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Unit No 3	**Unit Name : Magnetic properties of materials**	Date	14-11-2017

LECTURE NOTES

UNIT III MAGNETIC PROPERTIES OF MATERIALS

Magnetic dipole moment – atomic magnetic moments- magnetic permeability and susceptibility - Magnetic material classification: diamagnetism – paramagnetism – ferromagnetism – antiferromagnetism – ferrimagnetism – Ferromagnetism: origin and exchange interaction- saturation magnetization and Curie temperature – Domain Theory- M versus H behaviour – Hard and soft magnetic materials – examples and uses-– Magnetic principle in computer data storage
– Magnetic hard disc (GMR sensor).

3.1 INTRODUCTION

Any materials that can be magnetized by an applied by an applied external magnetic field is called a magnetic materials.

Magnetic materials can be easily magnetized because they have permanent or induced magnetic moment in the presence of applied magnetic field. Magnetism arise from the magnetic moment or magnetic dipole of the magnetic materials. Among the different eleven types of magnetic materials, only five magnetic materials are the most important for the practical application. They are

- Diamagnetic materials.
- Paramagnetic materials.
- Ferromagnetic materials.
- Antiferromagnetic materials.
- Ferromagnetic materials or ferrites

3.1 TERMS AND DEFINITIONS

Magnetic dipole moment (m)

Magnetic dipole moment m of a magnet is the product of magnetic pole strength and the distance between the two poles.

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Magnetic flux (φ)

Total number of magnetic lines of force passing through a surface is known as magnetic flux. It is represented by the symbol 'φ' and its unit (Wb).

Magnetic flux density (or) Magnetic induction (B)

Magnetic flux density at any point in a magnetic field is defined as the magnetic flux (φ) passing normally through unit area of cross section (A) at that point. It is denoted by the symbol B and its unit is weber / metre2 or tesla.

$$\mathbf{B = [\varphi / A]}$$

Intensity of Magnetisation (I)

The term magnetisation means the process of converting a non-magnetic material into a magnetic material.

The intensity of magnetisation (I) is the measure of magnetisation of magnetised specimen. It is defined as the magnetic moment per unit volume of the material.

$$\mathbf{I = [M/V]\ Wb/m^2}$$

Magnetic field intensity (or) strength (H)

Magnetic field intensity at any point in a magnetic field is the force experienced by unit North Pole placed at that point.

It is denoted by H and its unit is Newton per weber or ampere turns per meter (A/m).

Retentivity (or) Remanence

When the external magnetic field is applied to a magnetic material is removed, the magnetic material will not loss its magnetic property immediately. There exits some residual intensity of magnetization in the specimen even when the magnetic field is cut off. This is called residual magnetism (or) retentivity.

Coercivity

The residual magnetism can be completely removed from the material by applying a reverse magnetic field. Hence coercivity of the magnetic material is the strength of reverse magnetic field (-Hc) which is used to completely demagnetize the material.

3.2 MAGNETIC PERMEABILITY (μ)

Magnetic permeability of a substance measure 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)

$$\mathbf{B \propto H}$$

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

Where μ is a constant of proportionality and it is known as permeability or absolute permeability of the medium.

$$\mathbf{\mu = B / H}$$

Thus, the permeability of a substance is the ratio of the magnetic flux density (B) inside the substance to the magnetic field intensity (H).

Absolute permeability

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

$$\mathbf{\mu = \mu_0 \times \mu_r \ \ H/m}$$

Relative permeability (μ_r) of medium

Relative permeability of a medium is defined as the ratio between absolute permeability of a medium (μ) to the permeability of a free space (μ_0). It has no unit.

$$\mathbf{\mu_r = \mu / \mu_0}$$

3.3 MAGNETIC SUSCEPTIBILITY (χ)

Magnetic susceptibility (χ) of a specimen magnetized in a magnetic field. It is the ratio of intensity of magnetisation (I) induced in it to the magnetizing field (H).

$$\chi = I/H$$

3.5 CLASSIFICATION OF MAGNETIC MATERIALS

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

i) Diamagnetic materials – no permanent magnetic moment

ii) Paramagnetic, ferromagnetic, antiferromagnetic and ferromagnetic materials – having permanent magnetic moment

3.6 DIAMAGNETIC MATERIALS

Diamagnetism is exhibited by all the materials. The atoms in the diamagnetic materials do not possess permanent magnetic moment.

However, when a material is placed in a magnetic field, the electrons in the atomic orbits tend to counteract the external magnetic field and the atoms acquire an induced magnetic moment.

As a result, the material becomes magnetized. The direction of the induced dipole moment is opposite to that of externally applied magnetic field. Due to this effect, the material gets very weakly repelled, in the magnetic field. This phenomenon is known as diamagnetism.

When a magnetic field Ho is applied in the direction shown in fig., the atoms acquire an induced magnetic moment in the opposite direction to that of the field.

The strength of the induced magnetic moment is proportional to the applied field and hence magnetization of the material varies directly with the strength of the magnetic field.

The induced dipoles and magnetization vanish as soon as the applied field is removed.

The susceptibility of the diamagnetic materials is negative. Due to this, the materials is weekly repelled in the magnetic field.

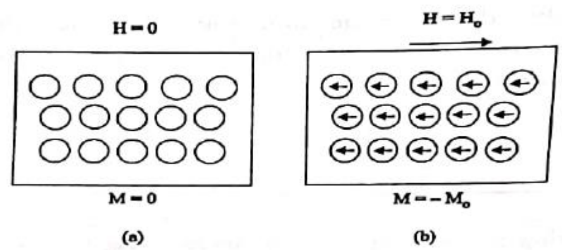


Fig shows – Diamagnetic material

Diamagnetic materials

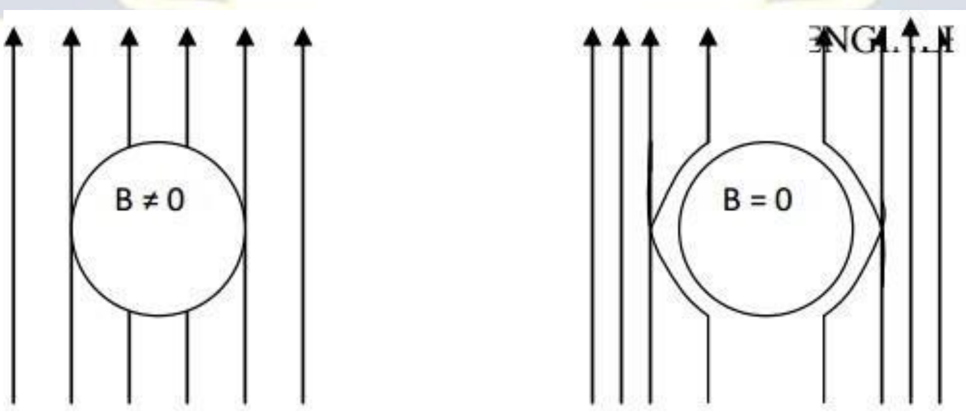
The materials which exhibit diamagnetism are called diamagnetic materials.

Properties of diamagnetic material

Diamagnetic magnetic material repels the magnetic lines of force. The behavior of diamagnetic material in the presence of magnetic field.

There is no permanent dipole moment. Therefore, the magnetic effects are very small

The magnetic susceptibility is negative and it is independent of temperature and applied magnetic field strength.



3.7 PARAMAGNETIC MATERIALS

In certain materials, each atom or molecule possesses a net permanent magnetic moment (due to orbital and spin magnetic moment) even in the absence of an external magnetic field.

The magnetic moments are randomly oriented in the absence of external magnetic field. Therefore the net magnetic moment is zero, and hence the magnetization of the material is zero.

But, when an external magnetic field is applied, the magnetic dipoles tend to align themselves in the direction of the magnetic field and the material becomes magnetized. As shown in fig. This effect is known as paramagnetism.

Thermal agitation disturbs the alignment of the magnetic moments. With an increase in temperature, the increase in thermal agitation tends to randomize the dipole direction thus leading to a decrease in magnetization.

This indicates that the paramagnetic susceptibility decreases with increases in temperature. It is noted that the paramagnetic susceptibility varies inversely with temperature.

$$\chi \propto 1 / T \qquad \chi = C / T$$

This is known as Curie law of paramagnetism and C is a constant called Curie constant

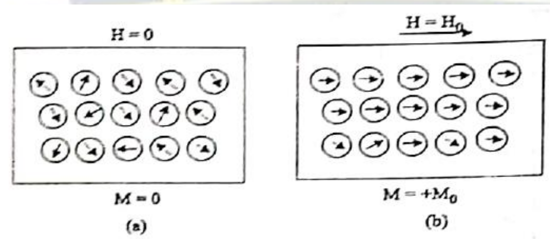


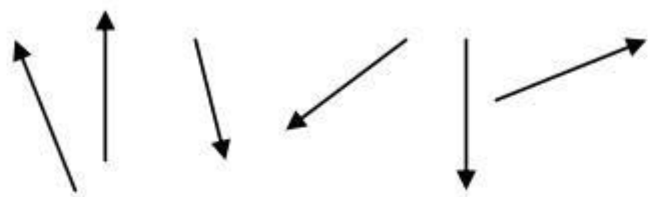
Fig shows – Paramagnetic materials

Properties of paramagnetic materials

Paramagnetic materials attract magnetic lines of force. They possess permanent dipole moment. The susceptibility is positive and depend on temperature is given by

$$\chi = -C\theta / T$$

The spin alignment is shown in fig.



Example- Manganous sulphate, ferric oxide, ferrous sulphate, nickel sulphate, etc

3.8 FERROMAGNETISM

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

These materials show the spontaneous magnetization i.e., they have magnetisation (atomic magnetic moments 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 moments align with each other.

This phenomenon is known as ferromagnetism.

3.9 ORIGIN OF FERROMAGNETISM AND EXCHANGE INTERACTION

The ferromagnetic property is exhibited by transition elements such as iron, cobalt, and nickel at room temperature and rare earth elements like gadolinium and dysprosium.

The ferromagnetic materials possess parallel alignment of dipoles. This parallel alignment of dipoles is not due to the magnetic force existing between any two dipoles. The reason is that the magnetic potential energy is very small and it is smaller than thermal energy.

The electronic configuration of iron is $1s^2$, $2s^2$, $2p^6$, $3s^2$, $3p^6$, $3d^6$, $4s^2$. For iron, the 3d subshell is an unfilled one. This 3d subshell have five orbitals.

For iron, the six electrons present in the 3d subshell occupy the orbitals such that there are four unpaired electrons and two paired electrons as shown in figure.

These four unpaired electrons contribute a magnetic moment of 4ß. This arrangement shows the parallel alignment of four unpaired electrons.

The parallel alignment of dipoles in iron is not due to the magnetic interaction. It is due to the Pauli's exclusion principle and electrostatic interaction energy.

The Pauli's exclusion principle and electrostatic interaction energy are combined together and constitute a new kind of interaction known as exchange interaction. The exchange interaction is a quantum mechanical concept.

The exchange interaction between any two atoms depends upon the interatomic separation between the two interacting atoms and the relative spins of the two outer electrons. The exchange interaction between any two atoms is given by

$$E_{ex} = -J_e S_1 S_2$$

Where Je is the numerical value of the exchange integral, S_1 and S_2 are the spin angular momenta of the first and second electrons.

The exchange integral value is negative for a number of elements. Therefore, the exchange energy value is negative (minimum energy configuration) when the spin angular momentum S_1 and S_2 are opposite direction.

Hence, antiparallel alignment of dipole is favored. This explains the antiparallel alignment of dipoles antiferromagnetic materials.

In some materials like iron, cobalt and nickel the exchange integral value is positive. The exchange energy is negative the spin angular momentum is in the same direction. This will produce a parallel alignment of dipoles.

A plot between the exchange integral and the ratio of the interatomic separation to the radius of 3d orbital (r/ r d) is shown in figure

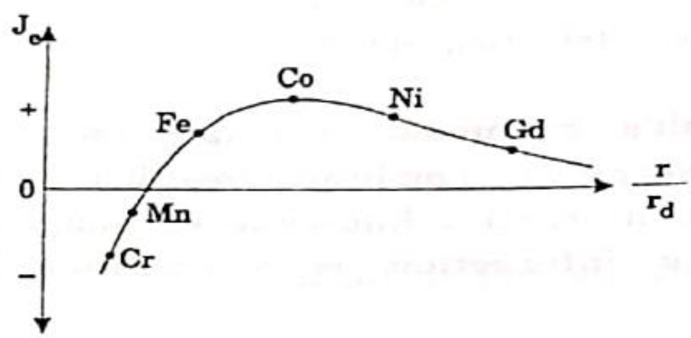


Fig shows – Exchange integral

For the transition metals like iron, cobalt, nickel and gadolinium the exchange integral is positive, whereas for manganese and chromium the exchange integral is negative.

The positive value of the exchange integral represents the material as ferromagnetic and the negative exchange integral value represents the material as antiferromagnetic.

In general, if the ratio, r/ r > 3, the material is ferromagnetic, otherwise the material is antiferromagnetic. It should be noted that manganese is suitably alloyed so that r/r > 3, and it will become ferromagnetic.

3.10 SATURATION MAGNETIZATION AND CURIE TEMPERATURE

Definition

The maximum magnetization in a ferromagnet when all the atomic magnetic moments are aligned is called the saturation magnetization M_{sat}

When temperature is increased, lattice vibrations become more energetic which leads to a disruption of the alignments of the spins. The spins cannot align perfectly with each other.

The lattice vibration may be sufficient to disorientate the spin of the atom.

The ferromagnetic behavior disappears at a critical temperature called the **Curie temperature**, denoted by T_c. At this temperature the thermal energy of lattice vibrations in the crystal can overcome the potential energy of the exchange interaction and hence destroy the spin alignments.

Above the Curie temperature, the ferromagnetic materials behaves like paramagnetic.

The saturation magnetization M sat therefore decreases from its maximum value M sat (0) at absolute zero temperature to zero at the Curie temperature.

Figure shows the dependence of M_{sat} on the temperature when M_{sat} is normalized to M_{sat} (0) and temperature is the reduced temperature, that is T/T_c when $T/T_c = 1, M_{sat} = 0$.

Since at the Curie temperature, the thermal is sufficient to overcome the exchange energy E_{ex} then

The magnetic susceptibility of ferromagnetic material, very large.

The **Curie temperature (T_c)** depends on the substance and it is well above the room temperature.

The susceptibility of ferromagnetic material is given by **Curie - Weiss law**:

Magnetic susceptibility, $X = C/T-T_C$

Where C is the Curie constant.

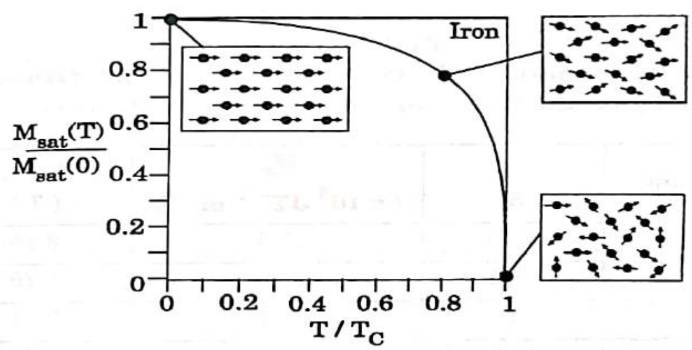


Fig shows – Normalized saturated magnetization versus reduced temperature T/T_C

3.11 DOMAIN THEORY OF FERROMAGNETISM

Weiss proposed the concept of domains in order to explain the properties of ferromagnetic materials.

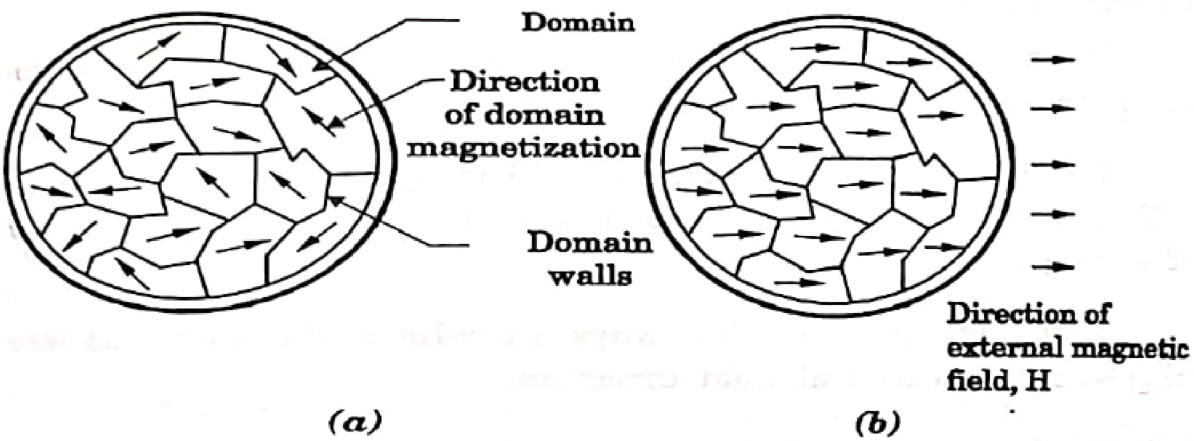
Principle

The group of atomic dipoles (atoms with permanent magnetic moment) organized in tiny bounded regions in the ferromagnetic materials are called magnetic domains.

Explanation

Ferromagnetic material contains a large number of domains. In each domain, the magnetic moments of the atoms are aligned in same direction.

Thus, the domain is a region of the ferromagnetic material in which all the magnetic moments are aligned to produce a net magnetic moment in one direction only. Thus, it behaves like a magnet with its own magnetic moment and axis.



a) **Schematic illustration of magnetic domains in a demagnetized ferromagnetic material. In each domains the magnetic dipoles are aligned but the domains are aligned at random so that net magnetization is zero.**
b) **Domain configuration in a magnetized body. The magnetic moments of domains are aligned resulting in strong net magnetization**

In a demagnetized ferromagnetic materials domains randomly oriented as shown in fig (a) so that the magnetization of the material as a whole is zero.

The boundaries separating the domains are called do walls. These domain walls are analogous to the boundaries in a poly crystalline material.

However, the domain walls are thicker than the grain boundaries. Like grain growth, the domain size can also due to the movement of domain walls.

When a magnetic field is applied externally to ferromagnetic material, the domains align themselves with field as shown in fig (b).

This results in a large net magnetization of the material

Note: The domain walls are also known as **Bloch walls.**

Process of Domain Magnetisation

We know that in an unmagnified specimen, the domains are randomly oriented and the net magnetization is zero.

When the external magnetic field is applied, domains align with the direction of field resulting in large net magnetization of a material.

There are two possible ways in which the domains are aligned in the external field direction.

(a) By the motion of domain walls

Fig (a) shows an unmagnified specimen in domains are randomly aligned.

When a small magnetic field is applied, the domains with magnetization direction parallel or nearly parallel to the field grow at the expense of others as shown in fig (b).

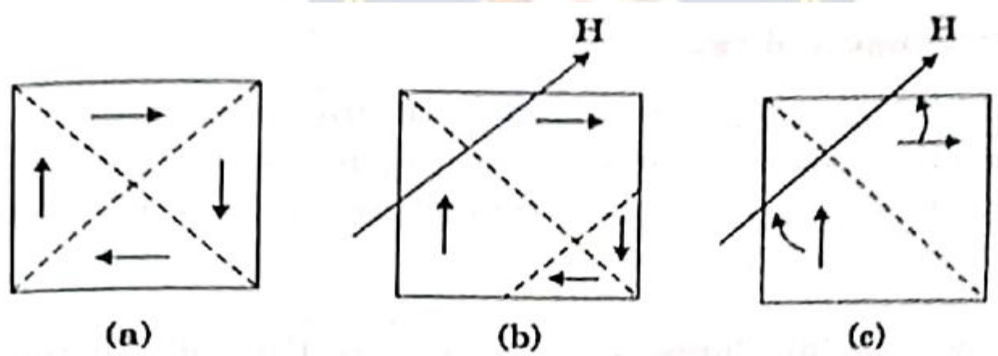


Fig shows – a) Random domain alignment b) Domain wall moment c) Domain rotation

This domain growth occurs due to the movement of domain walls away from the minimum energy state.

(b) By rotation of domains

As the magnetic field is increased to a large value (i.e., near saturation) further domain growth becomes impossible through domain wall movement.

Therefore, most favorably oriented and fully grown domains tend to rotate So as to be in complete alignment with the field direction, as shown in fig (c)

Origin of domains

We know that according to thermodynamics, the free energy of a solid tends to reach a minimum. It is found that the domain structure occurs in order to minimize the total energy of ferromagnetic solid.

Types of Energy involved in the process of domain growth

To study the domain structure clearly, we must know four energy involving in the process of domain growth. They are

(i) Exchange energy

(ii) Magnetostatic energy

(iii) Crystal anisotropy energy

(iv) Magnetostrictive energy

(i) Exchange energy

It is the energy associated with the quantum mechanical coupling that aligns the individual atomic dipoles within a single domain. It arises from interaction of electron spins. It depends upon the interatomic distance.

Fig (a) shows a cross section through from crystal having a single domain structure established by exchange energy with a saturation

(ii) Magnetostatic energy

Magnetostatic energy or magnetic potential energy is the energy present in any ferromagnetic material when the material produces an external field.

This is due to the presence of resultant dipole moment in that material even in the absence of external magnetic field.

The magnetic energy of the specimen can be reduced by dividing the single domain into two domains as shown in fig (b).

Further subdivision into N domains (fig. c) reduce the magnetic energy to 1 / N of the magnetic energy of the material with single domain.

A domain structure shown in fig (d) and (e) have zero magnetic energies due to the introduction of triangular domains at the top and bottom of the crystal. These triangular domains are called **closure domains.**

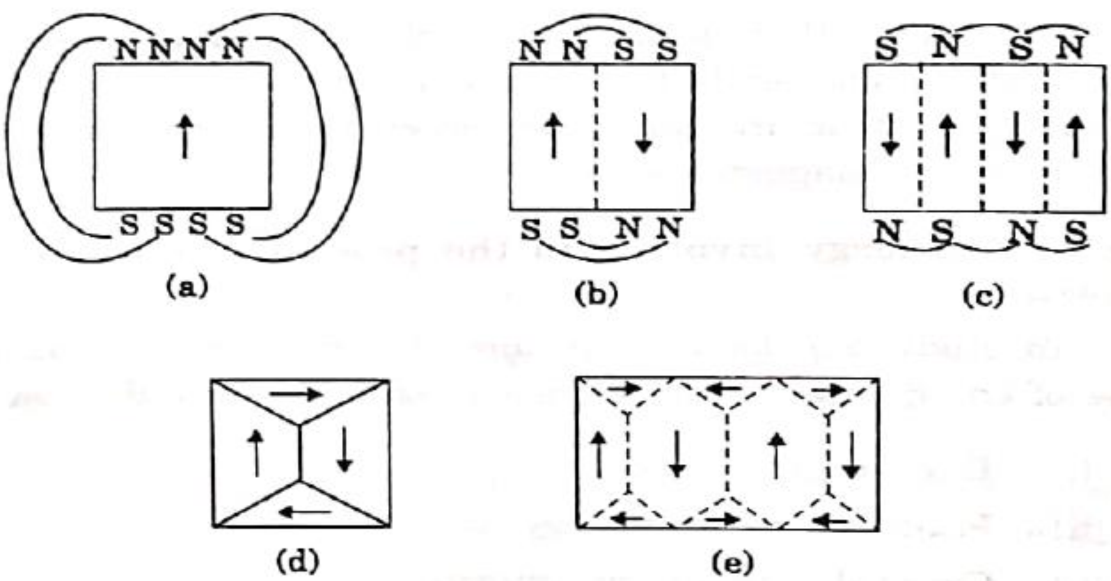


Fig shows – Origin of domains

(iii) Crystal anisotropy energy

It is the energy of magnetisation which is the function of orientation.

In fig shows, magnetisation curves for iron with applied field along different crystallographic directions have been drawn.

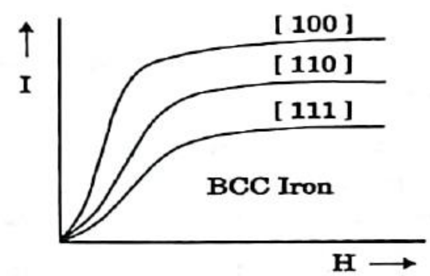


Fig shows – Hard and easy directions for magnetization

It is obvious from the figure that much greater fields are needed to produce magnetic saturation in [1 1 1] direction as compared to the field required in [I O O] direction.

The difference in magnetic energy to produce saturation in an easy [1 0 0] direction and hard [1 1 1] direction is called crystal anisotropic energy.

(iv) Magnetostrictive energy

When a material is magnetised, it is found that it suffers a change in dimensions. This phenomenon is known as **magnetostriction**.

This deformation is different along different crystal directions.

So if the domains are magnetised in different directions they will either expand or shrink. This means that work must be done against the elastic restoring forces.

The work done by the magnetic field against these elastic restoring forces is called the magneto - elastic energy or **magnetostrictive energy.**

3.12 HYSTERESIS - M Versus H BEHAVIOUR

The word hysteresis means lagging behind. The word hysteresis when a ferrornagnetic material is taken through a cycle of magnetisation, intensity of magnetisation (M) and magnetic induction lag behind the magnetising field.

Thus, even if the magnetising field is made zero, the value of I and B are not zero and there is a tendency in the material to retain its magnetic property. This lagging of **I** and **B** behind **H** is called hysteresis.

The variation of M (intensity of magnetisation) with respect to H (applied field) is represented by a closed loop (or) curve. This loop is called hysteresis loop or curve.

A graph is drawn by plotting magnetic field strength H along X -axis and magnetic induction 'B' along Y - axis as shown in fig

The magnetic induction B increases along the curve OA with the magnetic field H. Beyond the point A. even when the magnetic field is increased. The magnetic induction does not increase and it remains constant. At this point, the specimen is saturated with magnetization

Now the value of magnetic field is decreased, but the intensity of magnetisation does not decrease in the same rate as it increased.

When H = O, B = O. the magnetic induction has a definite value represented by OB and it is known as **retentivity.**

The applied magnetic field H is reversed and increased gradually till the point C is reached.

The magnetic induction B becomes zero at the point C and it is known as coercivity.

Further increase of magnetic field H, the magnetic induction increases along CD in the reverse direction as shown in the graph.

If the magnetic field is varied backwards, the magnetic induction follows a curve DEFA.

This completes one cycle magnetization.

The loop ABCDEFA is called **hysteresis loop.**

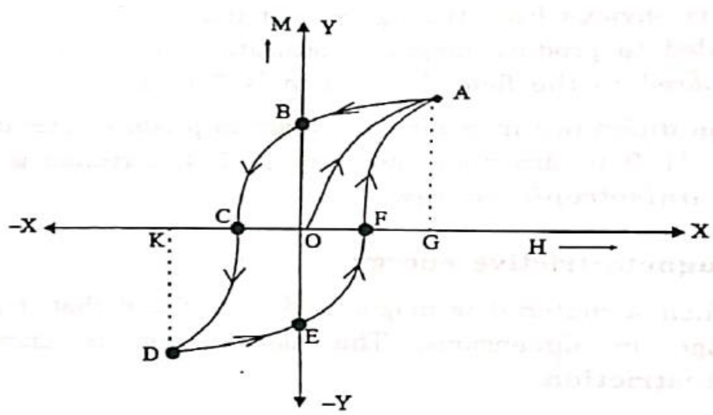


Fig shows – Hysteresis loop

From the above fact, it is clear that the intensity of magnetization M will not become zero, when the magnetic field strength H is zero. **It shows that the magnetic induction lags behind applied magnetic field strength.**

This lagging of intensity of magnetic induction behind the applied field strength is called magnetic hysteresis.

Retentivity or Residual magnetism

Retentivity or residual magnetism is the amount of magnetic induction retained in the material after removing the magnetising field. It is represented by OB in M—H curve.

Coercivity or Coercive force

Coercivity or coercive force is the amount magnetising field applied in the reverse direction to the residual magnetism completely from the material. It is represented by OC in curve.

Hysteresis loss

When a specimen is taken through a cycle of magnetization, then there is a loss of energy in the form of heat. This loss of energy is known as hysteresis loss

The area of the loop represents energy loss per cycle unit volume of the specimen.

Explanation of Hysteresis on the basis of Domain theory

It is found that when a ferromagnetic material is subjected to an external magnetic field, there is an increase in the value of the resultant magnetic moment of the specimen.

This is due to

(i) Motion of domain walls

(ii) Rotation of domain walls

When a small external magnetic field is applied, the domain walls are displaced slightly in the direction of **magnetisation.** This gives rise to small magnetization corresponding to the initial portion of the hysteresis curve (OA) as shown in fig.

When the applied magnetic field is removed, then the domain walls return to its original position and these domains are known as **reversible domains.**

If the magnetic field is increased, a large number of domains contribute to the magnetisation and thus the magnetization increases rapidly with H.

Now, even when the magnetic field is removed, because of the displacement of domain wall to a very large distance, the domain boundaries do not come back to their original position. The process is indicated as AB in the fig and these domains are called **irreversible domains.**

At point 'B' all the domains got magnetized along the easy direction.

Now, when the magnetic field is further increased, the domains start rotating along the field direction and the anisotropic energy is stored in the **hard direction** which is represented by BC in fig.

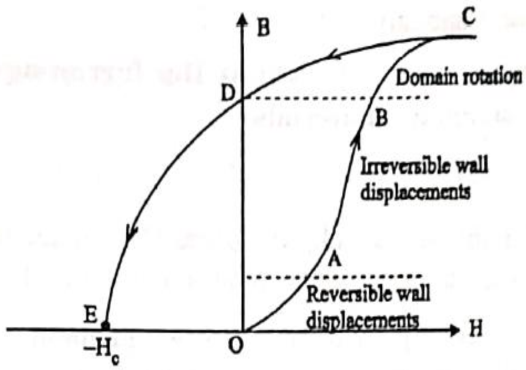


Fig shows – Magnetization curve of the virgin specimen

Now, the specimen is said to have attained the maximum magnetisation. At this position, even after the removal of external magnetic field the material has maximum magnetisation called **residual magnetism (or) retentivity** represented by OD in fig.

On the removal of the external field, the specimen will try to attain the original configuration by the movement of Bloch wall. But this movement is stopped due to the presence of Impurities, lattice imperfections etc.

Therefore to overcome this, a large amount of reverse magnetic field is applied to the specimen. **The amount of spent to reduce the magnetisation to zero is called coercivity** which is represented by OE in the fig

Ferromagnetic materials

The materials which exhibit the ferromagnetism called ferromagnetic materials.

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. This property of ferromagnetic materials is called as **spontaneous magnetisation.**

• They exhibit hysteresis (lagging of magnetisation with applied magnetic field).

• On heating, they lose their magnetisation slowly.

• The dipole alignment is as shown in fig.

• The magnetic susceptibility is very high and it depends on temperature.

It is given by, $\chi = C/T- \theta$

(For T > 0, paramagnetic behavior T < 0, ferromagnetic behavior) where C is Curie constant and θ ferromagnetic Curie temperature.

3.13 ANTIFERROMAGNETISM

Antiferromagnetic materials are magnetic materials which exhibit a small positive susceptibility of the order of 10^{-8} to 10^{-5}

3.14 FERRIMAGNETISM

There are some magnetic materials in which the moments of two sub lattices are in direction but exactly equal in magnitude (because of two different types ions in the lattices).

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

Ferrimagnetic materials or Ferrites

Materials exhibit ferrimagnetism are called ferrimagnetic materials or ferrites.

Properties of ferrites

- Ferrites has net magnetic moment.
- Above Curie temperature, it becomes para - magnetic and it behaves as ferrimagnetic material below Curie temperature.
- The susceptibility of ferrite is very large and positive. It depends on temperature.
- Spin alignment is antiparallel of different magnitudes as shown in fig.
- Mechanically, it has pure iron character.
- They have high permeability and high resistivity
- They have low eddy current loss and low hysteresis loss.

Applications Of ferrites

- 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 films in which demagnetization process occurs at the speed exceeding million times/second. This technology is important for electronics, automobiles and computer hardware
- Ferrites are used in information storage devices such as magnetic discs and tapes.
- Ferrite rods are used to produce ultrasonic by magnetostriction principle.
- Ferrite rods are used in radio receiver to increase sensitivity and selectivity.
- Since the ferrite has low hysteresis loss and eddy cur-Tent loss, it is used in two port microwave devices such as circulator and isolator.

Types of Magnetic Materials

Magnetic materials also are classified into two types based magnetisation

(i) Soft magnetic materials

(ii) Hard magnetic materials

3.15 SOFT MAGNETIC MATERIALS

Definition

Materials which are easy to demagnetize are called sop magnetic materials.

These magnetic materials do not retain the magnetic domains after the removal of the external magnetic field

Properties or soft magnetic materials

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

Examples of soft magnetic materials

- Pure or **ingot iron**
- **Cast iron** (carbon above 2.5 %)
- **Carbon steel**

- **Silicon steel** (little addition of silicon to steel)
- **Manganese and nickel steel** (addition of manganese and nickel to steel)
- **Perm alloy**: (nickel iron alloy contains Ni • 78.15%, Fe - 21% and small quantities of Cr, Co, Cu, and Mn)
- **Mumetal:** (nickel iron alloy Ni - 75.4%, Cu - Cr • 1.5% and the remaining iron)
- **Perminar** (Cobalt - nickel - iron alloys as Ni - 50%, Co - 25% Fe • 25%)
- **Soft ferrites**

Applications of soft magnetic materials

- **Cast iron** is used in the structure of electrical machinery and the frame work of D.C 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.

3.16 HARD MAGNETIC MATERIALS

Definition

Materials which retain their magnetism and difficult to demagnetize are called hard magnetic materials.

These magnetic materials retain the alignment of magnetic domains permanently even after the removal external magnetic field.

Properties

- The hand 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 of Hard magnetic materials

- **Tungsten steel:** It contains 4.5 to 6% tungsten, 0.5 to 0.7% carbon and the remaining is iron.
- **Cobalt steel:** It contains cobalt, chromium, 3.5 to tungsten and remaining is iron.

Applications of hard magnetic materials

- Tungsten steel is used in making permanent magnets for dynamos and motors.
- Cobalt steel is used in motors, fans and heavy duty
- 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_e) is known as energy product. It represents the maximum amount of energy stored in the specimen.

Therefore, for permanent magnets the value of should very high as shown in fig.

3.17 MAGNETIC PRINCIPLE IN COMPUTER DATA STORAGE

Magnetic materials used for recording/ reading the audio and video signals. They also used in storage devices such as magnetic tapes, floppy disks and hard disk.

With the advent of new technology, it has become very easy to store or retrive informations from the storage devices and this is done using the magnetic phenomenon.

Generally ferro or ferrimagnetie materials are used in the storage devices. In these materials the magnetic align themselves parallel to each other.

If a small magnetic field is applied, a large value of magnetisation is produced and using this property, informations are stored in the storage devices.

Magnetic recording involves the storage of data in the form of magnetisation pattern as a sequence of binary magnetisation tes in the magnetic medium.

Storage of Magnetic Data

The storage capacity of the main memory of a computer system is limited. Often, it is to store many data on memories. Moreover, it is also not possible to have permanent storage of data in the main memory of the computer.

As a result, additional memory called auxiliary memory is using in the most of the systems. **It is known as secondary storage device.**

This type of memory is also referred as **back-up storage** because it is used to store large volume of data on a permanent basis which can be partially transferred to the main memory storage when required for processing.

The main purpose of secondary storage is

(a) To increase the memory capacity

(b) To store the data permanently

Magnetic principles of the materials are used for the construction of wide range of secondary storage devices most common secondary memories are

(i) Magnetic tapes (cassettes)

(ii) Magnetic disk (floppy disk and hard disk)

(iii) Ferrite core memories

(iv) Magnetic bubble memories

Let us study more about these secondary storage devices in a detailed manner.

Magnetic Tape

Magnetic tape is one of the most popular storage medium for data recording.

It consists of a strip of plastic (mylar) tape over which a thin layer of magnetic material such as ferrous or ferric oxide is coated.

The standard tape is 0.5 inch wide and it contains 9 tracks. The magnetic tape which contains chromium dioxide has 18 tracks for the same 0.5 inch width. The data density of a 9 track tape is 250 characters per inch, while for a 18 track tape it is about 3,800 characters per inch.

These tapes are available in the market in form of a large reels or small cartridges or cassettes.

Recording and Reading Process

The data is stored on a magnetic tape in a sequence manner. The fig shows the magnetic tape along With read / write head.

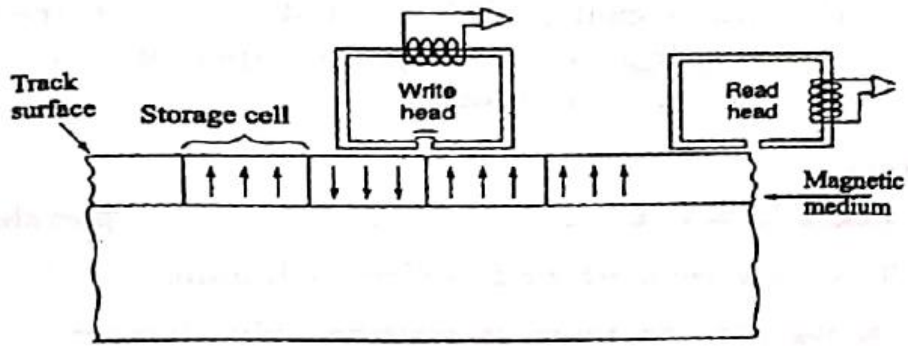


Fig shows – Representation of magnetic tape and heads

A specially constructed electromagnet read/write head is used. The north and south pole of the read/write head is separated by a narrow gap. This narrow gab is called **head gab**.

When the data (0 and 1) in the form of electrical signal is applied to the write head, it stores the data on the magnetic tape as logic '1', in a storage cell with magnetization in one direction.

Similarly, the next data is stored as logic '0' in the next storage cell with the magnetisation in the opposite direction. Generally data is stored on the tape in blocks.

The data stored on the magnetic tape is read out by the read/write head, when the tape moves across the head. When the magnetized (storage cell) spot reaches the read head, the storage cell induces small electrical signal in the head.

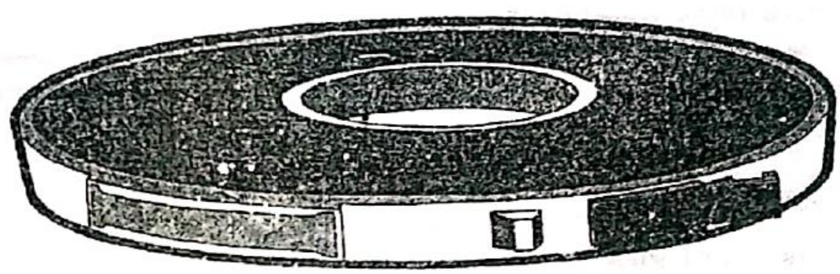


Fig shows – Magnetic tape

This electrical signal gives information about the data i.e., logic '1' or logic '0' state on the tape. In this way, the digital information stored is readout.

Advantages

- Magnetic tape is easy to handle and it is portable
- It is more compact and easier to handle
- Storing data on tapes is considerably cheaper.
- Tapes have large storage capacities, ranging from a few hundred kilobytes to several Giga bytes.

Disadvantages

- It is a sequential access memory and hence access time is more.

Application

- They are generally used only for long-term storage and backup
- Tapes are also used for transporting large amount of data.

Magnetic Disks (Diskettes)

Magnetic disks are the most popular **direct access storage devices**. These magnetic disk memories provide large storage capabilities and moderate operating speeds.

Types of Magnetic disks

There are two types of disks

(a) Hard disk

(b) Floppy disk

3.18 MAGNETIC HARD DISC

The hard disk is used for storing a large amount of information. This disk is available in different sizes Zach as 3.5 inch, 5.25 inch and 8 inch.

Construction

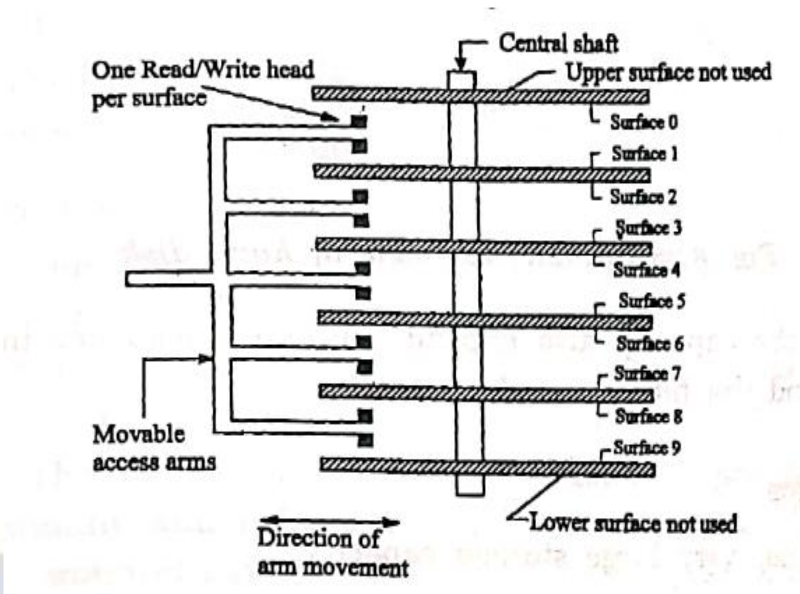


Fig - shows the construction of a hard disk

The hard disk is completely sealed and it is protected from the dust particles. The hard disk is also known as Winchester disk.

It consists of a number of magnetic disks (2 to 5) or aluminium platters. All these platters are packed together and they are mounted on a common shaft.

The central shaft rotates at the speed of 3600 or more revolutions per minute. All the disks of a hard disk move simultaneously in the same direction.

A number of access arms and read / write heads are used, to access two surfaces of the disks. Any particular data can be accessed by the respective read/write head.

The disk packs, read / write heads and the access mechanism are sealed in an airtight dust free container.

Storing and accessing information

Each disk has two sides on which information in both sides of the disk. Disk consists of a number of M corresponding trucks in all sides is called a cylinder

Each track is further divided into sectors. Presence of a magnetized spot represents '1' bit and its absence represents bit.

The storage capacity of a hard disk depends on the number of disk surfaces.

But, the capacity also depends on the tracks per inch of surfaces and the bits per inch of track.

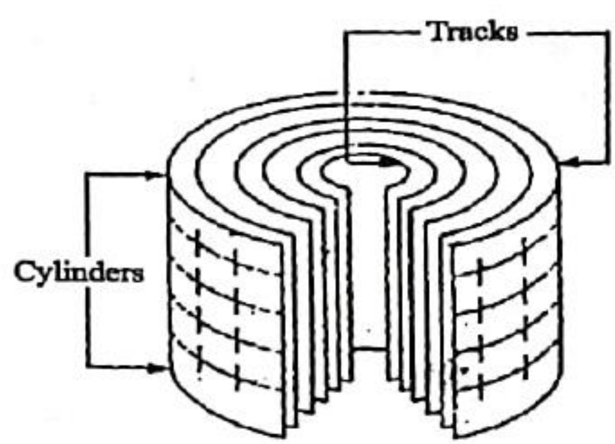


Fig shows – Tracks and cylinders of a hard disk

Advantages

- It has very large storage capacity.
- More files can be permanently stored.
- Very high speed (low access time) in retrieving data information can be both written on the disk and very d from them in a very short time.
- The data can be accessed very large number of times without degradation
- Hard disk is prevented from dust particles, since they sealed in a special chamber.

Disadvantages

- Hard disks are not easily portable.
- Its cost is more.
- More chance for errors.

Application

Hard disk is a common secondary storage device for all of computers. The storage capacity of a hard disk drive may be ranging from 20 Mega Bytes (MB) to 4 Gaga Bytes (GB).

Magneto resistance

Some metallic materials show a large change in resistance on the application of a magnetic field. This effect is called magneto resistance (MR).

Giant Magneto Resistance (GMR)

It is a quantum mechanical magnetoresistance effect observed in multilayers composed of alternating ferromagnetic and non-magnetic conductive layers.

Definition

The effect is observed as a significant change in the electrical resistance depending on whether the magnetization of adjacent ferromagnetic layers are in a parallel or an antiparallel alignment.

The overall resistance is relatively low for parallel alignment and relatively high for antiparallel alignment. The magnetization direction can be controlled, for example, by applying an external magnetic field.

The effect is based on the dependence of electron scattering on the spin orientation.

The main application GMR is magnetic field used to read data in a hard disk drives, biosensors, micro electromechanical systems (MEMS) and other devices multilayer structure are in magnetoresistive random memory (MRAM) as cells that store one bit of information.

Explanation

The GMR is seen in structures which have normal and ferromagnetic layers alternatively. The electrical conductivity depends on the relative orientation of magnetization in the successive ferromagnetic layers in the stack.

When the relative magnetizations of the layers are switched from parallel (to the plane of the layers) to antiparallel states. high and low resistivities are obtained in the structure This corresponds to 0 and 1 states in data storage format.

Two geometries are commonly used in GMR studies and are as shown in fig

(a) Current in Plane (CIP) of layers and

(b) Current Perpendicular to Plane (CPP) of layers.

Since the layers are only a few nanometers thick, the CIP offers high resistance to the small cross sectional area encountered by the electrons.

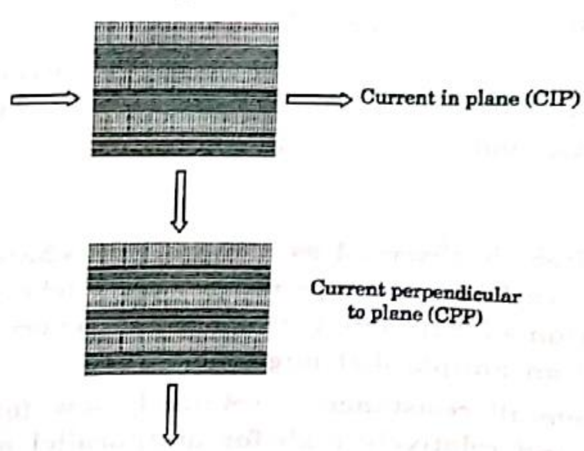


Fig shows – Geometries used in GMR

To alter the resistivity by controlling the spin-dependent scattering. The lateral dimensions of the structure must be small when compared with the electron mean free path.

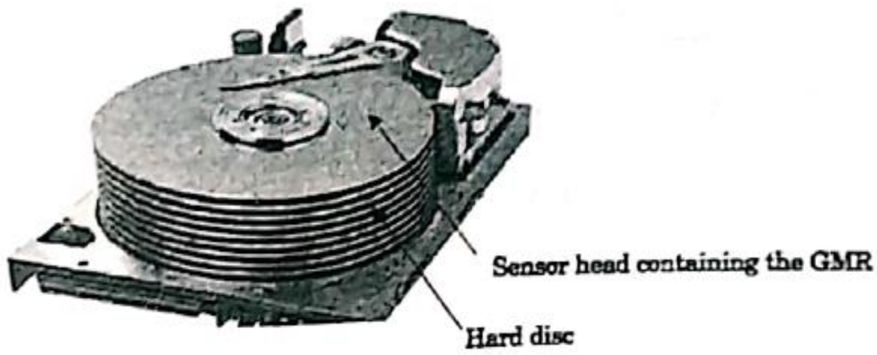
3.19 GIANT MAGNETO RESISTANCE (GMR) SENSOR - SPIN VALVE

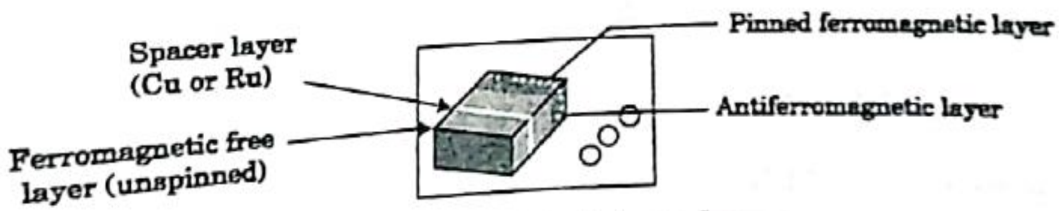
A device that woks on the principle of the GMR is a spin valve. This device is used in magnetic hard discs for high density data storage. There are 4 layers altogether in a spin valve.

Two ferro magnetic layers are separated by a thin spacer layer (Cu or Ru). One ferromagnetic layer is pinned (its direction of magnetization is fixed and is not distributed by changes in field. ms layer is pinned by adding a fourth layer: a strong anti ferromagnet.

The other layer, called the free layer, is sensitive to the field produced by the data bit. Permalloy (an alloy of Ni and Fe) is usually chosen for both feromangnetic layers. This structure is called the spin valve.

When a weak magnetic field, such as that from a bit on a hard disk, passes beneath such a structure, the magnetic orientation of the unpinned magnetic layer rotates relative to that of the pinned layer. This generates a significant change in electrical resistance due to the GMR effect.





• As the bit travels under the head, the resistance goes down, the electrons do not scatter very much and the current flow increases.

• As the bit moves on, the resistance increases, the electrons are scattered ore and the current decreases.

• As the bit travels further from the head, the resistance peaks and the current decreases to its lowest point.

• As the resistance change is quiet large, even small data bits can generate quite large resistance changes, thus increasing the capacity to store data bits in the hard disc.