CHAPTER 6

Unit VI

Engineering Materials and Applications

Syllabus

(**Prerequisites :** Paramagnetic materials, diamagnetic materials, ferromagnetic materials, crystal physics, conductors and insulators, free charges and bound charges inside a conductor, dielectric and electric polarization, capacitors and capacitance)

Liquid Crystals : Nematic, smectic and cholesteric phases, liquid crystal displays

Multiferroic. : Type I and Type II multiferroics and applications

Magnetoresistive oxides : Magnetoresistance, GMR and CMR materials, introduction to spintronics

Learning Objectives :

After reading this chapter, learner should be able to :

- Understand types of liquid crystals
- Explain function of LCD
- Describe multiferroics and its types
- Define magnetoresistance, GMR, CMR
- Introduce spintronics

6.1 Liquid Crystal and Phases

MU - May 12, May 13

Q. Explain different phases of liquid crystal. **(May 12, 3 Marks)**

Q. Explain the differences between three different liquid crystal phases w.r.t. the order in the arrangement of molecules, with the help of diagram. Which property of the liquid crystal is used for display? **(May 13, 5 Marks)**

Q. Describe various phases of liquid crystals.

6.1.1 Mesomorphic Phase

MU - Dec. 13, May 14

Q. What is mesomorphic state of matter? **(Dec.13, 2 Marks)**

Q. What is liquid crystal state of matter? Draw the diagram to describe molecular arrangement in their different phases. **(May 14, 5 Marks)**

"Altering the externally generated illumination"

– In some substances, the tendency toward an ordered arrangement of molecules is so great that crystalline solid does not melt directly into liquid state but passes first through an intermediate change called liquid crystal (or mesomorphic phase) before changing to liquid state on further application of heat.

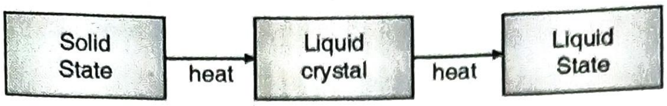

Fig. 6.1.1

- Liquid crystal is one of the homogeneous phases with properties distinct from either of the traditional states. The liquid crystals show some of the properties of solid state and some of the properties of liquid state.

Properties related to solid state	Properties related to liquid state
Exhibit properties like double refraction of light and interference patterns in polarized light	Exhibit properties like surface tension, flow and viscosity
Ordered arrangement of atoms or molecules is still found	Ordered arrangement of atoms or molecules is of shorter order

- The temperature at the transition point provides enough energy to disrupt the binding between some of the molecules but the energy is not sufficient to break the strong lateral force of attraction between the long molecules.
- The important property in liquid crystals for practical application is that the arrangement of molecules can be upset by very slight changes in their surrounding i.e. molecules in liquid crystal rearrange themselves when a small electric field is applied and the change from an isotropic to more isotropic arrangement changes the way the crystal absorbs light.
- A small electric field can disturb the alignment of molecules while the large electric field induces turbulence in the liquid crystal with light scattering.

Types of liquid crystals

(a) Smectic or soap-like liquid crystals
(b) Nematic or thread-like liquid crystals
(c) Cholesteric liquid crystals

(a) Smectic or soap-like liquid crystals

- Crystalline state, the orientation and periodicity – all these characteristics are retained.
- On heating, the crystal loses periodicity within the plane, but retains the orientation and arrangement in equispaced planes.

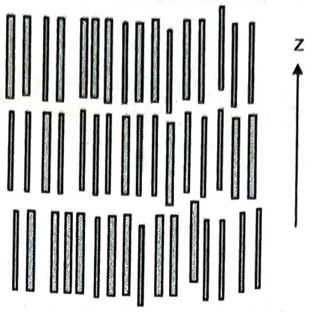

Fig. 6.1.2 : Smectic phase

(b) Nematic or thread-like liquid crystals

- These crystals on heating lose their planar or layered structure but retain a parallel alignment. Thus they retain orientation but lose periodicity.
- Hence molecules lie parallel to each other but can move up and down or sideways or can rotate along their axes.

Fig. 6.1.3 : Nematic phase

(c) Cholesteric liquid crystals

MU - Dec. 13

Q. Explain the cholesteric phase with neat diagram. **(Dec.13, 3 Marks)**

- These liquid crystals have the same arrangement of molecules as in nematic type, but their optical activity is many times higher than that of its solid crystalline variety.
- **The cholesteric phase :** The cholesteric phase of liquid crystals has molecules parallel to each other, but the direction of alignment twists gradually and results in a helical structure. Therefore the substance consists of parallel layers. Molecules are aligned parallel in each layer. The helical structure of cholesteric substance is responsible for optical activity (optical rotation).

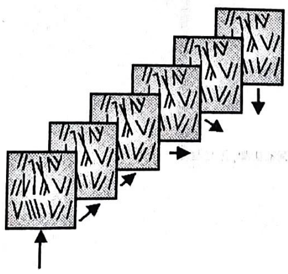

Fig. 6.1.4 : Cholesteric phase

6.1.2 Discotic Phase

They are disc-shaped rather than elongated. They form thermotropic liquid crystal phases.

6.1.3 Applications of Liquid Crystals

1. Liquid crystals are used in Liquid Crystal Displays (LCD) like digital watches and pocket calculators because of the fact that their orientation can be easily changed by electric field or pressure. The changed orientations have different light transmission and reflection. This is achieved by the application of electric field with the help of electrodes.
2. For smectic liquid crystals, the distance between planes having molecules that too with same orientation is considered to be the main feature. When a beam of light strikes these planes, the properties of reflected beam depend upon the distance in planes. This distance between the planes is highly temperature sensitive, and therefore colour of the reflected light depends upon temperature. Arrangement based upon this principle can have sensitivity as good as 0.01°C.
3. Liquid crystals are used in gas-liquid chromatography because they have electrical properties lying between crystalline solids and isotropic liquids.

6.2 Liquid Crystal Display

Q. How do liquid crystals display works?

- Liquid crystal display has *rotation of modules when a small electric voltage is applied across the liquid crystal* as the principle.
- Liquid crystals are basically organic compounds consisting of long rod-like molecules. In their natural state they arrange themselves with their long axes roughly parallel. However when they come into contact with a grooved surface they line up parallel along the grooves.
- When two finely grooved surfaces have their grooves 90° to each other, the liquid crystal sandwiched between them will twist. When light is made incident, it follows the alignment of molecules and therefore light is also twisted by 90° while passing through liquid crystal. When a small voltage is applied to the liquid crystal, the molecules rotates and rearrange themselves vertically and permit light to pass through untwisted.
- The use of two polarizers to control the brightness is the core principle behind LCD monitors. In LCD, the brightness of each pixel needs to be independently controlled. Since there are millions of pixels available on monitor, mechanically it is impractical to rotate polarizers within each one of the pixels.
- But using for any colour monitor, each pixel is divided into three smaller subpixels. These subpixels are covered with red, green and blue filters and display brightness to these components of light. Each of the subpixel acts as an independent pixel, but due to their small size and proximity with each other, viewer's eyes fail to distinguish them as separate pixels. All the colours that can be sensed by us are produced using different combinations of red, green and blue light.

6.3 Multiferroics

- Combination of electricity and magnetism has provided us with electromagnetism.
- Through Maxwell's equations, we have gone through an ocean of applications which have changed human life drastically. But electric and magnetic ordering in solids is usually considered separately. The reason behind this is very clear - the electrons and ions are responsible for charge effects whereas electron's spin is responsible for magnetic properties.

- A reader can start with piezoelectric effect wherein application of mechanical stress produces static electricity due to polarization of charges in some natural crystals. The applications were limited as piezoelectric constant was small.
- A new class of manmade materials with increased piezoelectric constants was discovered. They were described as ferroelectrics.
- Along the same lines the concept of piezomagnetism is developed wherein one can induce magnetic moment by applying physical stress or a physical deformation by applying a magnetic field. Some antiferromagnetic crystals exhibit this effect.
- A new possibility was coined when two independent phenomena
  (1) The appearance of magnetization M in an electric field E
  (2) Appearance of electric polarization P due to magnetic field coexists, but also two types of ordering i.e.
    (a) Spontaneous ordering of orbital and spin magnetic moments i.e. ferromagnetism
    (b) Spontaneous ordering of electric dipole moments i.e. ferroelectricity

coexist in a material without applying any external electric or magnetic fields. These materials are called multiferroics.

6.3.1 Classification of Multiferroics

To understand multiferroics further, they are classified into two main categories

(1) Type – I multiferroics

(2) Type – II multiferroics

Sr. No.	Type – I Multiferroic	Type – II Multiferroic
1.	Ferroelectricity and magnetism occur at different temperatures.	Ferroelectricity and magnetism occur at same temperature.
2.	Ferroelectricity and magnetism occur due to different mechanism.	Ferroelectricity and magnetism occur due to same mechanism.
3.	In such materials, ferroelectericity is the result of structural distortion which occurs at high temperature denoted by T_L.	In such materials inversion symmetry is broken through magnetic ordering and directly ferroelectricity is observed.
4.	Magnetic ordering sets in at low temperature donated by T_N	Ferroelectricity and magnetism occur at same temperature.
5.	Example : For $BiFeO_3$, $T_C = 1100°$ k and $T_N = 643°$ K	Example $TbMnO_3$

6.3.2 Applications of Multiferroics

- Multiferroics have offered a completely new technological avenue for us i.e. to control magnetism by using electric field using a novel way of magnetoelectric coupling.
- This has the potential to reduce energy in conventional devices working on electromagnetism.
- New devices which work on magnetoelectricity like TMR sensor (Tunnel Magneto Resistance), also high sensitivity AC magnetic field sensors and tunable microwave devices are conceptualized.

6.4 Magnetoresistive Oxides

6.4.1 Magnetoresistance

Q. Explain the term magnetoresistance. Describe GMR and CMR materials in detail.

It is the characteristic exhibited by a material preferably ferromagnetic to cause the variation in the value of electrical resistance when external magnetic field is applied to it.

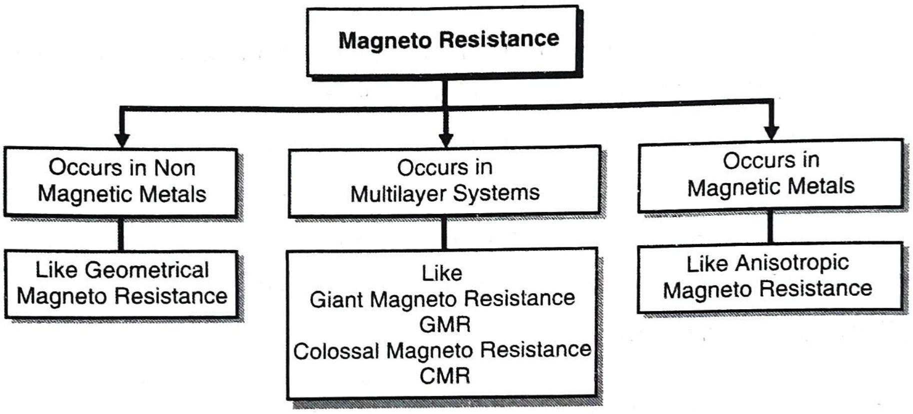

Fig. 6.4.1

1. Giant Magneto Resistance (GMR)

Let's consider

$$R(H) = \text{Electrical resistance in magnetic field } (H)$$

$$R(0) = \text{Electrical resistance when } H = 0$$

$$\therefore \quad \delta_H = \frac{R(H) - R(0)}{R(0)}$$

- Here δ_H represents magnetoresistance. The term giant magnetoresistance is used here because δ_H is very high.
- GMR is basically a quantum mechanical effect observed in alternative ferromagnetic and non-magnetic conductive layers. If $R(H)/R(0) \rightarrow H$ graph is plotted it appears as shown below.

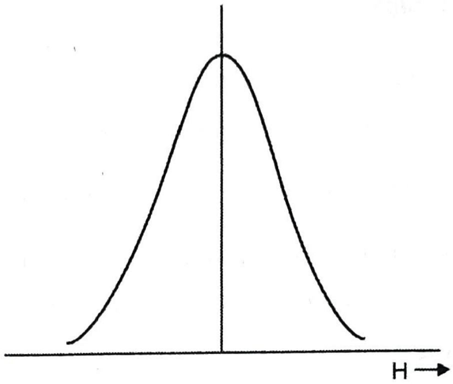

Fig. 6.4.2

Applications :

1. Magnetic field sensors
2. To read data hard disk drives and bio-sensors

2. Colossal Magneto Resistance (CMR)

- CMR is relatively a very advance topic. Complete understanding is still not so clear. It can be said honestly that it is a matter of current research activities.
- It is a property observed in manganese-based perovskite oxides.
- Like GMR, CMR also offers change in resistance with respect to change in external magnetic field.
- CMR provides interesting scope for the strong coupling of magnetic properties to the lattice structure and ordering of spin charge and angular momentum.

6.5 Introduction to Spintronics

Q. What is spintronics? Why is it considered so important for the future?

- As the name suggests, it is spin-based electronics. It is a nanotechnology which deals with spin-dependent properties of an electron instead of charge-dependent properties.
- It is the focus of attention because in contrast to electronics where electron charge is used for storage and transfer of information, spintronics uses spin in addition to or in place of the electron charge.
- Spin is represented by clockwise or anticlockwise i.e. two orientations $\pm\hbar/2$.
- Directional and coherent motion of electron spin circulates a spin current which can be used to carry information controlled by quantum spin in spintronic devices.

Significance :

- Size of transistors or other components has already reached such a small level that very soon we will be unable to reduce it further. Spintronics is one of the effective solutions expected in the future.