hard drive has one major technical difference, except the removable media. Read head in the floppy drive has a direct contact with magnetic media. Floppy drive is therefore significantly slower, otherwise the media or the head could be damaged.

Floppy disks have a low speed and also they have low reliability.

Optical Drives



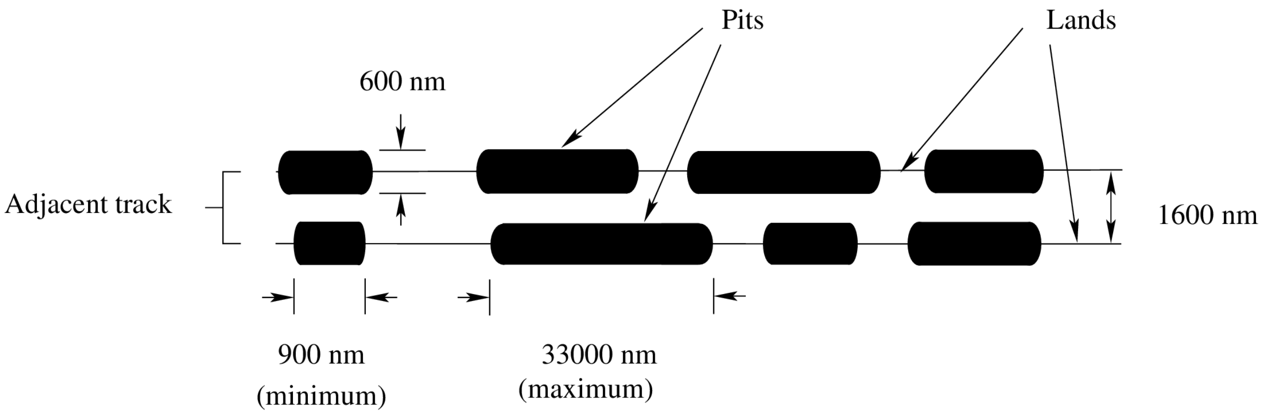
… Optical Drives

The laser diode emits the beam through a semi-transparent mirror to the first lens. Pre-focused laser beam continues through the second focusing lens to CD-ROM media. Pits or lands may/may not reflect he beam back. The bottom reflexive layer of the mirror directs the beam to the sensor – laser photo diode. This diode converts the reflected signal to a digital one and the device controller decodes them to data.

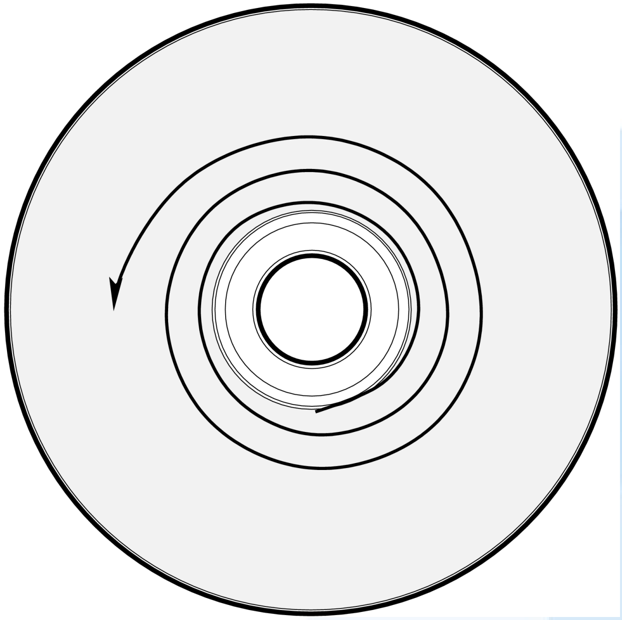
The CD-ROM media has its data layer under the transparent polycarbonate surface and laser beam must pass it twice. On the opposite side there is data layer protected by a reflective layer, protective layer and paint.

Pit depth is directly derived from the laser wavelength of 780 nm used in CD-ROM drive. Refractive index of polycarbonate is 1.55 and thus laser wavelength in polycarbonate is 500nm. The pit depth is ¼ of that value – 125nm (light reflected from the pit has half a wavelength longer path).

Optical Media



Dimensions of pits and lands on medium are shown in the diagram above. Track on CD-ROM media is in a spiral shape (not concentric circles). It is seen on the picture below:



… Optical Media

Comparison of CD and DVD pits and lands dimensions is in the following table:

	CD	DVD
Pit lenght	0.9 – 3.3 μm	0.4 – 1.9 μm
Pit depth	0.125 μm	0.105 μm
Pit width	0.6 μm	0.4 μm
Adjacent track	1.6 μm	0.74 μm
Data area	$8605 mm^2$	$8759 mm^2$
Capacity	650 – 700 MB	4.7 – 17 GB

Capacity of DVD is greater not only due to higher density of information on DVD media. Changed encoding of stored data increases overall capacity of media nearly 7x.

… Optical Media

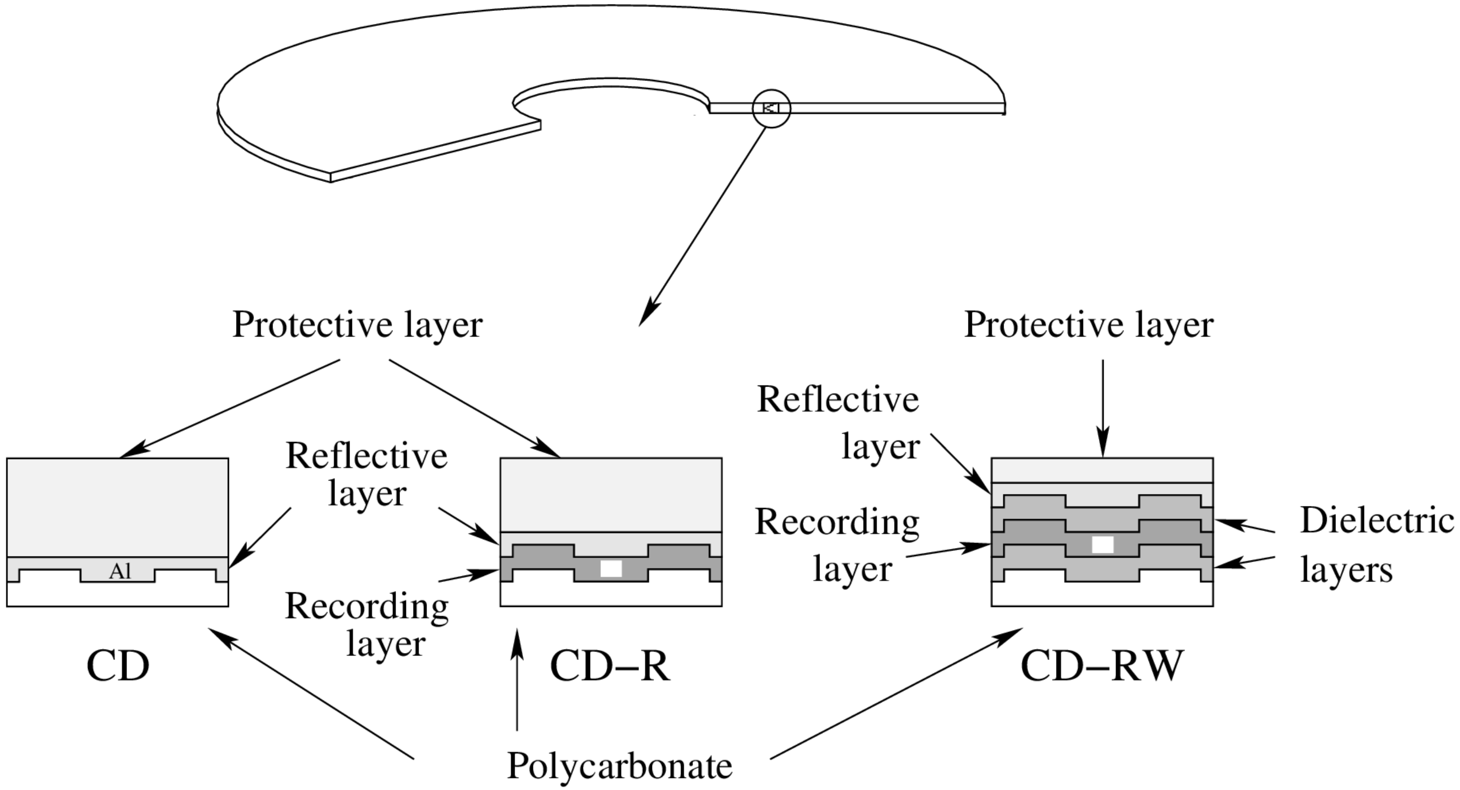
As previously mentioned, the CD-ROM has data stored in the spiral shape. This spiral represents totally up to 22188 turns with a total length up to 5.77 km. The DVD media store data with the higher density so the total length is 11.84 km. The DVD media allows to store data in two layers on one side – capacity 8.5GB – and DVD media can store data on both sides – total capacity of 4 layers is 17GB.

Track on the optical media is divided to sectors of 2048 bytes (the disk has 512 bytes).

Basic read speed of the CD-ROM was 150kB/s. This speed is marked as single speed. The drive speed is derived from this value. For DVD the basic speed is 1.38MB/s (nearly ten times faster than the CD-ROM).

Maximum transfer speed given by manufacturer of optical drives can be achieved only on the outer edge of media.

CD-ROM, CD-R, CD-RW



This image shows the three types of CD media and cross-sections show the layers on polycarbonate disc.

CD-ROM, CD-R, CD-RW

The CD-ROM drive has a content of data layer given by manufacturer. Data is pressed into an aluminum layer permanently.

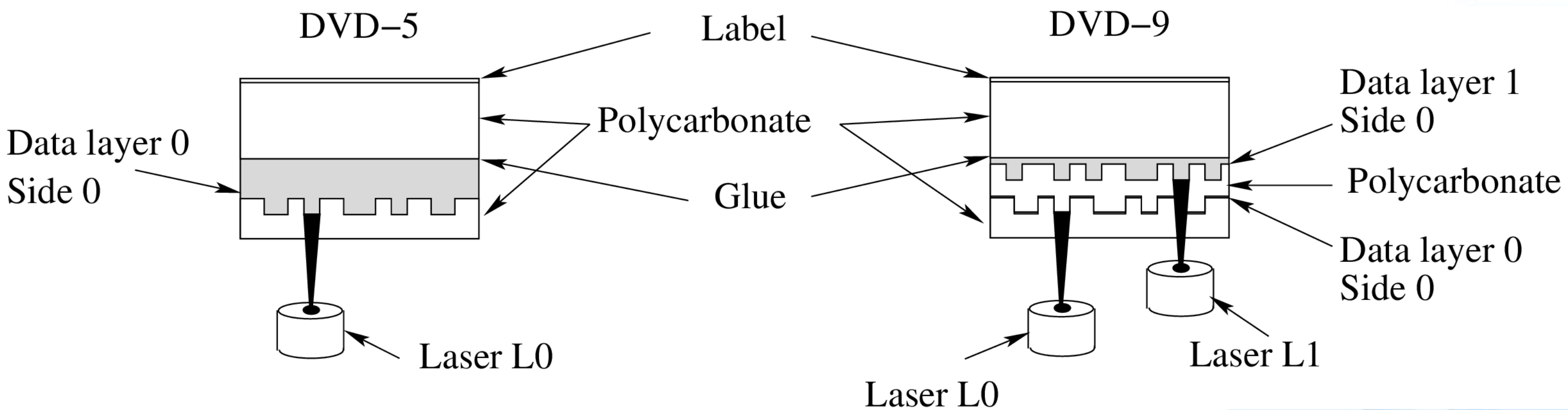
The CD-R medium allows users to write their own data to the disk only once. The material of the recording layer allows to create pits by laser. But the laser must be ten times stronger for writing than for reading. The CD-R disc can store data for several years, the recording layer ages.

The CD-RW medium allows rewriting the data. The recording layer is from a special material. It is located between two layers of dielectric. The recording layer can be melted by the laser and after the cooling it allows to write data in the same way as the CD-R medium. This process can be repeated many times. But each data write causes a little damage of recording layer. The problem is with the high speed of media rotation too. When the recording layer is melted, it is affected by centrifugal force. This force must not disrupt the recording layer!

DVD Media

The DVD disk has the same dimension as the CD-ROM disk. But the DVD disk can use both sides for data and therefore it is composed of two thinner (0.6 mm) polycarbonate disks. Data layer is between them. Disks are connected with glue. In addition, the drive allows two data layers on each side.

Next pictures shows two cross-sections of the single side DVD disk with data in single (DVD-5) and two layers (DVD-9). The DVD drive uses two laser beams for two layered disk.



Magneto-optical Disks

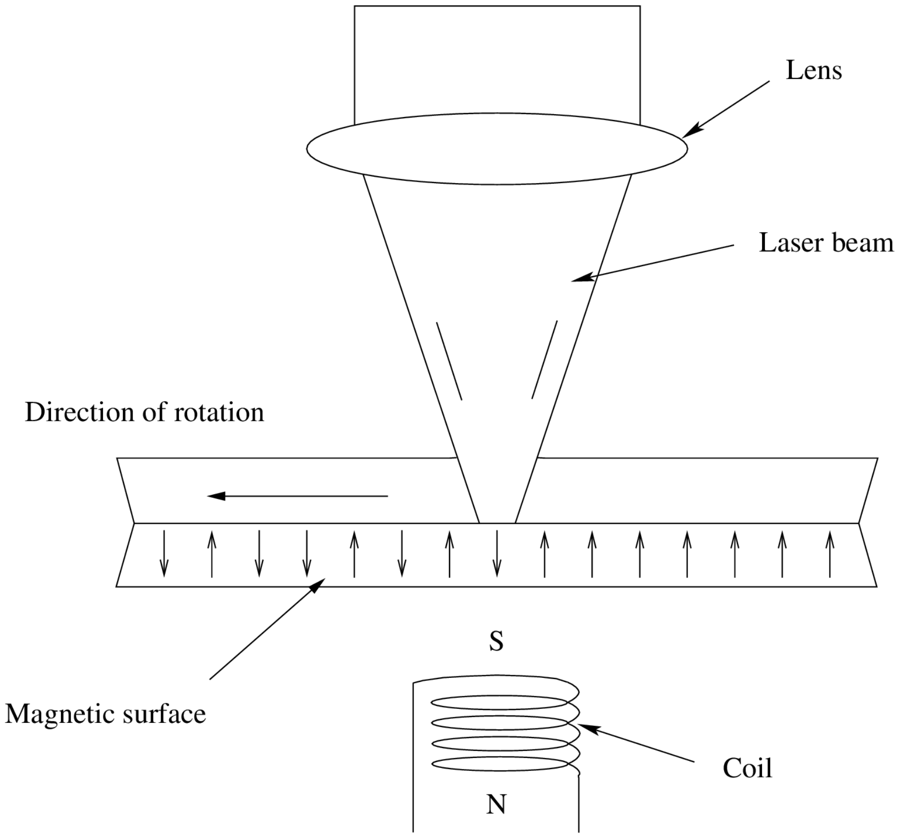
The magneto-optical medium uses for data storage a combination of two principles: magnetic and optical.

The surface of plates is thermo-magnetic. Information is saved as magnetic orientation (as on hard disk). Magnetic surface uses Curie temperature, when material change its ferromagnetic behavior to paramagnetic. This temperature point is about 180°C. The surface is usually heated up by laser. The paramagnetic material allows to change its magnetic orientation by the weaker magnetic field.

The powerful laser beam heats up the track in a width of a few micrometers and the write head stores data quickly. Because the heated track is very thin, its surrounding cools it quickly.

The principle is shown on the next diagram:

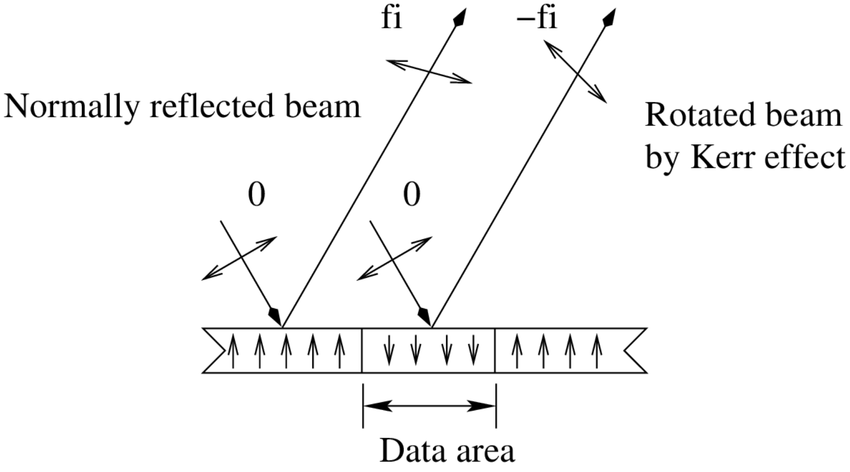
… Magneto-optical Disks



Arrows indicate the recording magnetic direction of magnetic orientations in surface.

… Magneto-optical Disks

The magneto-optical drive uses other physical phenomenon for reading. The Kerr magneto-optical effect. The polarized light changes its orientation, when it passes through the magnetic field. Because the surface on the disk is magnetic, it is possible to read all data by the polarized light. The light receiver only recognizes polarization. Polarization changes are then decoded to data. Speed of reading is the same as on hard disk.



Magneto-optical Disk Parameters

- Effective – the high capacity with low price ranging from a few hundreds MB up to 600GB.
- Changeable – disks are changed in drive.
- Durability – information written to the disk remains there more than 100 years. The disk can be cleaned in normal way by water and detergent.
- Safe – the rewriting is possible only when the surface is heated.
- Many rewrites – it allows many millions of rewrite cycles.