

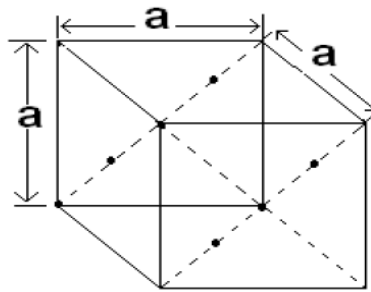
- Q.2 a. Define atomic packing. Show that the atomic packing factor for FCC and HCP metals are the same.

**Answer:**

In FCC structure the number of atoms per unit cell are 4 an atomic radius  $r = \frac{a\sqrt{2}}{4}$

$$r = \frac{a\sqrt{2}}{4}; \quad \text{APF} = \frac{\text{Volume of atoms per unit cell}}{\text{Volume of unit cell}}$$

$$= \frac{4 \times \frac{4\pi r^3}{3}}{a \times a \times a} = \frac{16\pi \frac{a\sqrt{2}^3}{4}}{3 \times 64a^3} = \frac{\pi}{3\sqrt{2}} = 0.74$$



FCC

In HCP unit cell, the corner atoms are touching the centre atom on top and bottom faces. Therefore  $a = 2r$  or  $r = a/2$

$$\text{APF} = \frac{\text{Volume of atoms per unit cell}}{\text{Volume of unit cell}}$$

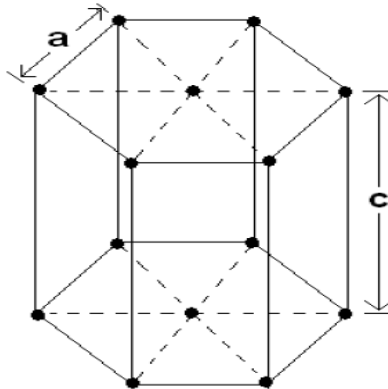
Volume of the hexagon = 33.8767

$$= \frac{6 \times \frac{4\pi r^3}{3}}{3a \sin 60 \times c} = \frac{6 \times \frac{4\pi a^3}{2^3}}{3a^2 \sin 60 \times c} = \frac{\pi a}{3 \sin 60 \times c}$$

Taking  $c/a$  ratio for HCP structure = 1.633

$$\text{APF} = \frac{\pi}{3 \times 0.866 \times 1.633} = 0.74$$

Thus it is seen that the atomic packing factor for HCP is the same as for an FCC structure.



HCP

- b. Obtain the miller indices of a plane which intercepts at  $a$ ,  $b/2$ ,  $3c$  in a cubic unit cell. Draw a neat diagram showing the plane, (where  $a, b, c$  are lattice parameters.)

**Answer:**

Obtain the Miller indices of a plane which intercepts at  $a$ ,  $b/2$ ,  $3c$  in a simple Cubic unit cell. Draw a neat diagram showing the plane. (Where  $a, b, c$  are lattice parameters)

**Ans:**

- (i) The intercepts made by the plane along three crystallographic axes ( $x, y$  and  $z$  axes).

$$\begin{array}{ccc} \underline{X} & \underline{Y} & \underline{Z} \\ a & b/2 & 3c \\ pa & qb & rc \\ \text{with } p = 1, q = \frac{1}{2}, r = 3. \end{array}$$

- (ii) The intercepts as multiples of unit cell dimensions along the axes:

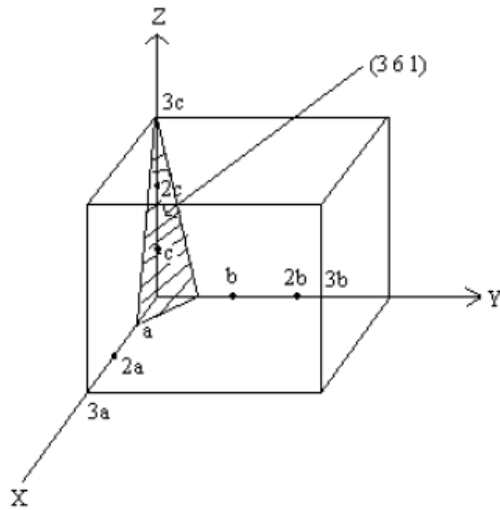
$$\frac{a}{a} \quad \frac{b/2}{b} \quad \frac{3c}{c}$$

i.e. 1      $\frac{1}{2}$      3

(iii) The reciprocal of these numbers:     1     2      $\frac{1}{3}$

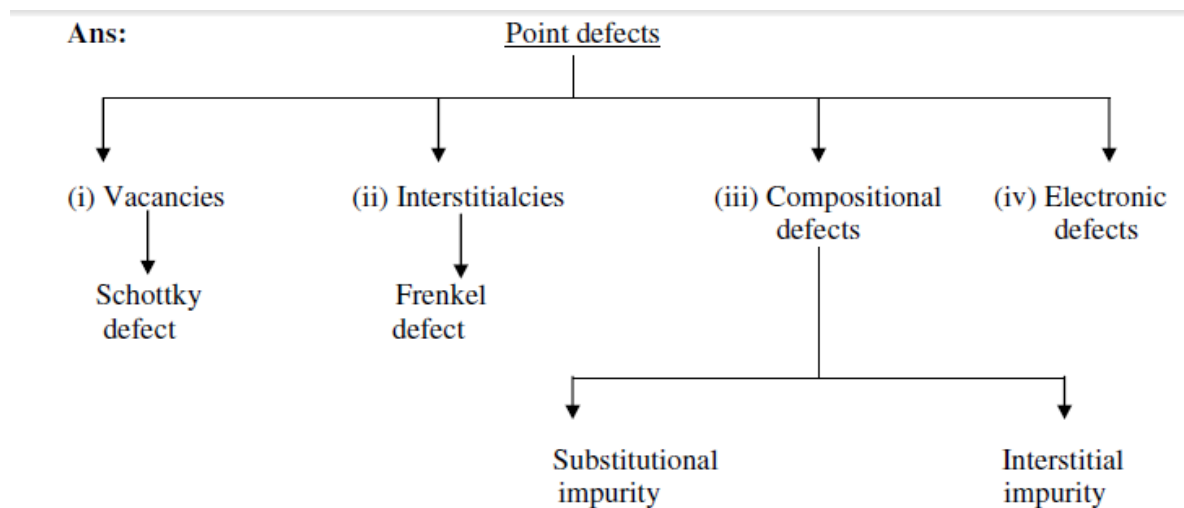
(iv) Smallest set of integral numbers  
of the above reciprocals:      $3 \times 1$       $3 \times 2$       $3 \times \frac{1}{3}$   
3     6     1

Thus the Miller indices of the plane is (3 6 1.) as shown in the figure.



**Q.3** a. What are different types of point defects and how are they caused?

**Answer:**



- (i) Vacancies: This refers to a missing atom or a vacant atomic site due to absence of a matrix atom.  
Missing of one cation and one anion ion in an ionic crystal is called Schottky imperfection. Electrical neutrality is maintained in this type of imperfection which is observed in alkali halides.
- (ii) Interstitialcies: An extra atom (substantially smaller than the parent atoms) enters the interstitial void or space between the regularly positioned atoms. The vacancy and interstitialcy are, therefore, inverse phenomena.  
Displacement of cation ions from a lattice site into the void space is called Frankel imperfection and this results in creation of vacancy. An imperfection does not affect the overall electrical neutrality of the crystal.

Compositional defect:

- (iii) Substitutional impurity: Presence of foreign atom in place of a matrix atom is called substitutional impurity.  
If a foreign atom occupies a vacant position within the crystal lattice, this defect is known as interstitial impurity.
- (iv) Electronic defects: Errors in charge distribution in solids are termed as electronic defects. There is departure from the normal regularity of charge distribution. This effect is responsible for the operation of p-n junction and transistors.

The point defects formed by

- (i) thermal fluctuations during preparation of crystals.
- (ii) Quenching (quick cooling) from a higher temperature
- (iii) Severe deformation like hammering or rolling.
- (iv) External bombardment by atoms or high energy particles (e.g. cyclotron or nuclear reactor).

- b. Explain in detail the ionic and metallic bonds observed in materials with an example.

**Answer:**

For two – component systems, the degree of freedom can be calculated by the modified phase rule given as:

$$F = C - P + 2$$

And the total number of variables can be calculated by:

$$P(C-1) + 2 \text{ Therefore,}$$

<u>No. of Phases</u>	<u>Total Variables</u>	<u>Degree of freedom</u>
1	3	3
2	4	2
3	5	1
4	6	0

The System cannot have more than four phases in equilibrium.

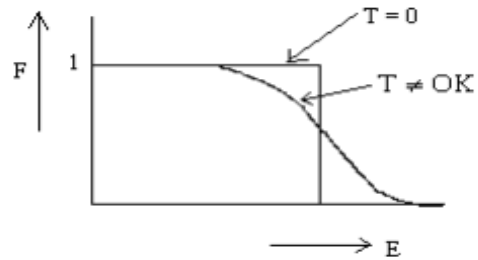
- Q.4 a. The Fermi level for potassium is 2.1eV. Calculate the velocity of the electrons at the Fermi level. Show that the probability of occupancy of energy level E by an electron is 50% for  $E = E_F$  at temperature ( $T \neq 0^{\circ}\text{K}$ ).

Answer:

$$\begin{aligned} \frac{1}{2} * m * v^2 &= 2.1 \text{ eV} \\ \frac{1}{2} * 9.1 * 10^{-31} * v^2 &= 2.1 * 1.6 * 10^{-19} \\ \text{Therefore, } v^2 &= .738 * 10^{12} \\ \text{And so, } v &= .859 * 10^6 \text{ m/sec} \end{aligned}$$

$$F = \frac{1}{1 + e^{\frac{E - E_F}{kT}}}$$

$$\text{At } E = E_F, T \neq 0, F = \frac{1}{2} = 50\% .$$



- b. How do temperature and impurities affect electrical resistivity of metals.

Answer:

Temperature effect on resistivity:

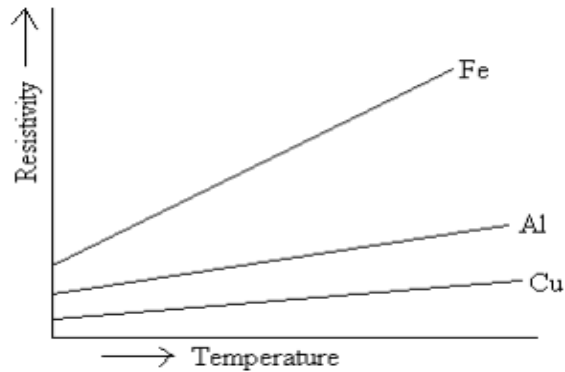
Any increase in temperature of a conductor increases thermal agitation of the metallic ions as they vibrate about their mean positions. This reduces the mean free path and restricts the flow of electrons, thus reducing the conductivity of the material and increasing its resistivity

$$P_t = P_{20} [1 + \alpha_0 (t - 20)]$$

$P_t$  → resistivity at temperature

$P_{20}$  → resistivity at 20° c.

$\alpha_0$  → coefficient of temperature which is positive.



Effect of impurities on resistivity:

A small percentage of impurities can result in significant increase in resistivity i.e. decrease in the conductivity.

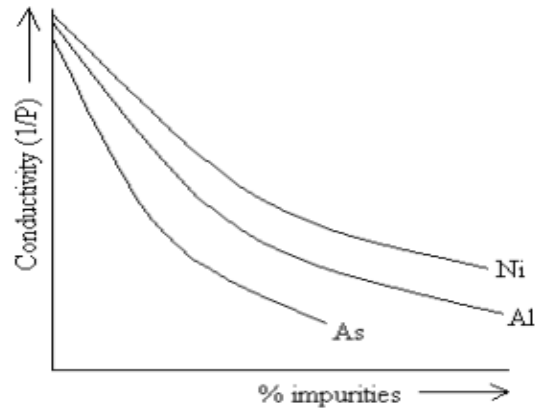
Mathematically, it can be represented as

$$P_{\text{alloy}} = P_{\text{metal}} + Y P_i$$

where  $P_{\text{alloy}}$  → resistivity of alloy.

$P_{\text{metal}}$  → resistivity of parent metal

$P_i$  → resistivity of impurity added



**Q.5** a. What is piezoelectricity? What are the different applications in which piezoelectricity is used. Describe materials that show piezoelectricity.

**Answer:**

**Piezoelectricity:** Piezoelectricity provides us a means of converting electrical energy to assume new geometric positions and the mechanical dimensions of the substance are altered. This phenomenon is called electrostriction. The reverse effect i.e. production of polarization by the application of mechanical stresses can take place only if the lattice has no center of symmetry, this phenomenon is known as piezoelectricity. Example – Rochelle salt, Quartz, Barium titante.

**Applications:** Piezoelectric materials serve as a source of ultrasonic waves. At sea, they may be used to measure depth, distance of shore, position of icebergs, submarines. They are also used in microphones, phonograph pickups, and strain gauges.

b. Explain the properties of common dielectric materials. Write the application area of these dielectric materials.

**Answer:**

A dielectric material is a substance that is a poor conductor of electricity, but an efficient supporter of electrostatic field. In practice, most dielectric materials are solid. Examples include porcelain (ceramic), mica, glass, plastics, and the oxides of various metals. Some liquids and gases can serve as good dielectric materials. Dry air is an excellent dielectric, and is used in variable capacitors and some types of transmission lines. Distilled water is a fair dielectric. A vacuum is an exceptionally efficient dielectric.

An important property of a dielectric is its ability to support an electrostatic field while dissipating minimal energy in the form of heat. The lower the dielectric loss (the proportion of energy lost as heat), the more effective is a dielectric material. Another consideration is the dielectric constant, the extent to which a substance concentrates the electrostatic lines of flux. Substances with a low dielectric constant include a perfect vacuum, dry air, and most pure, dry gases such as helium and nitrogen. Materials with moderate dielectric constants include ceramics, distilled water, paper, mica, polyethylene, and glass. Metal oxides, in general, have high dielectric constants. The prime asset of high-dielectric-constant substances, such as aluminium oxide, is the fact that they make possible the manufacture of high-value capacitors with small physical volume. But these materials are generally not able to withstand electrostatic fields as intense as low dielectric-constant substances such as air. If the voltage across a dielectric material becomes too great -- that is, if the electrostatic field becomes too intense -- the material will suddenly begin to conduct current. This phenomenon is called dielectric breakdown. In components that use gases or liquids as the dielectric medium, this condition reverses itself if the voltage decreases below the critical point. But in components containing solid dielectrics, dielectric breakdown usually results in permanent damage.

- Q.6** a. Qualitatively explain, the domain theory of ferromagnetic materials. Explain how are the domains formed and are affected by temperature changes?

**Answer:**

The long range order which creates magnetic domains in ferromagnetic materials arises from a quantum mechanical interaction at the atomic level. This interaction is remarkable in that it locks the magnetic moments of neighbouring atoms into a rigid parallel order over a large number of atoms in spite of the thermal agitation which tends to randomize any atomic level order. Sizes of domains range from a 0.1 mm to a few mm. When an external magnetic field is applied, the domains already aligned in the direction of this field grow at the expense of their neighbours. If all the spins were aligned in a piece of iron, the field would be about 2.1 Tesla. A magnetic field of about 1 T can be produced in annealed iron with an external field of about 0.0002 T, a multiplication of the external field by a factor of 5000! For a given ferromagnetic material the long range order abruptly disappears at a certain temperature which

is called the Curie temperature for the material. The Curie temperature of iron is about 1043 K.

- b. Explain the significance of hysteresis. Sketch a neat representation of hysteresis loop for a –
- (i) Transformer core.
  - (ii) Strong electromagnet.
  - (iii) Magnetic tape.

**Answer:**

Hysteresis is well known in ferromagnetic materials. When an external magnetic field is

applied to a Ferro magnet, the atomic dipoles align themselves with the external field. Even when the external field is removed, part of the alignment will be retained: the material has become magnetized.

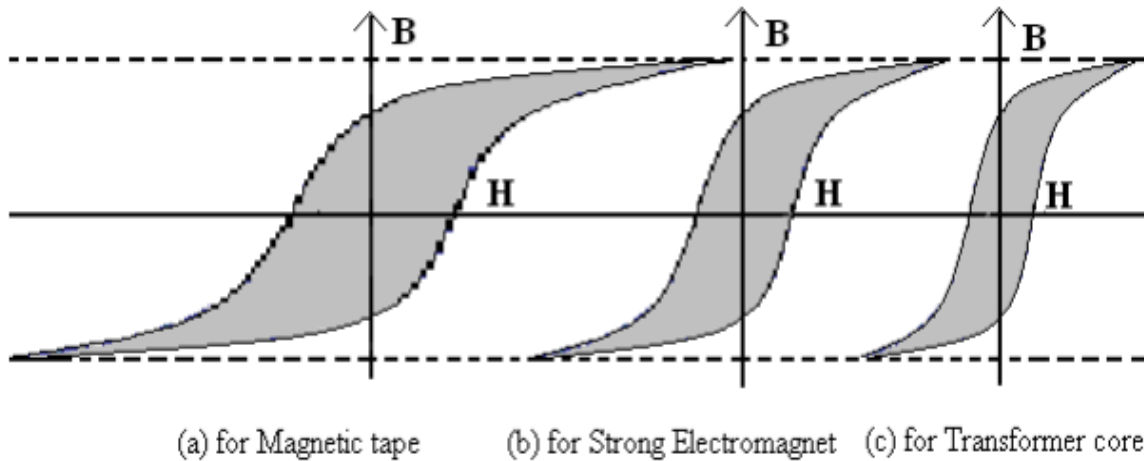
The relationship between magnetic field strength (H) and magnetic flux density (B) is not linear in such materials. If the relationship between the two is plotted for increasing levels of field strength, it will follow a curve up to a point where further increases in magnetic field strength will result in no further change in flux density. This condition is called magnetic saturation.

If the magnetic field is now reduced linearly, the plotted relationship will follow a different curve back towards zero field strength at which point it will be offset from the original curve by an amount called the remanent flux density or remanence.

If this relationship is plotted for all strengths of applied magnetic field, the result is a sort of S-shaped loop. The 'thickness' of the middle bit of the S describes the amount of hysteresis, related to the coercivity of the material.

Hysteresis signifies the lagging of magnetization or induction flux density (B) behind the magnetizing force (H) or it is that quality of a magnetic substance due to which energy is dissipated in it on the reversal of its magnetism. The hysteresis loop equals the work which is necessary to reverse the direction of magnetization





- Q.7** a. With respect to semiconducting materials explain with suitable diagrams the atomic model of diffusion. How does drift current differ from diffusion current? What is Einstein's relationship?

**Answer:**

Diffusion occurs as a result of repeated jumps of atoms from their sites to other neighboring sites. Even when atoms jump randomly, a net mass flow can occur down a concentration gradient, when a large number of such jumps take place.

The Unit step in the diffusion process is a single jump by the diffusing species. Diffusion could be of various types. In Interstitial diffusion, the solute atoms which are small enough to occupy interstitial sites, diffuse by jumping from one interstitial site to another and in Vacancy diffusion, atoms diffuse by interchanging positions with neighboring vacant sites.



*Fig: Vacancy & Interstitial diffusion.*

Einstein's relationship:  $\frac{\mu}{D} = \frac{e}{kT}$  where  $\mu$  and  $D$  are mobility and diffusion coefficient for a charge carrier (hole or electron).

Drift current is the electric current, or movement of charge carriers, which is due to the applied electric field, often stated as the electromotive force over a given distance. It is distinguished from thermally-induced Diffusion current, which results from the random Brownian motion of charge carriers independent of electrical stimulus.

- b. In a semiconductor the effective mass of an electron is  $0.07 m_0$  and that of a hole is  $0.4 m_0$ , where  $m_0$  is free electron mass. Assuming that the average relaxation time for the holes is half that for the electrons. Calculate the mobility of the holes when the mobility of the electrons is  $0.8 \text{ m}^2 \text{ volt}^{-1} \text{ sec}^{-1}$

**Answer:**

The general expression for mobility is,

$$\mu = \frac{e\tau}{m} \quad \text{i.e.} \quad \mu_n = \frac{e\tau_n}{m_e^*} \quad \text{for electrons}$$

$$\& \quad \mu_h = \frac{e\tau_h}{m_h^*} \quad \text{for holes.}$$

$$\frac{\mu_h}{\mu_n} = \frac{\tau_h m_e^*}{m_h^* \tau_n} = \frac{1}{2} \times \frac{0.07}{0.4}$$

$$\text{or, } \mu_h = \frac{0.8}{2} \times \frac{0.07}{0.4}$$

$$\text{or, } \mu_h = 0.07 \text{ m}^2 \text{ v}^{-1} \text{ s}^{-1}.$$

- Q.8** a. Explain the term 'depletion layer' across a p-n junction in a semiconducting device. Discuss how P-N junction functions as a rectifier.

**Answer:**

The rectifying action of p-n diode can be explained on the basis of the electronic structure of the semiconductor. When a pure semiconductor is doped to become n-type, the Fermi level shifts up from the middle of the energy gap towards the donor level. This is so because the position corresponding to 50% probability of occupation moves up due to the relatively high concentration of donor electrons in the conduction band. If the crystal is p-type, the Fermi level shifts down towards the acceptor level. When the same crystal is doped to become n-type on one side and p-type on the other side, the Fermi level has to be constant throughout the crystal in thermal equilibrium. This results in the electron energy levels at the bottom of the conduction band in the n-part to be lower than those in the p-part, by an amount equal to the contact potential  $eV_0$  as shown in Fig a. The contact potential at the junction gives rise to energy barrier or depletion layer.

Fig.

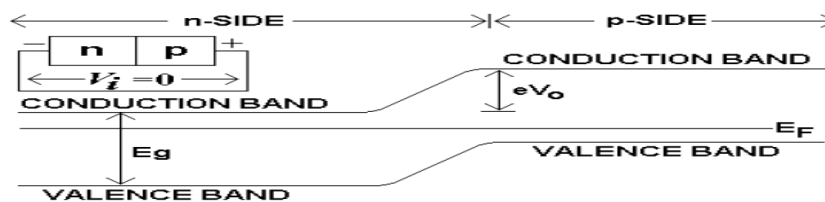


Fig. a

At equilibrium, there is no net current flowing across the p-n junction. The concentration of electrons in the conduction band in the conduction band on the p-side is small. These electrons can accelerate down the potential hill across the junction to the n-side resulting in a current  $I_0$ , which is proportional to their number. The concentration of electrons in the conduction band on the n-side is large in comparison, due to the donor contribution. However, only a small number of these electrons can flow to the p-side across the junction as they face a potential barrier.

If an external voltage  $V_i$  is now applied to the crystal such that the p-side becomes positive with respect to the n-side the electron energy levels will change as shown in Fig b. The barrier at the junction is now lowered by an amount  $eV_i$  resulting in a greatly enhanced current flow in the forward direction that is from the n-side to p-side. This change in barrier does not affect the flow of electrons in the reverse direction, from the p-side to the n-side, as the flow here is still down the potential hill. So the applied voltage causes a large net current flow in the forward direction. If an external voltage  $V_i$  is applied in the reverse direction the potential barrier for electrons at the junction is increased by an amount  $eV_i$  as shown in Fig.c.

This would drastically reduce the current flow from the n-side to p-side. It is seen that the forward current increases exponentially and the reverse current remains a constant at a small value. This characteristic explains how a p-n junction can act as a rectifier.

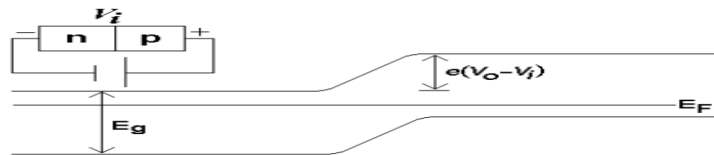


Fig. b FORWARD BIAS

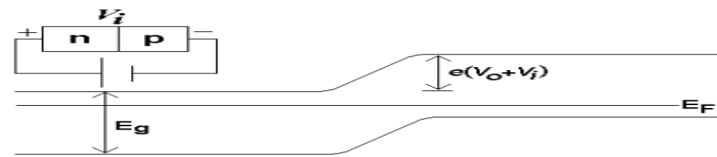


Fig. c REVERSE BIAS

b. Discuss the properties and application area of the following materials-

(i) Ceramic

(ii) Mica

**Answer:**

(i) Properties of Bakelite

Bakelite is a material based on the thermosetting phenol formaldehyde resin. Formed by the reaction under heat and pressure of phenol (a toxic, colourless crystalline solid) and formaldehyde (a simple organic compound), generally with a wood flour filler, it was the first plastic made from synthetic components. It was used for its electrically nonconductive and heat-resistant properties in radio and telephone casings and electrical

insulators, and was also used in such diverse products as kitchenware, jewellery, pipe stems, and children's toys.

Today, Bakelite is manufactured and produced in the form of sheets, rods and tubes for hundreds of industrial applications in the electronics, power generation and aerospace industries, and under a variety of commercial brand names, including Garolite.

Bakelite sheet is a hard, dense material made by applying heat and pressure to layers of paper or glass cloth impregnated with synthetic resin. These layers of laminations are usually of cellulose paper, cotton fabrics, synthetic yarn fabrics, glass fabrics or unwoven fabrics. When heat and pressure are applied to the layers, a chemical reaction (polymerization) transforms the layers into a high-pressure thermosetting industrial laminated plastic. When rubbed, original Bakelite has a telltale odor.

#### Applications and usage

Although not extensively used as an industrial manufacturing material any more, in the past Bakelite was used in myriad applications, such as saxophone mouthpieces, cameras, solid body electric guitars, rotary-dial telephones, early machine guns, and appliance casings. It was at one point considered for the manufacture of coins, due to a shortage of traditional manufacturing material.

#### (ii) Properties and uses of MICA

Mica has a high dielectric strength and excellent chemical stability, making it a favoured material for manufacturing capacitors for radio frequency applications. It has also been used as an insulator in high voltage electrical equipment. It is also birefringent and is commonly used to make quarter and a half wave plates. Because mica is resistant to heat it is used instead of glass in windows for stoves and kerosene heaters. It is also used to separate electrical conductors in cables that are designed to have a fire-resistance rating in order to provide circuit integrity. The idea is to keep the metal conductors away from fusing in order to prevent a short-circuit so that the cables remain operational during a fire, which can be important for applications such as emergency lighting. Illites or clay micas have a low cation exchange capacity for 2:1 clays.  $K^+$  ions between layers of mica prevent swelling by blocking water molecules. Aventurine is a variety of quartz with mica inclusions used as a gemstone. Pressed Mica sheets are often used in place of glass in greenhouses. Muscovite mica is the most common substrate for sample preparation for the atomic force microscope. Some brands of

toothpaste include powdered white mica. This acts as a mild abrasive to aid polishing of the tooth surface, and also adds a cosmetically-pleasing glittery shimmer to the paste. The shimmer from mica is also used in makeup, as it gives a translucent "glow" to the skin or helps to mask imperfections. Mica sheets are used to provide structure for heating wire (like Kanthal, Nichrome, etc.) in heating elements and can withstand up to 900 °C.

Another use of Mica is in the production of ultra flat thin film surfaces (e.g. gold surfaces) using mica as substrate. Although the deposited film surface is still rough due to deposition kinetics, the back side of the film at mica-film interface provides ultra flatness, when the film is removed from the substrate. Mica slices are used in electronics to provide electric insulation between a heat generating component and the heat sink used to cool it.

**Q.9** a. For an n- channel silicon FET with  $a = 3 \times 10^{-4}$  cm (effective channel width) and  $N_D = 10^{15}$  electron/cm<sup>3</sup>. Find:

(1) pinch of voltage

(2) the channel half width for  $V_{GS} = 1/2V_P$  and  $I_D = 0$ .

**Answer:**

**Solution**

$$\begin{aligned} \text{(a)} \quad V_P &= \frac{e N_D}{2\epsilon} a^2 \\ &= \frac{1.6 \times 10^{-19} \times 10^{15} \times (3 \times 10^{-4})^2}{2 \times 12 \times (36\pi \times 10^{11})^{-1}} \\ &= 6.8 \text{V} \end{aligned}$$

$$\begin{aligned} \text{(b)} \quad b &= ? \text{ for } V_{GS} = \frac{V_P}{2}, \\ b &= a \left[ 1 - \left( \frac{V_{GS}}{V_P} \right)^2 \right] \\ &= (3 \times 10^{-4}) \left( 1 - \left( \frac{1}{2} \right)^2 \right) \\ &= 0.87 \times 10^{-4} \text{cm} \end{aligned}$$

b. Write short notes on:

1. Grown junction
2. Zone refining.

**Answer:**

(1) Zone refining is a method of separation by melting in which a molten zone traverses a long ingot of impure metal or chemical. In its common use for purification, the molten region

melts impure solid at its forward edge and leaves a wake of purer material solidified behind it

as it moves through the ingot. The impurities concentrate in the melt, and are moved to one

end of the ingot. Zone refining was developed by William Gardner Pfann in Bell Labs as a method to prepare high purity materials for manufacturing transistors. Its early use was on germanium for this purpose, but it can be extended to virtually any solute-solvent system having an appreciable concentration difference between solid and liquid phases at equilibrium.

This process is also known as the Float zone process, particularly in semiconductor materials processing.

In zone refining, solutes are segregated at one end of the ingot in order to purify the remainder, or to concentrate the impurities for analytical or other purposes. In zone leveling, the objective is to distribute solute evenly throughout the purified material, which may be sought in the form of a single crystal. For example, in the preparation of a transistor or a semiconductor diode, an ingot of germanium is first purified by zone refining. Then a small amount of antimony is placed in the molten zone, which is passed through the pure germanium. With the proper choice of rate of heating and other variables, the antimony can be spread evenly through the germanium. This technique is also used for the preparation of silicon for use in computer chips

### **Super Conductivity**

A large number of metals become superconducting below a temperature, which is characteristic of the particular metal. The metals which are very good conductors at room temperature e.g. Cu, Ag, and Au do not exhibit superconducting properties, whereas metals

and compounds which superconducting are rather bad conductors at ordinary temperatures.

Monovalent metal and ferromagnetic and anti ferromagnetic metals are not superconducting.

The transition temperature of superconductor varies with the isotopic mass, showing that super conductivity may be the result of interactions between electrons and lattice vibrations

.The resistivity of a superconductor is zero. At the same time it has been observed that the magnetic flux density  $B$  though such a substance also vanishes.

**Effect of magnetic field on superconductors:**

It is possible to destroy superconductivity by the application of a strong magnetic field. When the magnetic field exceeds a certain critical value, the superconducting state disappears, the magnetic field penetrates the material and the electrical resistance is restored.

The transition from the superconducting to the conducting state is reversible. The critical magnetic field  $H_c$  is a function of temperature  $T$ .

The disappearance of superconductivity by means of a strong magnetic field is the principle

on which switching elements like the cryotrons operate. Superconductors are used for producing a magnetic field of about 50 teals.

**Application of superconductors in Electrical and Electronic Engineering**

(i) The most important application of superconductor is the exploitation of zero electrical resistance. By making current carrying conductors superconducting, losses due to the

resistance of wire which carry electrical power over a long distance through transmission lines, would be eliminated.

(ii) In production of very powerful magnets

(iii) With the invent of high temperature superconducting materials, superconducting magnets find application in many areas like magnetic resonance Imaging (medical diagnose and spectroscopy) ore refining, magnetic shielding and in magnetic levitation high speed trains

(iv) In electronic engineering there are two areas in which superconducting properties can be advantageously used viz in chip interconnections and in electronics gates.