3. Magnetic and optical data storage techniques

3.1. Introduction

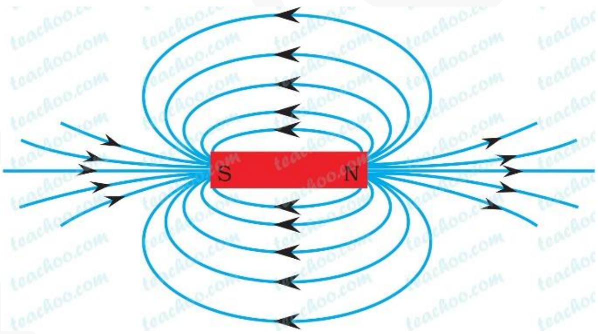
A very large number of modern devices depends upon magnetic properties of materials for their working. For example, the speakers, electrical power generators, electrical machines, transformers, television, data storage devices like magnetic tapes and disks, magnetic compass etc., Magnetic Resonance Imaging (MRI) scan is an important non-invasive diagnostic tool used in the medical field. Understanding the origin of magnetism and behaviour of magnetic materials will be helpful not only in the selection of suitable materials for a particular application but also in proper utilization of such devices. Further, it is highly useful in designing new applications of these materials.

3.2. Magnetism in materials

It arises from the magnetic moment or magnetic dipole of the magnetic materials. When an electrons revolves around the positive nucleus, orbital magnetic moment arises. Similarly when the electron spins, spin magnetic moment arises. Materials which can be magnetised by an external magnetic field are called magnetic materials.

The space around the magnet or the current carrying conductor where the magnetic effect is felt is called magnetic field.

Magnetic line of force is a continuous curve in a magnetic field as shown in figure.



The tangent at any point of this curve gives the direction of resultant intensity at that point. All the molecules of a material contain electrons rotating around the nucleus. These orbits are equivalent to circulating currents. So they produce a magnetic motive force (MMF). MMF is a force which produces the magnetic effect.

In most of the molecules, each MMF due to an individual orbit is neutralized by an opposite one. But, in the magnetic materials like iron and steel, there are number of unneutralized orbits. Then, the resultant axis of MMF produces a magnetic dipole.

In unmagnetized specimens, the molecular MMF axes lie along continuous closed paths. Therefore, no external magnetic effect can be found.

In magnetic specimens, the magnetic dipoles will line up parallel with the exciting MMF. When the exciting MMF is removed, the magnetic dipoles may remain aligned in the direction of the external field. Thus it produces permanent magnetism.

3.3. Basis definition

Magnetic dipole moment (m)

It is the product of magnetic pole strength and the distance between the two poles.

Magnetic flux (Φ)

Total number of magnetic lines of force passing through a surface is known as magnetic flux (Φ). Unit: Weber.

Magnetic flux density (or) Magnetic induction (B)

Magnetic flux density at any point in magnetic field is defined as the magnetic flux (Φ) passing normally through unit area of cross section (A) at that point.

Formula: $B = \frac{\phi}{A}$ Unit: Weber / meter ^{2} (or) Tesla

Intensity of magnetization

The term magnetization means the process of converting a non-magnetic material into a magnetic material. When an external magnetic field is applied to the metals such as iron, steel, some alloys etc., they are magnetized to different degrees. The intensity of magnetization (I) is the measure of magnetization of magnetised specimen. It is defined as the magnetic moment per unit volume of the material.

$$\text{Intensity of magnetization (I)} = \frac{\text{Magnetic moment (M)}}{\text{Volume(V)}}$$ Unit: Weber / meter^2.

Magnetic field intensity (or) strength (H)

It is the force experienced by a unit North Pole placed at any point in the magnetic field. Unit: Newton per weber (N/Wb) (or) Ampere turns per meter (A/m)

Magnetic permeability (μ)

Magnetic permeability of a substance measures the degree to which the magnetic field can penetrate through the substance. It is found that magnetic flux density (B) is directly proportional to the magnetic field strength (H)

$$B \propto H$$

(or) $B = \mu H$

Where μ is the proportionality constant called permeability (or) absolute permeability of the medium

$$\mu = \frac{B}{H}$$

"Permeability of a substance is the ratio of magnetic flux density (B) inside the substance to magnetic field intensity (H)".

Absolute permeability of a medium (or)a material is also defined as the product of permeability of a free space (μ_0) and the relative permeability of the medium (μ_r)

i.e., $\mu = \mu_0 \times \mu_r$

where unit of permeability is Henry / meter.

Relative Permeability (μ_r) of the medium

It is the ratio between absolute permeability of the medium (μ) to the permeability of a free space (μ_0). This is purely a number and has no unit. For air and non-magnetic material, its value is '1'

$$\mu_r = \frac{\mu}{\mu_0}$$

Magnetic susceptibility (χ)

Magnetic susceptibility of a specimen is a measure of how easily a specimen can be magnetised in a magnetic field. It is defined as the intensity of magnetization produced in the substance per unit magnetic field strength (H)

$$\chi = \frac{I}{H}$$

It is a dimensionless quantity because both I and H have same units

Magnetic induction in a given magnetic material for the applied field strength 'H' is given by

$$B = \mu_0 (H + I)$$

(or) $B = \mu_0 H (1 + \frac{I}{H})$

(or) $\frac{B}{H} = \mu_0 (1 + \chi)$

(or) $\mu = \mu_0 (1 + \chi)$

(or) $\frac{\mu}{\mu_0} = (1 + \chi)$

(or) $\mu_r = 1 + \chi$

(or) $\chi = \mu_r - 1$

3.4. Atomic magnetic moments

The fundamental reason for the response of a material to an external magnetic field is that the atoms possess magnetic moments. That is, each atom acts like a tiny magnet. There are two source that contribute to atomic magnetic moment.

(i) Magnetic moment due to the movement of electrons in orbits around the nucleus, i.e., due to orbital angular momentum. This is called the orbital magnetic moment.

(ii) Magnetic moment due to spin of the electrons, i.e., due to spin angular momentum . This is called spin magnetic moment.

(iii) in addition to the above two contribution, there is a small contribution due to spin angular momentum of the nucleus called the nuclear magnetic moment. But the nuclear magnetic moments are very much smaller and so their interaction of the electronic magnetic moment.

3.5. Classification of magnetic materials

Magnetic materials can be classified into two categories based on existence of dipole moment and the response of dipole moment and the response of magnetic material to external magnetic fields namely

(1) **Diamagnetic materials** - no permanent magnetic moment

(2) Paramagnetic, ferromagnetic, antiferromagnetic and ferrimagnetic materials – having permanent magnetic moment.

Ferromagnetism

Certain metals like iron (Fe), Cobalt (Co), Nickel (Ni) and certain alloys exhibit high degree of magnetisation.

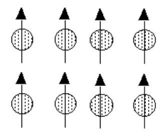
These materials show the spontaneous magnetisation. i.e., they have magnetization (atomic magnetic moments are aligned) even in the absence of an external magnetic field. This indicates that there is a strong internal field within the material which makes the atomic magnetic moment align with each other. This phenomenon is known as ferromagnetism.

Definition

Ferromagnetism is a phenomenon by which spontaneous magnetization occurs when $T \leq T_c$ *and so even in the absence of applied filed, the magnetic moments are enormous. Here* T_c *is the curie temperature of the material.*

Properties

- All the dipoles are aligned parallel to each other due to the magnetic interaction between the dipoles.
- They have permanent dipole moment. They are strongly attracted by the magnetic field.
- They exhibit magnetisation even in the absence of magnetic field.
- They exhibit hysteresis (lagging of magnetization with the applied magnetic field).
- On heating, they lose their magnetisation slowly.
- The dipole alignment is as shown in figure



- The magnetic susceptibility is very high and it depends on temperature which is given by $\chi = \frac{C}{T - \theta}$ for (T > θ, paramagnetic; T < θ, ferromagnetic). Here C is Curie's constant.

3.12. Ferrimagnetism

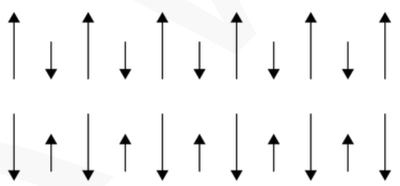
There are some magnetic materials in which the magnetic moments of two sub lattices are opposite in direction but not exactly equal in magnitude (because of two different types of ions in the lattices). Such crystals possess spontaneous magnetization and exhibit most of the properties of ferromagnetic materials. This uncompensated antiferromagnetism is known as ferrimagnetism.

Ferrimagnetic materials (or) ferrites

Substance which possess a spontaneous magnetization in which the magnetic moments of the two sub lattice are opposite in direction but not exactly equal in magnitude are called "Ferrites".

Properties

- Ferrites has net magnetic moment
- Above Curie temperature, it becomes paramagnetic and it behaves as ferrimagnetic material below Curie temperature.
- The susceptibility of ferrite is very large and positive. It depends on temperature. It is given by $\chi_{ferri} = \frac{C}{T \pm \theta}$ for $T > T_N$.
- Spin alignment is antiparallel of different magnitudes as shown in figure.



- Mechanically, it has pure iron character.
- They have high permeability and high resistivity
- They have low eddy current loss and low hysteresis loss.

Applications

- Hard magnetic ferrites are used in the manufacture of permanent magnets
- Such magnets are used in super high frequency technology.
- Soft magnetic ferrites are used in the production of cores for inductor coils used in telecommunication and low power transformers.
- Ferrites are used in magnetic flims in which demagnetization process occurs at the speed exceeding million times/second. This technology is important for electronics, automobiles and computer hardware engineering.
- Ferrites re used in information storage devices such as magnetic discs and tapes.

- Ferrite rods are used to produce ultrasonics by magnetostriction principle.
- Ferrite rods are used in radio receiver to increase sensitivity and selectivity.
- Since the ferrite has low hysteresis loss and eddy current loss, it is used in two port m microwave devices such as gyrator, circulator and isolator.

3.13. Types of magnetic materials

Magnetic materials are classified in to two types based on magnetization

(i) Soft magnetic materials (ii) Hard magnetic materials

Soft magnetic materials

Definition

Materials which are easy to magnetize and demagnetize are called soft magnetic materials. These magnetic materials do not retain the alignment of magnetic domains after the removal of the external magnetic field.

Properties

- The soft magnetic materials can be magnetised and demagnetised easily.
- They have high permeability
- They have low residual magnetism
- They exhibit low hysteresis loss
- They have low hysteresis loss
- The magnetic energy stored is low

Examples:

- Pure or ingot iron
- Cast iron (carbon above 2.5%)
- Carbon steel
- Silicon steel
- Manganese and nickel steel
- Permalloy (Ni: Fe alloy = 78.15% : 21% + small quantities of Cr, Co, Cu and Mn)
- Mumetal (Ni =75.4%, Cu-4%, Cr-1.5% and remaining Fe)
- Perminar (Co-Ni-Fe alloy = 50%, 25%, 25%)
- Soft ferrites

Applications

- Cast iron is sued in the structure of electricity machinery and the frame work of DC machine
- Carbon steel has high mechanical strength and it is used in making motor of turbo alternators

- Silicon steel is used for the construction of poles of motor and dynamo and core plates of transformer
- Manganese and nickel steel is used for making cable boxes, meter cases and end rings of turbo alternators
- Permalloy is used as thin tape wrapped around the conductors of loaded submarine cables.
- Mumetal is used for making cores of transformers.
- Perminar is used in armatures of motors, transformer cores, etc.,

Hard magnetic materials

Definition

Materials which retain their magnetism and are difficult to demagnetize are called hard magnetic materials. These magnetic materials retain the alignment of the magnetic domains permanently even after the removal of external magnetic field

Properties

- The hard magnetic materials have low permeability and strongly repel the magnetic field
- They have high retentivity and coercivity
- They require high magnetising force to attain magnetic saturation
- They have large hysteresis loop area and large energy loss.
- The value of B – H product is high.

Examples

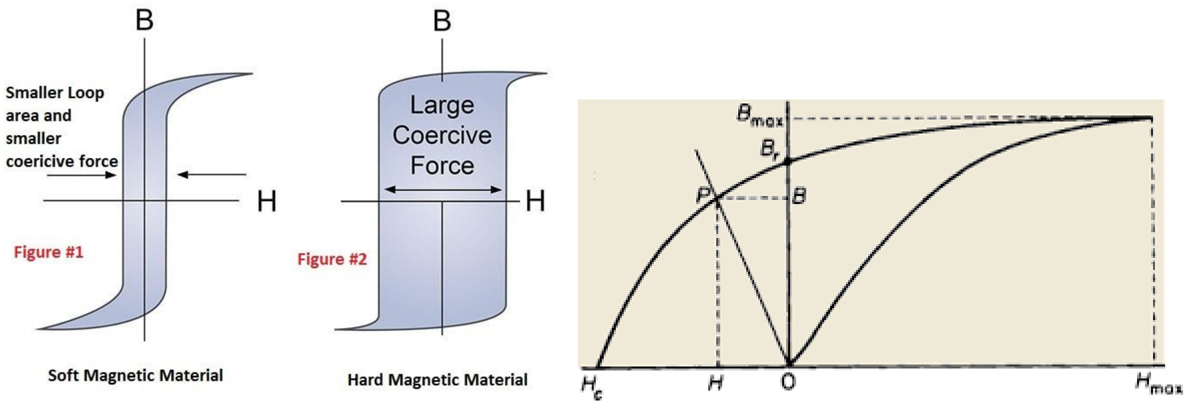
- **Tungsten steel**: it contains 4.5 to 6% tungsten, o.5 to 0.7% carbon and the remaining is iron.
- **Carbon steel**: It contains 34% cobalt, 5% chromium, 3.5 to 6% tungsten and remaining is iron.
- **Alini:** it contains 10 – 15% aluminium, 25-30% nickel and 65-75% iron.
- **Alinco**: It contains 18% nickel, 10% aluminium, 5% copper, 15% cobalt and remaining is iron.
- **Cunife**: It contains 50% copper, 30% nickel and 20% iron
- **Hypernic**: It contains 50% of nickel and 50% of iron.

Applications

- Tungsten steel is used in making permanent magnets for dynamos and motors.
- Cobalt steel is used in motors, fans and heavy duty instruments.
- Alini is used in the design of portable and light weight instruments
- Alnico is used for the production of permanent magnets in smaller size
- Cunife is useful in producing small size magnets.

Energy product

The product of retentivity (B_r) and coercivity (H_c) is known as energy product. It represents the maximum amount of energy stored in the specimen. Therefore, for permanent magnets the value of energy product should be very high as shown in figure.



3.14. Magnetic principle in computer data storage

In general memory units are the devices used to store the information in the form of bits. [8 bit =1 byte]

The memory units are classified as

(i) Main memory (or) Internal memory
(ii) Auxiliary memory (or) External memory

<u>Main Memory:</u>

The memory unit of CPU is called main memory. Thus data's are write and finally be erased if necessary.

Eg: EPROM, ROM, RAM etc.,

<u>Auxiliary Memory:</u>

This type of memory is also referred to as back-up storages because; it is used to store large volume of data on permanent basis. This date can be accessed or recopied if necessary.

Eg: Magnetic tapes, Magnetic disk, Ferrite core memories and Bubble memories.

1. <u>Magnetic Tape:</u>

The tape is a plastic ribbon with metal oxide material coated on one side which can be magnetized, in this information can be written and also can be read by write/read heads.

Information recorded in the tape is in the form of tiny magnetized and non-magnetized spots on the metal oxide coating. The magnetized spot represents '1' sun magnetized spot represent '0' in binary code. The information can be accessed, processed, erased and can be stored again in same area.

Advantages:-

- Storage capacity is large
- Easy to handle
- Loss expensive
- Erased and reused.

Disadvantages:-

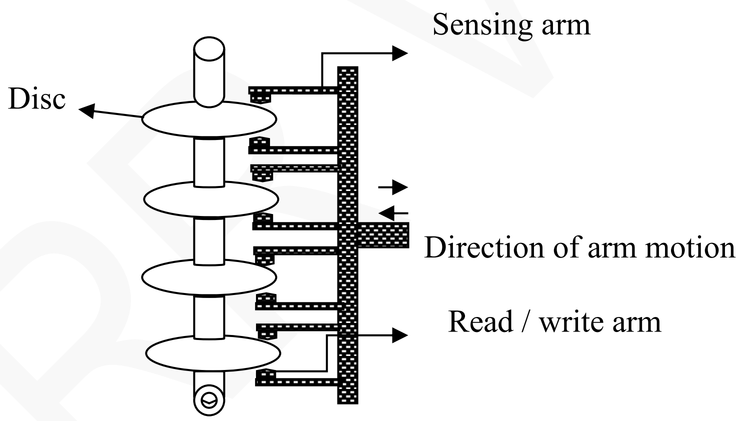
- It consumes lot of time.

2. Magnetic Disc Devices:

(A) Hard disk drives:

It is the direct access storage device made up of hard aluminum platters. This platter surface is carefully machined for flat. This surface is coated with magnetic oxides and built in to a bar.

Similar such disks are mounted on a vertical shaft, forming a disk pack as shown in figure. The drive mechanism drives the disc pack with the spindle. The data is written can read by the R/W heads in the horizontal sensing arms by moving in and out between the platters with the precaution that the R/W head doesn't touches the surface instead, it fly over the disk surface by a fraction of a mm.



Advantages:-

- It has large storage capacity.
- Thousand of files can be permanently stored.
- Very high speed in reading and writing the information
- This is prevented from dust, since they are sealed.

Disadvantages:-

- It is very costly
- If data is completed, there is a heavy loss.

(*B) Floppy disc drives*:

Floppy is made of a very thin and flexible plastic materials coated with magnetic materials. This disc is inserted in floppy disc drive for read/write operation by the read/write head in the disc. Size: 5.25" called mini floppy, 3.25" called micro floppy.

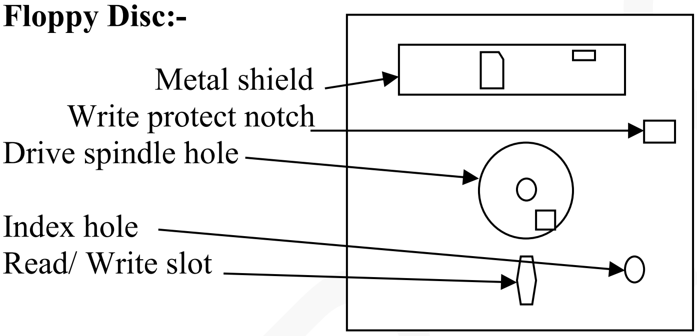
<u>Organization:-</u>

Surface of the floppy disc is divided into a number of concentric circles known as tracks where the information is recorded. The tiny magnetic spots are used to record the logic 1 (or) 0 state. The spot magnetized in one direction are '1' state and in other direction are called '0' state. Each track has number of sectors

<u>Operation;-</u>

When the floppy is put in drive unit. When drive is operated. The floppy disc is rotated which makes physical contact with read/write head. This magnetic material movement is controlled by serve mechanism.

Floppy Disc:-



<u>Advantages:-</u>

(i) Storing and transporting of data is easier.
(ii) Cost is less
(iii) It can reused many times

<u>Disadvantages:-</u>

(i) Storage capacity is less
(ii) Care to be taken for handling.

3. <u>Ferrite Core Memory:</u>

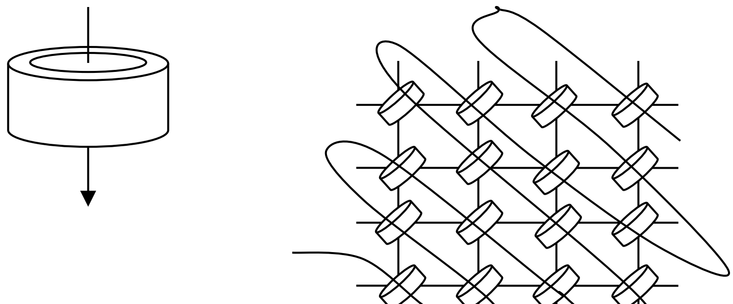


Figure (3)

Here the magnetic core consists of a ferrite core in the shape of a torrid ring as shown in figure.

We know that the ferrites have square hysteresis loop and low coercivity as shown in figure. Such hysteresis is used for making core memory as a different form of magnetic recording.

The magnetic cones of the memory are arranged in a matrix interlaced thought fine metal wires both horizontally and vertically as shown in figure (3)

A change in the state only occurs during reinforced magnetization i.e. both the horizontal current and vertical current pass through the core in same direction. The current passing through one of the wires will not induce a change in the magnetization of the cores reading of the magnetic cores is achieved using a third sense wire threaded through the core. It will pick up an induced voltage, if the core changes state. To facilitate a fast response for a high speed memory, soft magnets are always used in the core.

Giant Magneto Resistance effect

Principle

In hard disk drives, the binary data in terms of zero's (0) an one's (1) are stored by inducing magnetic moment in a thin magnetic layer and GMR effect is used as the principle to read the data in HDD. Here zero (0) represents missing transition and one (1) represents transition in the medium.

Construction

The HD consists of recording medium madeup of thin layer of magnetic garnets grown over the substrate. The GMR sensor, which is made up of ferrites and antiferromagnetic materials is used as reading element. The writing element is madeup of inductive magnetic transducer. The writing element and the GMR sensor shall be made to slide over the recording media in the longitudinal direction as shown in figure. Hence this method is also called as longitudinal recording. The flow of current through the GMR sensor and writing element shall be adjusted and in turn the magnetization is sensed (or) controlled in the recording media.

Working

Writing / Storing

1. Initially the current is passed through the writing element and a magnetic field is induced in between the gap of the inductive magnetic transducer.

2. During writing, the amplitude of current is kept constant, and the direction of current is reversed.

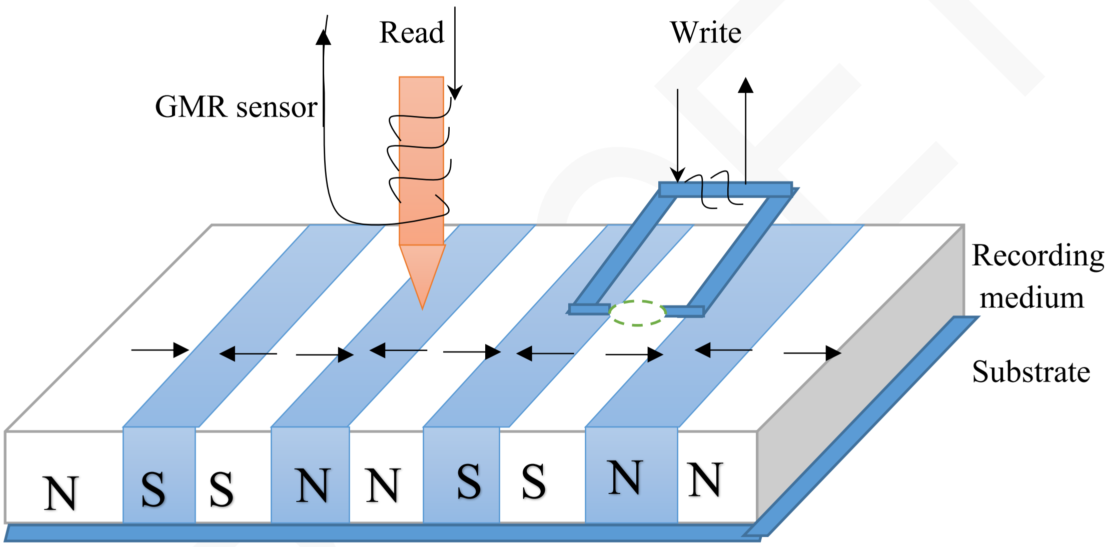
3. Due to reversal of current, the magnetization orientation is reversed in the recording medium i.e., from south → North as shown in figure

4. When the induced magnetic field is greater than the coercivity of the recording media, then data is recorded in the form of 1.

5. Thus one (1) is stored as data in the recording medium as a magnetic transition.

6. When there is no magnetic transition, then it is referred as zero (0).

7. In this way the zero's (0's) and one's (1's) are stored in the recording medium.



Reading / Retrieving

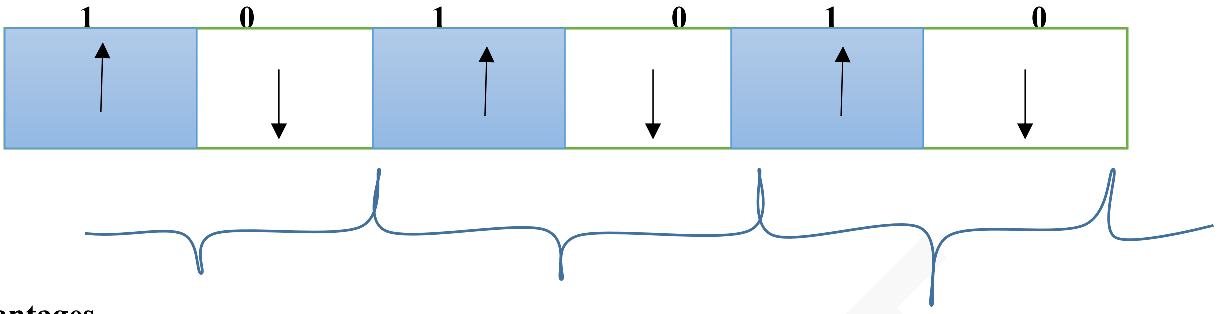
1. Giant Magnetoresistive (GMR) effect is the principle used to read / retrieve the data from the recording medium.

2. When the GMR sensor is made to move near the recorded medium, then the resistance of the GMR sensor varies with respect to the orientation of the magnetic moments as follows.

3. When the layers are magnetized in parallel manner, then the resistance in the GMR sensor is minimum and therefore maximum current flows through the sensor, which represents the data as one (1)

4. When the layers are magnetized in antiparallel manner, then the resistance in the GMR sensor is maximum and therefore minimum(or) almost no current flows through the sensor, which represents the data as zero (0)

5. Therefore with the help of the reading current, the zero's (0's) and one's (1's) can be retrieved from the magnetic hard disk drive.



Advantages

- HDD can store the data in terabytes
- It has very large storage capacity
- It is compact in size and can be easily transferred from one place to another.
- The size of recording medium is reduce up to few nano meter range using nanotechnology
- GMR sensor are non-diffusive and are very sensitive in reading

Disadvantages

- HDD is slower than soli state drives
- Consume large power
- Data may be corrupted due to thermal radiation
- HDD has bulkier form factor
- GMR noise ratio is high for nano size recording media

Applications

- Used as storage devices in cloud applications
- Used in coding and signal processing units
- Used in control systems, Nano electronics, etc.,

4.11. Optical Data Storage

The optical data storage techniques resulted in increased storage capacities after the invention of laser. In general they are classified as surface storage and volume storage.

Optical tape

For many years photosensitive film roles are used as optical tapes for recording optical information. Even acoustical information are recorded in such tapes as sound tracks.

Optical Disc (CD)

Principle

The data to be stored is first converted into binary form as 0's and 1's. it is then store in the form of reflecting and non-reflecting micro points in spiral path on a disc. During the read-out process, variation in the reflected intensity of laser is converted back to data.

This optical disc is further classified as *reading only* and *Recording and reading type* based on their storage technique and capabilities. However in either type's laser diode, lenses and photodiodes are used.

During recording, it change electrical information into optical information and then records the information on the optical disc. While reading the head optically reads the recorded information and changes the optical information in to electrical information. The commercial system make use of discs that are 90, 120, 130 and 300nm in diameter. A mini disc, 64nm in diameter is also used for digital audio.

Read only optical discs equipment

CD's which are 120mm in diameter are typical digital audio discs. Compact discs usually means digital audio compact discs, but it is also includes the read only memory (CD –ROM) for data memory and interactive compact disc (CD- I) for multimedia use. Audio information (sound) is digitally recorded in stereo on the surface of a CD in the form of microscope "pits" and flats". The light emitted from the laser diode passes through the lens and it is focussed to a diameter of about 1mm on the surface of a disk. As the CD rotates, the lens and beam follow the track under control of a servo motor. The laser light which is altered by the pits and flats along the recorded track is reflected back from the track through the lens and optical system to infrared photodiodes. The signal from the photodiodes is then use to reproduce the digitally recorded sound.

CD audio

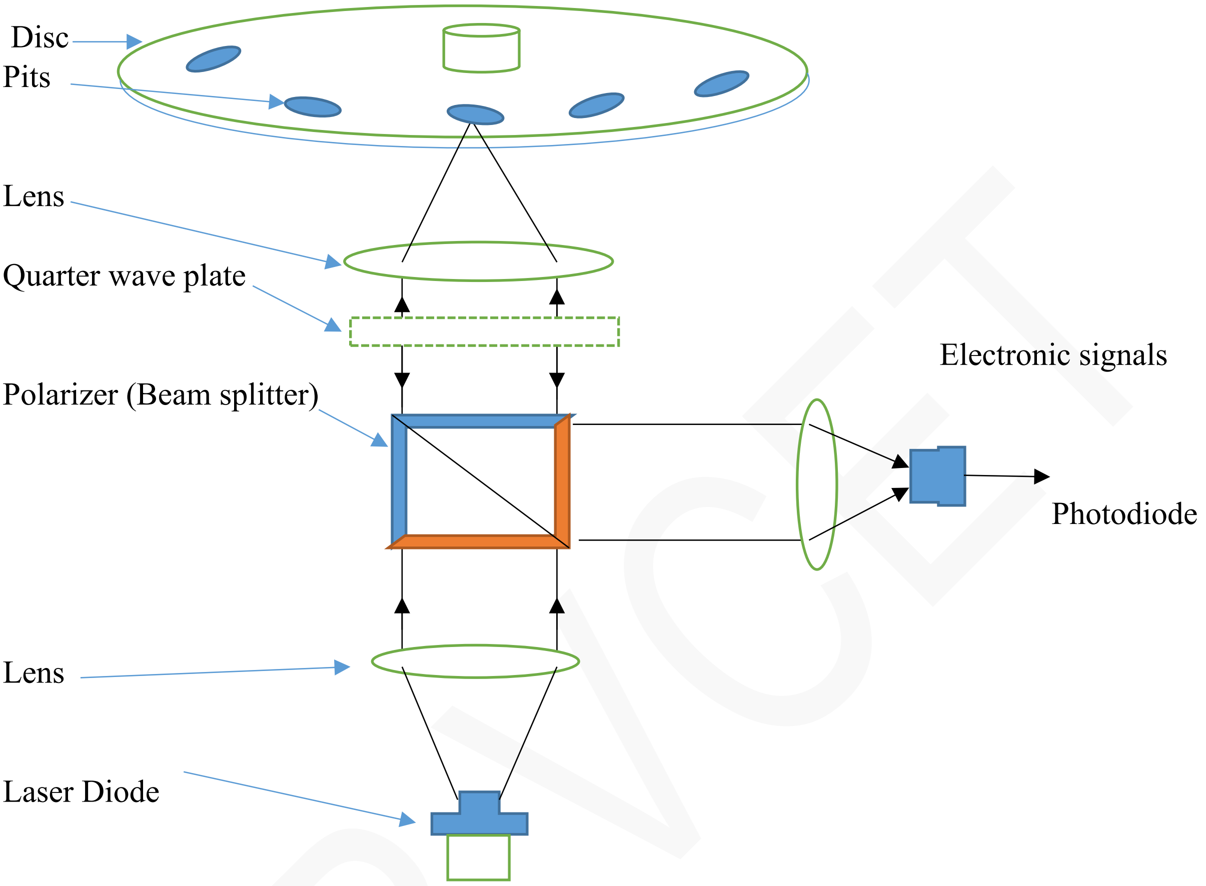
The substrate of the disc is either plastic or photo polymer. First audio signal to be stored is stored is converted into binary. This is then stored in the form of reflecting and non – reflecting micro points in spiral path on a on a metallic master using sharply focussed laser beam. The digital data is pressed onto the substrate by injection moulding. Thus mass production of the CD form base on this concept.

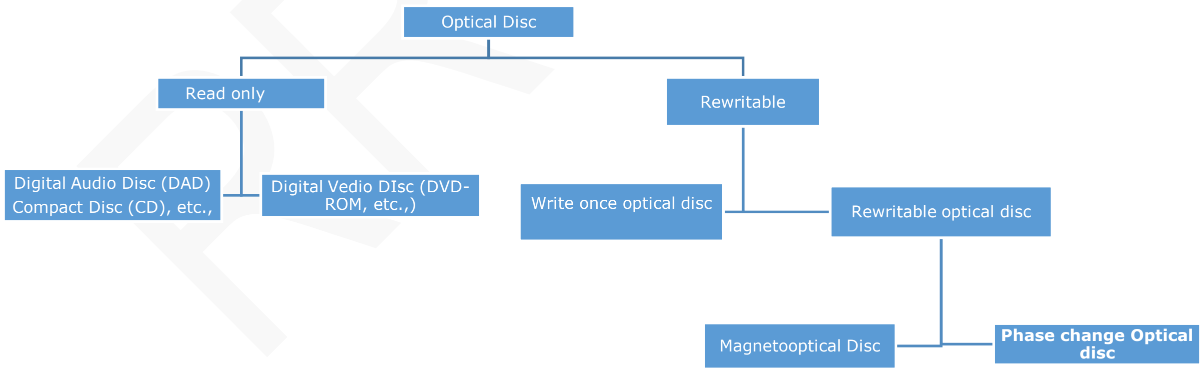
CD ROM

This is similar to that of CD audio with a difference that here in this case video signal is converted into binary and stored in a metallic master. The data thus replicated from the master on a plastic substrate can be read any number of times but cannot be changed and hence this name.

CD – WORM

In this the active layer is chemically coated on the substrate. The laser pulses generated in the CD writer burns the chemical coating and there by creates reflecting and non-reflecting micro points. We can write the data once and read any number of times but the data written cannot be either copied or erased and rewritten and hence the name. For copies each disc has to be written burning the chemical coating. This technique we use to record functions such as marriages, etc.,



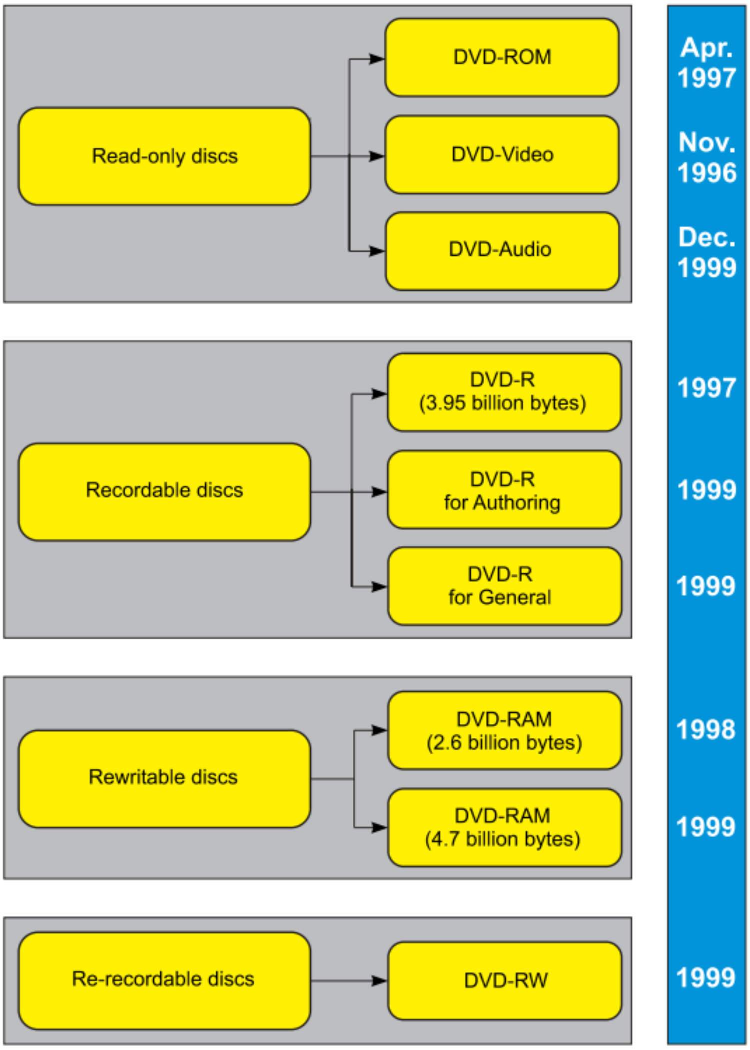


CD R/W

In this type of CD we can write the data, read and rewrite after erasure. For this two different materials / phenomena via phase change materials and magneto-optic materials are used in general.

Digital Versatile Disc (DVD)

In 1996, a new read only optical system called digital versatile disc with enough capacity (4.7GB) to hold 130 minutes of compressed video, or more than 90% of all feature-length movies using laser of shorter wavelength and focusing lens of larger numerical aperture is introduced. Then DVD R/W also introduced.



Digital Video Recording (DVR)

With this system, 22GB can be recorded on a single layer of 12cm disc. The most important commercial application of this system is recording of high definition digital video. By reducing the spot size using a laser of shorter wavelength and objective lens of higher numerical aperture a real density is increased.

Feature	DVD-Audio	DVD-Video	CD-DA
Disc size	8 cm, 12 cm		
Storage capacity	4.376 GB (single layer)		650 MB
Playback time [min]	74 - 160 [1)]	130 (on average)	74
Sampling frequency [kHz]	44.1, 88.2, 176.4 48, 96, 192	48 or 96	44.1
Quantization	16, 20, or 24 bits		16 bits
Audio coding	LPCM, MLP, DTS, DSD, MPEG-1 and -2, MPEG-4 AAC, ATRAC3plus, MP3, WMA	LPCM, MPEG-1, MPEG-2, Dolby Digital, DTS, SDDS	LPCM
No. of audio channels	up to 6	up to 8	2
Theoretical frequency response [2)] [Hz]	20 - 96,000	20 - 48,000	20 - 22,000
Bit rate [kbit/s]	1411.2 - 9600	64 - 1644	1411.2
Still and moving pictures	available		CD-Text CD-Graphics
Copy protection	CPPM watermarking	CSS regional code	none

Advantages of optical disc

The optical discs have several advantages over semiconductor memories. Some of these include their larger data storage capacity, shorter access time size. Therefore they are used in terminal equipment of computers as well as in audio visual equipment.

Blue ray disc

In order to stand a chance in the market, a possible new format needed to be distinctly better than DVD. Two options were considered: an extension of the CD/DVD-paradigm and magneto-optical recording. The technology that prevailed stayed close to CD and DVD. A choice for a technology close to CD and DVD included the perspective to a complete family of disc formats: read only, write-once, and rewritable, the former being difficult to realize using magneto-optical technology. Also from an economic perspective an extension of the CD/DVD paradigm was the preferred option, as it was more likely to allow future use of recent investments by industry, both in capital and in expertise. A system close to CD and DVD also offered a realistic opportunity to work on backwards compatible drives. In this way consumers could play earlier format discs in new drives. Such a system was preferred, but in 1997 it was not certain whether it would actually be possible to combine legacy design choices with a sufficiently large performance step.

An important design-choice was the laser wavelength. The size of the optical spot probing the disc scales proportional to the wavelength of the light. So, shorter wavelengths would be better, and the target was a blue laser. The question to be answered concerned the feasibility of blue solid state lasers. There had been blue-laser research projects at several companies, including Philips.

The actual solution was found by Shuji Nakamura and his team of the Japanese company Nichia Corporation. In 1997 Nakamura and co-workers developed a gallium nitride based solid-state blue-violet laser with a wavelength of 405 nm.

Meanwhile, many of the initial experiments on the third generation optical storage technology were however done either with a red-light laser, after which an appropriate arithmetic scaling could be done, or with a large table-top gas laser emitting blue-violet light. The combination of the higher numerical aperture with the shorter wavelength allowed a higher optical resolution, and therefore an increase of the storage capacity. The scaling of the spot diameter is proportional to the wavelength, and inversely proportional to the numerical aperture. The combination of NA = 0.85 and a 405 nm wavelength would lead to a factor of 4 capacity increase with respect to the DVD system.

A higher numerical aperture also leads to a need to rethink the design of the disc layout and the optics. System tolerances like the disc-tilt margins, the tolerance for disc cover layer thickness variations and the depth of focus scale proportional to the wavelength and inversely proportional to higher orders of the numerical aperture. The aggressive reduction of some of these margins is more detrimental than the benefits of the stronger lens and shorter wavelength. A system architecture that takes this into account is complicated but crucial.

To the surprise of many, rival Matsushita also presented a blue laser based, NA = 0.85, 0.1 mm cover layer thickness, groove-only format at the same conference. The three companies met in the following weeks and decided to team up. Blu-ray Disc (BD) was born

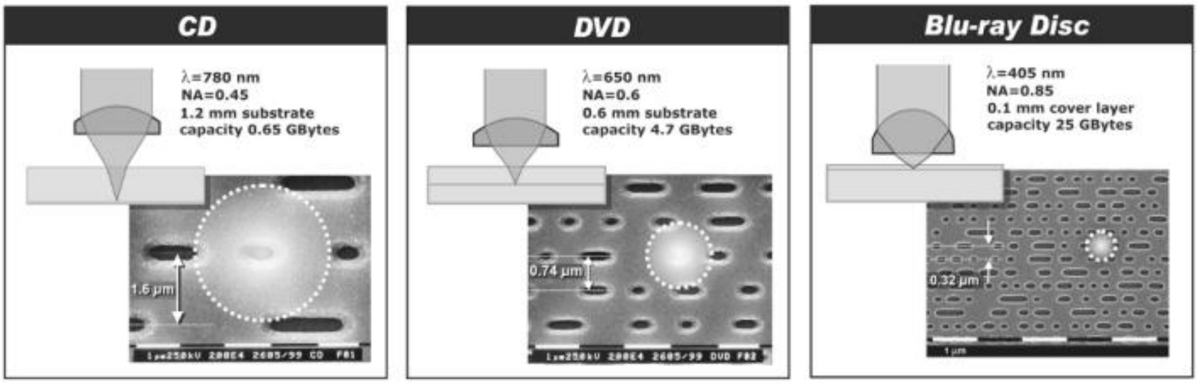


Fig. 1. Schematic diagrams for the three optical storage generations: CD, DVD and BD, with wavelength λ, Numerical Aperture NA and disc substrate thickness. The circles on the scanning electron microscope pictures of the read-only discs indicate the spot size.

The rewritable Blu-ray Disc format has a predetermined, small amplitude (10 nm) wobble superimposed on each track. This wobble is used for write-clock generation and for retrieving accurate timing and address information. The sub-micron structures defining the physical disc format were transferred to replicated discs via so called master discs. The production of these masters involves the careful, high-resolution writing of the information on a nonstructured photo-resist layer. This is followed by development, galvanic coating and then reproduction of master's from the original, via a so-called family-process. This is a highly specialized, multidisciplinary activity and is a crucial technology for any optical disc format.

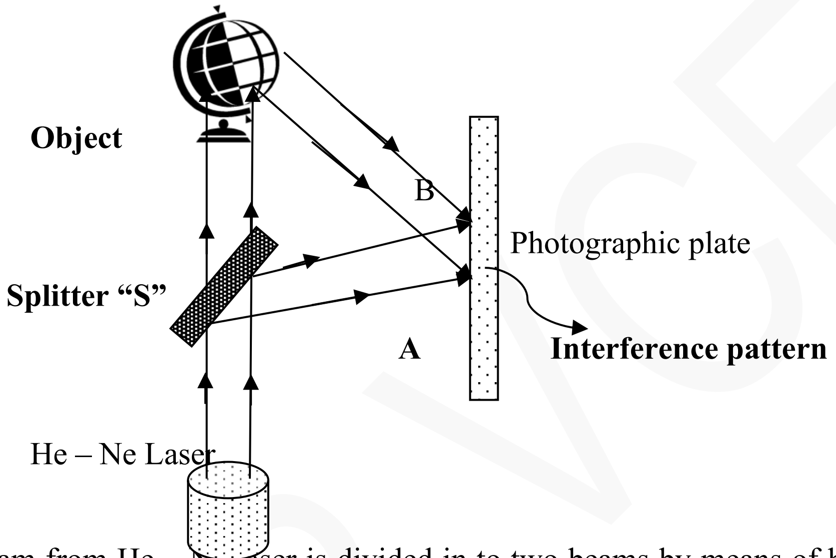
An optical solution was highly desirable to avoid such a drastic change in mastering technology. In an effort to develop such a solution, a start was made from the deep-UV (257 nm) gas lasers and optics that had already been introduced in the Optical Disc Technology Centre. The use of a powerful deep-UV light source required special skills and care in the construction of an experimental mastering system.

The initial Blu-ray Disc format was a recording format primarily aimed at video-recording with a set-top box directly connected to the TV. The disc was developed in a cartridge to provide protection against dust, fingerprints and scratches, to which the fine structure in the BD disc appeared to be more sensitive.

Next to the rewritable format (BD-RE), a write-once (BD-R) and a pressed format (BD-ROM) were introduced. For BD-ROM, a new video application format was developed to be able to offer the best consumer experience in this next generation video publishing format. After several years of experience with the DVD video, it was felt that there were many opportunities to offer better and more sophisticated possibilities in a Blu-ray Disc video publishing format

Construction and reconstruction of a holographic image

Construction (Making a Hologram): Figure shows the arrangement for recording a hologram

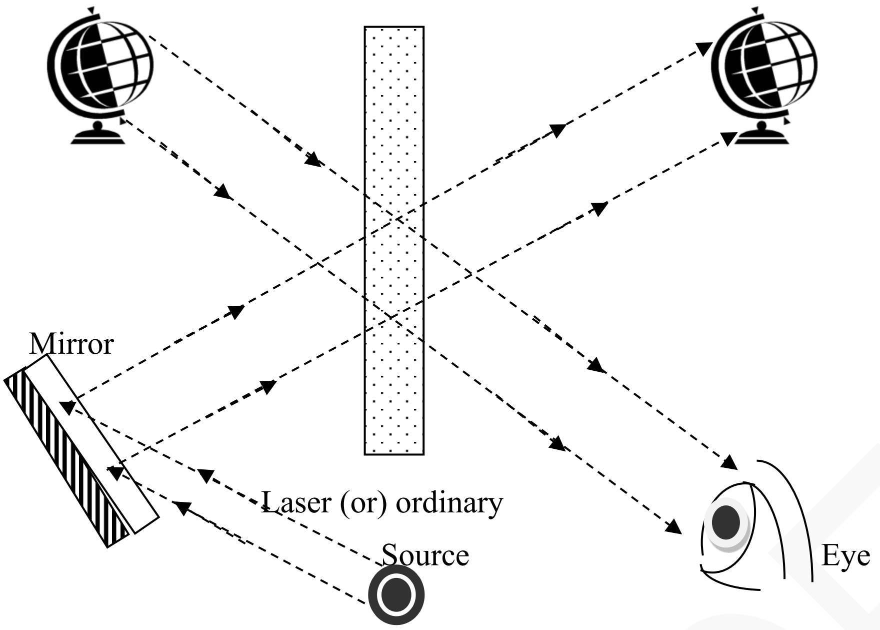


A beam from He – Ne laser is divided in to two beams by means of beam splitter. The transmitted beam is called object beam (A beam). This illuminates the object to be recorded in hologram. A part of this light scatters from the object and falls on the photographic plate P. the reflected beam called reference beam (B – beam) also fall on this photographic plate. These two beams interfere with each other and form an interference pattern which is recorded on the plate. This pattern is very small with a separation of less than 0.001mm.when the plate is developed, we get a transparent hologram.

Reconstruction of Hologram: (Displaying a Hologram)

The object is recreated from hologram by directing a beam of light at the plate as shown in figure.

The readout beam (laser beam) interacts with the interference pattern on the plate. It produces two images from the diffracted beams emerging from the hologram. One of them appears at the original position occupied by the object called virtual image and the other real image can be photographed without using a lens.



The virtual image which can be seen by looking through the hologram appears in a complete three dimensional from. If we move our eye from the viewing point, the perspective of the picture changes and it is possible to see the other side of the object..

Applications:

(i) It is a reliable method for data storage

(ii) Holographic NDT is used to find stress in pipeline, vibration pattern of a guitar

(iii) It is used to determine the degree and nature of deformation of the observed surface

Questions and Answers

Part – A

1. What is Bohr magnetron?

When the atom is placed in a magnetic field, the orbital magnetic moment of the electron is quantized. A quantum of magnetic moment of an atomic system is known as Bohr magnetron.

$$\mu_B = \frac{eh}{4\pi m}$$

2. What is ferromagnetism?

Certain materials like iron, cobalt, nickel and certain alloys exhibit spontaneous magnetization. i.e., they have amount of magnetization (atomic moments are aligned) even in the absence of an external magnetic field. This phenomenon is called ferromagnetism.

3. **What are the properties of ferro magnetic materials?**

- It exhibits magnetization even in the absence of external field
- This materials exists as ferro magnetic when temperature is below ferromagnetic curie temperature and become paramagnetic above ferromagnetic curie temperature
- It consists of number of small spontaneously magnetized region called domains
- During heating they loss their magnetization slowly
- Spin alignment are parallel in same direction
- They attracts magnetic lines of forces strongly
- Susceptibility is very large & positive

4. **What are the properties of ferri magnetic materials?**

- It possess net magnetic moment
- Magnetic susceptibility is very large & positive. It is given by $\chi = \frac{C}{T \pm \theta_N}$

  Where θ_N- Neel Temperature.
- Spin alignment is antiparallel of different magnitude
- The susceptibility is graphically temperature dependent.

5. **What are soft magnetic materials?**

Materials which are easy to magnetize and demagnetize are called soft magnetic materials

6. **State the properties of soft magnetic materials?**

- They have high permeability
- They have low coercive force.
- They have low hysteresis loss.

7. **What are the essential differences between hard and soft magnetic materials?**

S.No	Hard magnetic materials	Soft Magnetic Materials
1.	They have large hysteresis loss	They have small hysteresis loss
2.	The eddy current loss is high	Eddy current loss is low
3.	They have small values of permeability & Susceptibility	They have large values of permeability & Susceptibility
4.	Domain wall movement is difficult& irreversible in nature	Domain wall moves easily& reversibly
5.	The coercivity & retentivity are large	The coercivity & retentivity are small

6.	Eg: Carbon steel, Tungsten Steel, Chromium Steel.	Eg: Iron, Ferrites, Silicon Alloys

8. Define Susceptibility?

The ratio of the intensity of magnetization produced in the sample (I) to the magnetic field intensity which produces the magnetization (H). i.e., $\chi = \frac{I}{H}$

9. State few applications of soft magnetic materials

- Cast iron is used in the structure of electrical machinery and frame work of DC machine
- Carbon steel has high mechanical strength used in making motor of turbo alternators.

10. What are hard magnetic materials?

Materials that retain their magnetization and are difficult to demagnetize are called hard magnetic materials.

11. State the properties of hard magnetic materials

- They possess high retentivity
- They possess high value of B-H product
- They have high coercivity
- They have low permeability

12. Mention few applications of hard magnetic materials.

- Tungsten steel is used in making permanent magnets for dynamos, motor.
- Cobalt steel is sued in motor, fans and heavy duty instruments.

13. What are Ferrites and mention its types?

Ferrites are modified structure of iron with no carbon atoms in which the adjacent magnetic moment are of unequal magnitudes aligned in antiparallel direction.

General Formula: $X^{2+} Fe^{3+}O_4^{2-}$

Types: Regular Spinal, Inverse Spinal

14. **State the applications of ferrites?**

- They are used in transformer cores for high frequencies up to microwaves.
- They are used in radio receivers to increase the sensitivity and selectivity of the receiver

- They are used in digital computers and data processing circuits
- They are used in power limiting and harmonic generation devices

15. What is ferrite core memory?

It is the memory made up of a ferrite core in the form of rings used for random storage of data '0' & '1' by magnetizing the ring in any of the two opposite direction.

16. **Define Hysteresis?**

When the ferromagnetic material undergo a cycle of magnetization, the intensity of magnetization (I) & magnetic flux density (B) lags behind the applied magnetic field strength (H) & this process is called Hysteresis.

17. What is the principle of magnetic recording system?

It states the data in the form of magnetization pattern as a sequence of binary magnetization states in the magnetic medium because the ferromagnetic material produces the magnetic dipoles align themselves parallel to each other.

18. What are the advantages and disadvantages of magnetic discs?

Advantage:

- It has very large storage capacity
- Thousands of files can be permanently stored
- Very high speed in writing & reading the information
- Prevented from dust particles, because it is sealed

Disadvantage:

- It is very costly
- If data is once corrupted, there is a heavy loss of data

Part – B Question and Answers

1. Distinguish between soft and hard magnetic materials.

Magnetic materials are classified in to two types based on magnetization
(i) Soft magnetic materials (ii) Hard magnetic materials

Soft magnetic materials

Definition

Materials which are easy to magnetize and demagnetize are called soft magnetic materials. These magnetic materials do not retain the alignment of magnetic domains after the removal of the external magnetic field.

Properties

- The soft magnetic materials can be magnetised and demagnetised easily.
- They have high permeability
- They have low residual magnetism
- They exhibit low hysteresis loss
- They have low hysteresis loss
- The magnetic energy stored is low

Examples:

- Pure or ingot iron
- Cast iron (carbon above 2.5%)
- Carbon steel
- Silicon steel
- Manganese and nickel steel
- Permalloy (Ni: Fe alloy = 78.15% : 21% + small quantities of Cr, Co, Cu and Mn)
- Mumetal (Ni =75.4%, Cu-4%, Cr-1.5% and remaining Fe)
- Perminar (Co-Ni-Fe alloy = 50%, 25%, 25%)
- Soft ferrites

Applications

- Cast iron is sued in the structure of electricity machinery and the frame work of DC machine
- Carbon steel has high mechanical strength and it is used in making motor of turbo alternators
- Silicon steel is used for the construction of poles of motor and dynamo and core plates of transformer
- Manganese and nickel steel is used for making cable boxes, meter cases and end rings of turbo alternators
- Permalloy is used as thin tape wrapped around the conductors of loaded submarine cables.
- Mumetal is used for making cores of transformers.
- Perminar is used in armatures of motors, transformer cores, etc.,

Hard magnetic materials

Definition

Materials which retain their magnetism and are difficult to demagnetize are called hard magnetic materials. These magnetic materials retain the alignment of the magnetic domains permanently even after the removal of external magnetic field

Properties

- The hard magnetic materials have low permeability and strongly repel the magnetic field

- They have high retentivity and coercivity
- They require high magnetising force to attain magnetic saturation
- They have large hysteresis loop area and large energy loss.
- The value of B – H product is high.

Examples

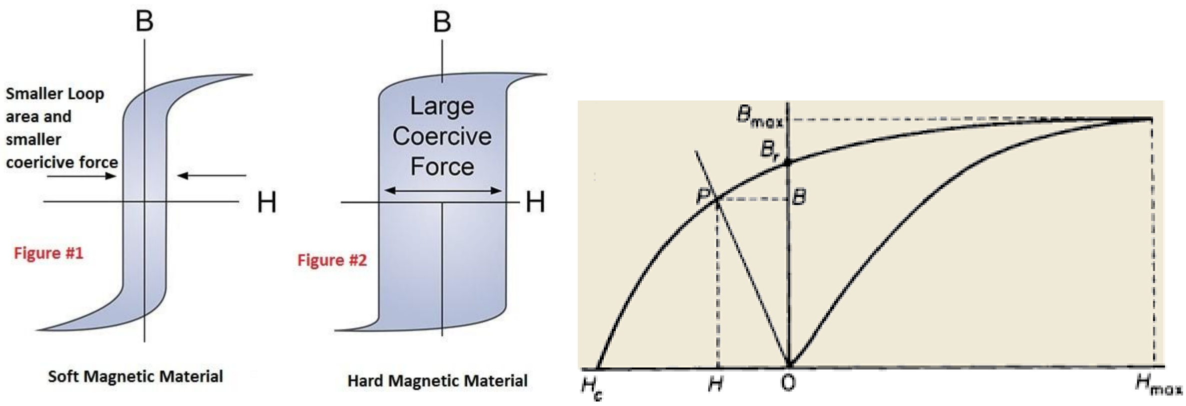
- **Tungsten steel**: it contains 4.5 to 6% tungsten, o.5 to 0.7% carbon and the remaining is iron.
- **Carbon steel**: It contains 34% cobalt, 5% chromium, 3.5 to 6% tungsten and remaining is iron.
- **Alini:** it contains 10 – 15% aluminium, 25-30% nickel and 65-75% iron.
- **Alinco**: It contains 18% nickel, 10% aluminium, 5% copper, 15% cobalt and remaining is iron.
- **Cunife**: It contains 50% copper, 30% nickel and 20% iron
- **Hypernic**: It contains 50% of nickel and 50% of iron.

Applications

- Tungsten steel is used in making permanent magnets for dynamos and motors.
- Cobalt steel is used in motors, fans and heavy duty instruments.
- Alini is used in the design of portable and light weight instruments
- Alnico is used for the production of permanent magnets in smaller size
- Cunife is useful in producing small size magnets.

Energy product

The product of retentivity (B_r) and coercivity (H_c) is known as energy product. It represents the maximum amount of energy stored in the specimen. Therefore, for permanent magnets the value of energy product should be very high as shown in figure.



2. Explain in detail about ferrimagnetism.

Ferrimagnetism

There are some magnetic materials in which the magnetic moments of two sub lattices are opposite in direction but not exactly equal in magnitude (because of two different types of ions in the lattices).

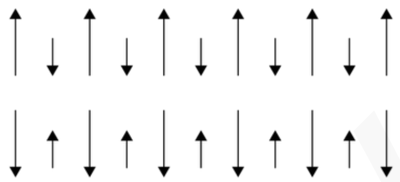
Such crystals possess spontaneous magnetization and exhibit most of the properties of ferromagnetic materials. This uncompensated antiferromagnetism is known as ferrimagnetism.

Ferrimagnetic materials (or) ferrites

Substance which possess a spontaneous magnetization in which the magnetic moments of the two sub lattice are opposite in direction but not exactly equal in magnitude are called "Ferrites".

Properties

- Ferrites has net magnetic moment
- Above Curie temperature, it becomes paramagnetic and it behaves as ferrimagnetic material below Curie temperature.
- The susceptibility of ferrite is very large and positive. It depends on temperature. It is given by $\chi_{ferri} = \frac{C}{T \pm \theta}$ for $T > T_N$.
- Spin alignment is antiparallel of different magnitudes as shown in figure.



- Mechanically, it has pure iron character.
- They have high permeability and high resistivity
- They have low eddy current loss and low hysteresis loss.

Applications

- Hard magnetic ferrites are used in the manufacture of permanent magnets
- Such magnets are used in super high frequency technology.
- Soft magnetic ferrites are used in the production of cores for inductor coils used in telecommunication and low power transformers.
- Ferrites are used in magnetic flims in which demagnetization process occurs at the speed exceeding million times/second. This technology is important for electronics, automobiles and computer hardware engineering.
- Ferrites re used in information storage devices such as magnetic discs and tapes.
- Ferrite rods are used to produce ultrasonics by magnetostriction principle.
- Ferrite rods are used in radio receiver to increase sensitivity and selectivity.
- Since the ferrite has low hysteresis loss and eddy current loss, it is used in two port m microwave devices such as gyrator, circulator and isolator.

3. Explain magnetic principle in data storage mechanism.

In general memory units are the devices used to store the information in the form of bits. [8 bit =1 byte]. The memory units are classified as (i) Main memory (or) internal memory (ii) Auxiliary memory (or) External memory

<u>Main Memory:</u>

The memory unit of CPU is called main memory. Thus data's are write and finally be erased if necessary. Eg: EPROM, ROM, RAM etc.,

Auxiliary Memory:

This type of memory is also referred to as back-up storages because; it is used to store large volume of data on permanent basis. This date can be accessed or recopied if necessary. Eg: Magnetic tapes, Magnetic disk, Ferrite core memories and Bubble memories.

1. Magnetic Tape:

The tape is a plastic ribbon with metal oxide material coated on one side which can be magnetized, in this information can be written and also can be read by write/read heads. Information recorded in the tape is in the form of tiny magnetized and non-magnetized spots on the metal oxide coating. The magnetized spot represents '1' sun magnetized spot represent '0' in binary code. The information can be accessed, processed, erased and can be stored again in same area.

Advantages:-

- Storage capacity is large, Easy to handle
- Loss expensive, Erased and reused.

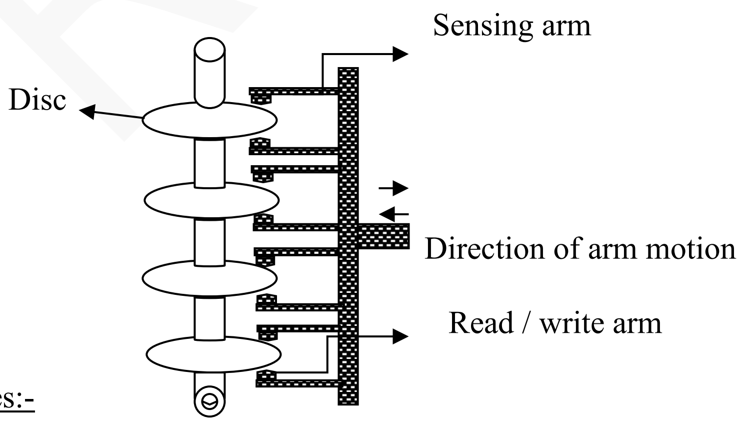
Disadvantages:-

- It consumes lot of time.

2. Magnetic Disc Devices:

(A) Hard disk drives:

It is the direct access storage device made up of hard aluminum platters. This platter surface is carefully machined for flat. This surface is coated with magnetic oxides and built in to a bar. Similar such disks are mounted on a vertical shaft, forming a disk pack as shown in figure. The drive mechanism drives the disc pack with the spindle. The data is written can read by the R/W heads in the horizontal sensing arms by moving in and out between the platters with the precaution that the R/W head doesn't touches the surface instead, it fly over the disk surface by a fraction of a mm.



Advantages:-

- It has large storage capacity.

- Thousand of files can be permanently stored.
- Very high speed in reading and writing the information
- This is prevented from dust, since they are sealed.

Disadvantages:-

- It is very costly
- If data is completed, there is a heavy loss.

(*B) Floppy disc drives*:

Floppy is made of a very thin and flexible plastic materials coated with magnetic materials. This disc is inserted in floppy disc drive for read/write operation by the read/write head in the disc. Size: 5.25" called mini floppy, 3.25" called micro floppy.

Organization:-

Surface of the floppy disc is divided into a number of concentric circles known as tracks where the information is recorded. The tiny magnetic spots are used to record the logic 1 (or) 0 state. The spot magnetized in one direction are '1' state and in other direction are called '0' state. Each track has number of sectors

Operation;-

When the floppy is put in drive unit. When drive is operated. The floppy disc is rotated which makes physical contact with read/write head. This magnetic material movement is controlled by serve mechanism.

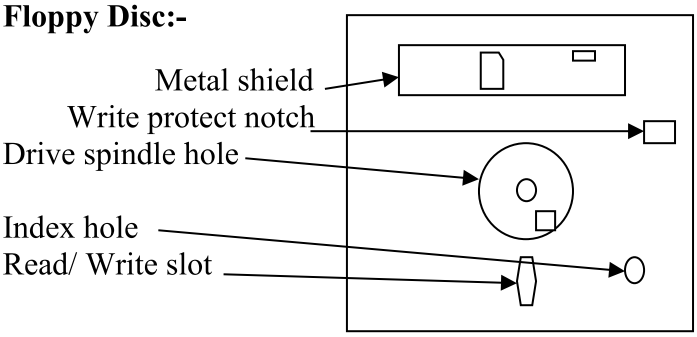
Advantages:-

(iv) Storing and transporting of data is easier.
(v) Cost is less
(vi) It can reused many times

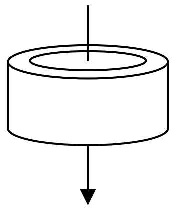
Disadvantages:-

(i) Storage capacity is less
(ii) Care to be taken for handling.

Floppy Disc:-



3. Ferrite Core Memory:



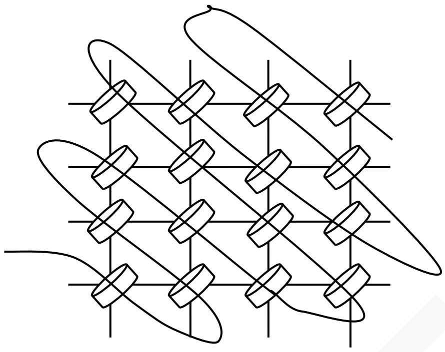


Figure (3)

Here the magnetic core consists of a ferrite core in the shape of a torrid ring as shown in figure. We know that the ferrites have square hysteresis loop and low coercivity as shown in figure. Such hysteresis is used for making core memory as a different form of magnetic recording.

The magnetic cones of the memory are arranged in a matrix interlaced thought fine metal wires both horizontally and vertically as shown in figure (3). A change in the state only occurs during reinforced magnetization i.e. both the horizontal current and vertical current pass through the core in same direction. The current passing through one of the wires will not induce a change in the magnetization of the cores reading of the magnetic cores is achieved using a third sense wire threaded through the core. It will pick up an induced voltage, if the core changes state. To facilitate a fast response for a high speed memory, soft magnets are always used in the core.

4. Describe the working of magnetic hard disc based on Giant Magneto Resistance sensor (GMR).

Principle

In hard disk drives, the binary data in terms of zero's (0) an one's (1) are stored by inducing magnetic moment in a thin magnetic layer and GMR effect is used as the principle to read the data in HDD. Here zero (0) represents missing transition and one (1) represents transition in the medium.

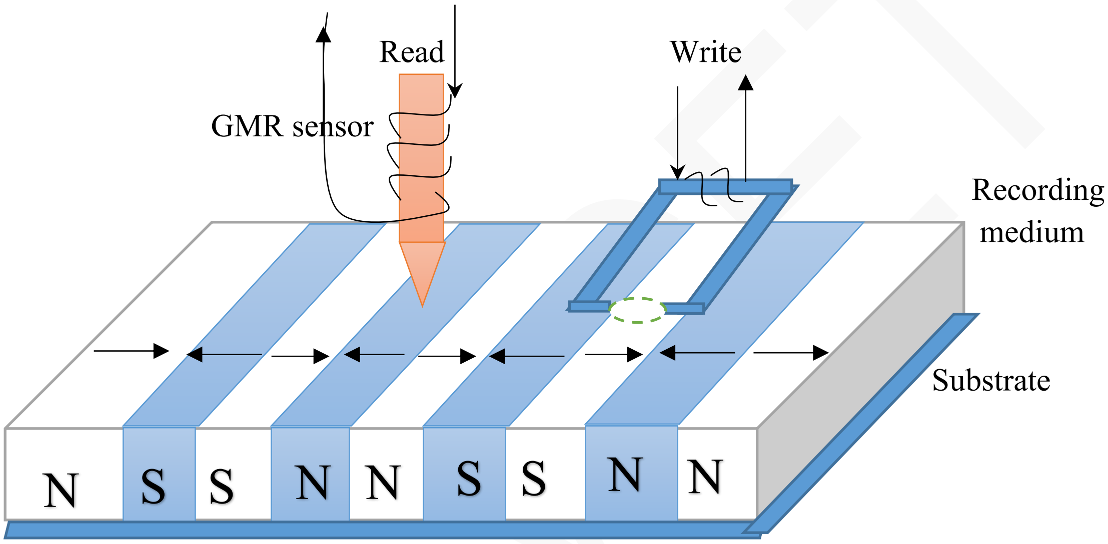
Construction

The HD consists of recording medium madeup of thin layer of magnetic garnets grown over the substrate. The GMR sensor, which is made up of ferrites and antiferromagnetic materials is used as reading element. The writing element is madeup of inductive magnetic transducer. The writing element and the GMR sensor shall be made to slide over the recording media in the longitudinal direction as shown in figure. Hence this method is also called as longitudinal recording. The flow of current through the GMR sensor and writing element shall be adjusted and in turn the magnetization is sensed (or) controlled in the recording media.

Working

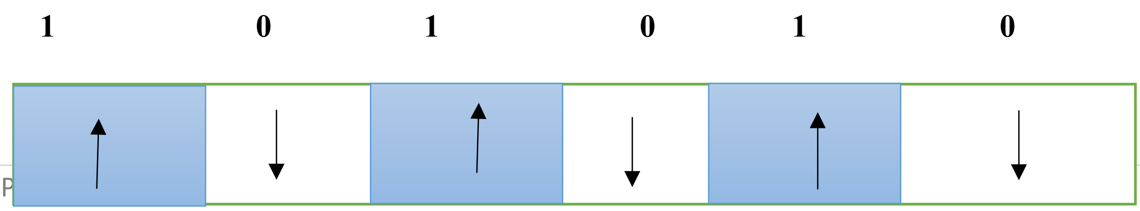
Writing / Storing

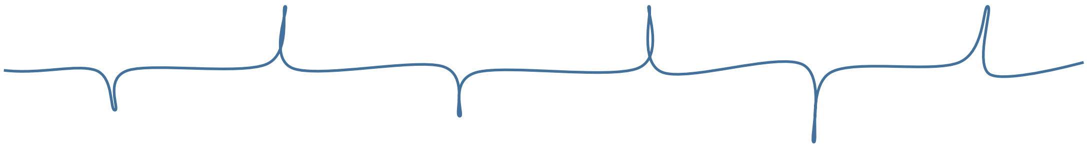
1. Initially the current is passed through the writing element and a magnetic field is induced in between the gap of the inductive magnetic transducer.
2. During writing, the amplitude of current is kept constant, and the direction of current is reversed.
3. Due to reversal of current, the magnetization orientation is reversed in the recording medium i.e., from south → North as shown in figure
4. When the induced magnetic field is greater than the coercivity of the recording media, then data is recorded in the form of 1.
5. Thus one (1) is stored as data in the recording medium as a magnetic transition.
6. When there is no magnetic transition, then it is referred as zero (0).
7. In this way the zero's (0's) and one's (1's) are stored in the recording medium.



Reading / Retrieving

1. Giant Magnetoresistive (GMR) effect is the principle used to read / retrieve the data from the recording medium.
2. When the GMR sensor is made to move near the recorded medium, then the resistance of the GMR sensor varies with respect to the orientation of the magnetic moments as follows.
3. When the layers are magnetized in parallel manner, then the resistance in the GMR sensor is minimum and therefore maximum current flows through the sensor, which represents the data as one (1)
4. When the layers are magnetized in antiparallel manner, then the resistance in the GMR sensor is maximum and therefore minimum(or) almost no current flows through the sensor, which represents the data as zero (0)
5. Therefore with the help of the reading current, the zero's (0's) and one's (1's) can be retrieved from the magnetic hard disk drive.





Advantages

- HDD can store the data in terabytes
- It has very large storage capacity
- It is compact in size and can be easily transferred from one place to another.
- The size of recording medium is reduce up to few nano meter range using nanotechnology
- GMR sensor are non-diffusive and are very sensitive in reading

Disadvantages

- HDD is slower than soli state drives
- Consume large power
- Data may be corrupted due to thermal radiation
- HDD has bulkier form factor
- GMR noise ratio is high for nano size recording media

Applications

- Used as storage devices in cloud applications
- Used in coding and signal processing units
- Used in control systems, Nano electronics, etc.,

5. Explain in detail about optical data storage with necessary diagrams?

The optical data storage techniques resulted in increased storage capacities after the invention of laser. In general they are classified as surface storage and volume storage.

Optical tape

For many years photosensitive film roles are used as optical tapes for recording optical information. Even acoustical information are recorded in such tapes as sound tracks.

Optical Disc (CD)

Principle

The data to be stored is first converted into binary form as 0's and 1's. it is then store in the form of reflecting and non-reflecting micro points in spiral path on a disc. During the read-out process, variation in the reflected intensity of laser is converted back to data.

This optical disc is further classified as *reading only* and *Recording and reading type* based on their storage technique and capabilities. However in either type's laser diode, lenses and photodiodes are used.

During recording, it change electrical information into optical information and then records the information on the optical disc. While reading the head optically reads the recorded information and changes the optical information in to electrical information. The commercial system make use of discs that are 90, 120, 130 and 300nm in diameter. A mini disc, 64nm in diameter is also used for digital audio.

CD audio

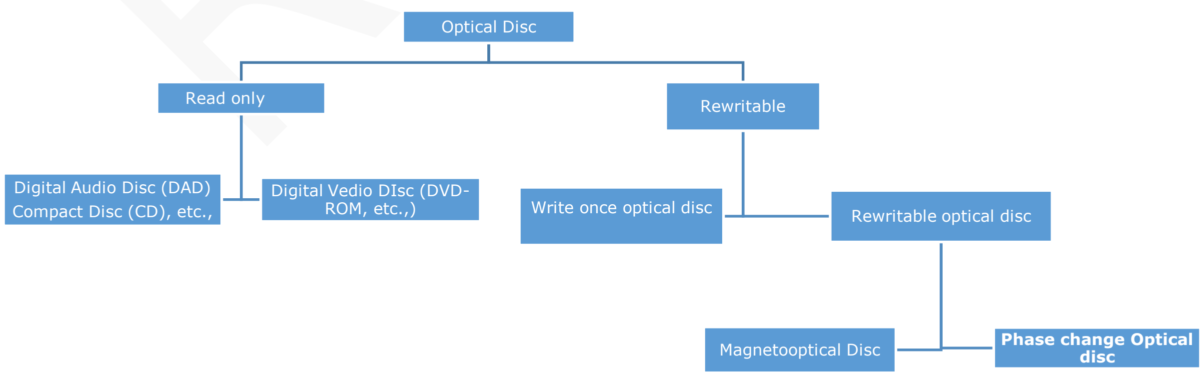
The substrate of the disc is either plastic or photo polymer. First audio signal to be stored is stored is converted into binary. This is then stored in the form of reflecting and non – reflecting micro points in spiral path on a on a metallic master using sharply focussed laser beam. The digital data is pressed onto the substrate by injection moulding. Thus mass production of the CD form base on this concept.

CD ROM

This is similar to that of CD audio with a difference that here in this case video signal is converted into binary and stored in a metallic master. The data thus replicated from the master on a plastic substrate can be read any number of times but cannot be changed and hence this name.

CD – WORM

In this the active layer is chemically coated on the substrate. The laser pulses generated in the CD writer burns the chemical coating and there by creates reflecting and non-reflecting micro points. We can write the data once and read any number of times but the data written cannot be either copied or erased and rewritten and hence the name. For copies each disc has to be written burning the chemical coating. This technique we use to record functions such as marriages, etc.,



CD R/W

In this type of CD we can write the data, read and rewrite after erasure. For this two different materials / phenomena via phase change materials and magneto-optic materials are used in general.

Digital Versatile Disc (DVD)

In 1996, a new read only optical system called digital versatile disc with enough capacity (4.7GB) to hold 130 minutes of compressed video, or more than 90% of all feature-length movies using laser of shorter wavelength and focusing lens of larger numerical aperture is introduced. Then DVD R/W also introduced.

Digital Video Recording (DVR)

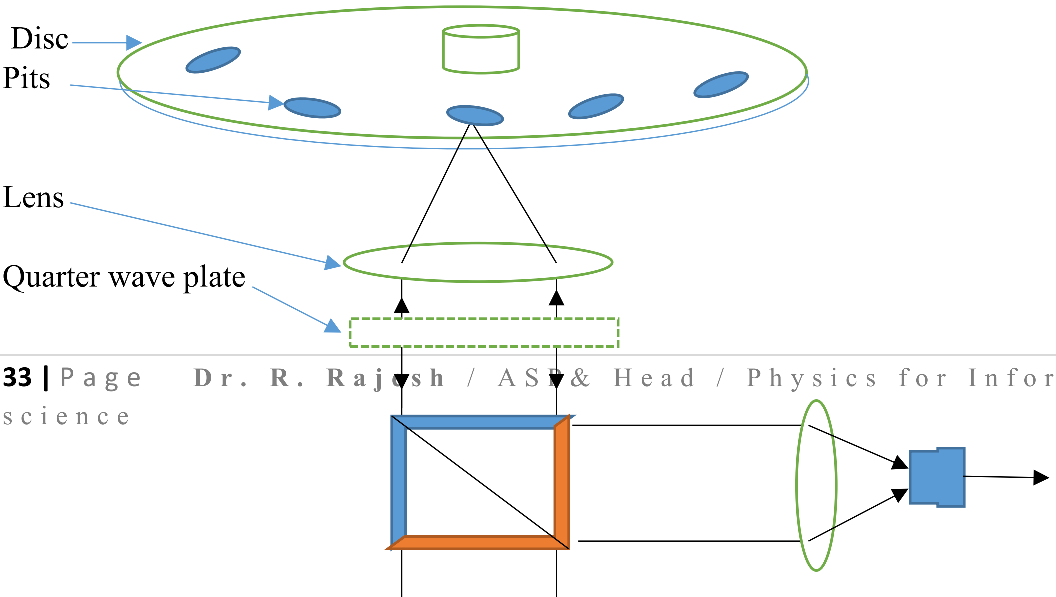
With this system, 22GB can be recorded on a single layer of 12cm disc. The most important commercial application of this system is recording of high definition digital video. By reducing the spot size using a laser of shorter wavelength and objective lens of higher numerical aperture a real density is increased.

Advantages of optical disc

The optical discs have several advantages over semiconductor memories. Some of these include their larger data storage capacity, shorter access time size. Therefore they are used in terminal equipment of computers as well as in audio visual equipment.

Read only optical discs equipment

CD's which are 120mm in diameter are typical digital audio discs. Compact discs usually means digital audio compact discs, but it is also includes the read only memory (CD –ROM) for data memory and interactive compact disc (CD- I) for multimedia use. Audio information (sound) is digitally recorded in stereo on the surface of a CD in the form of microscope "pits" and flats". The light emitted from the laser diode passes through the lens and it is focussed to a diameter of about 1mm on the surface of a disk. As the CD rotates, the lens and beam follow the track under control of a servo motor. The laser light which is altered by the pits and flats along the recorded track is reflected back from the track through the lens and optical system to infrared photodiodes. The signal from the photodiodes is then use to reproduce the digitally recorded sound.



Electronic signals

Polarizer (Beam splitter)

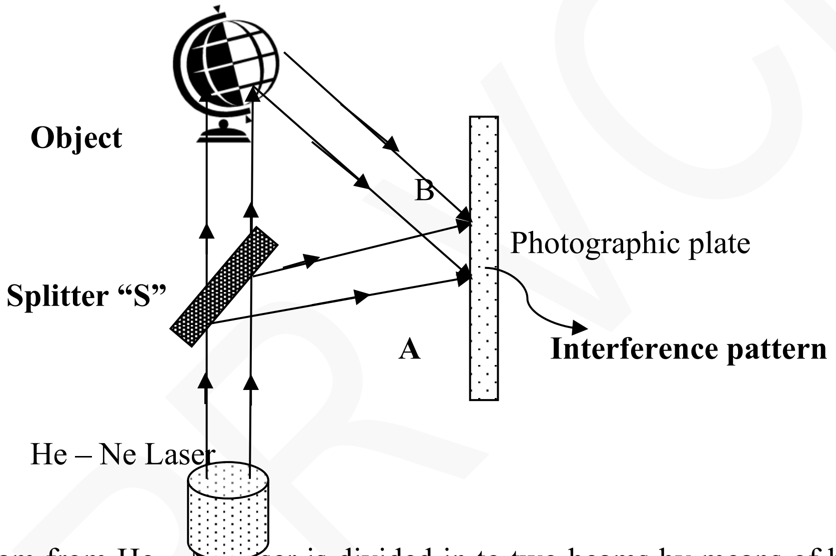
Photodiode

Lens

Laser Diode

6. Explain the Construction and reconstruction of a holographic image with essential diagram.

Construction (Making a Hologram): Figure shows the arrangement for recording a hologram

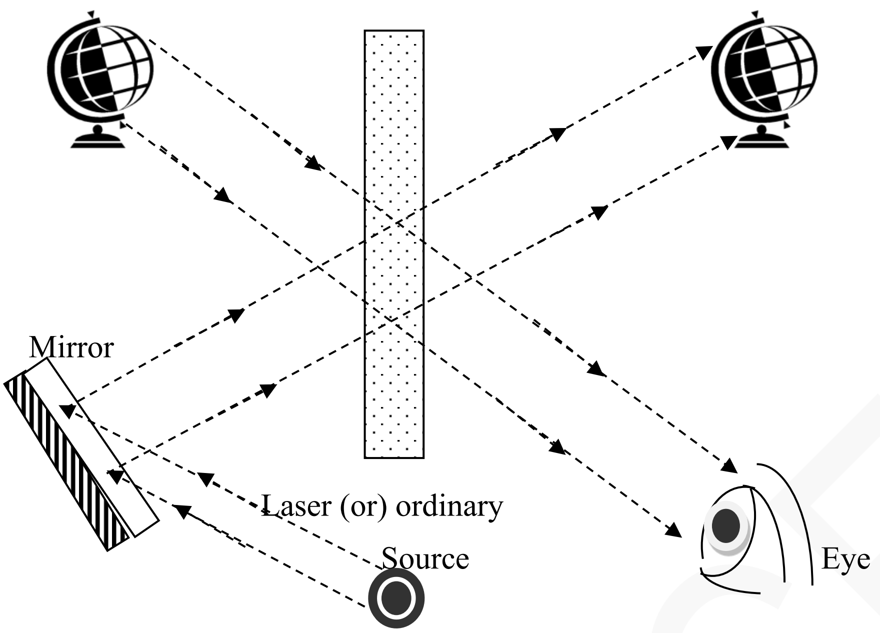


A beam from He – Ne laser is divided in to two beams by means of beam splitter. The transmitted beam is called object beam (A beam). This illuminates the object to be recorded in hologram. A part of this light scatters from the object and falls on the photographic plate P. the reflected beam called reference beam (B – beam) also fall on this photographic plate. These two beams interfere with each other and form an interference pattern which is recorded on the plate. This pattern is very small with a separation of less than 0.001mm.when the plate is developed, we get a transparent hologram.

Reconstruction of Hologram: (Displaying a Hologram)

The object is recreated from hologram by directing a beam of light at the plate as shown in figure.

The readout beam (laser beam) interacts with the interference pattern on the plate. It produces two images from the diffracted beams emerging from the hologram. One of them appears at the original position occupied by the object called virtual image and the other real image can be photographed without using a lens.



The virtual image which can be seen by looking through the hologram appears in a complete three dimensional from. If we move our eye from the viewing point, the perspective of the picture changes and it is possible to see the other side of the object.

Applications:

(i) It is a reliable method for data storage

(ii) Holographic NDT is used to find stress in pipeline, vibration pattern of a guitar

(iii) It is used to determine the degree and nature of deformation of the observed surface