Q 2 (a) Explain the electron gas model of a metal.

Answer **The electron gas model of a metal**

The mechanism inside a current carrying conductor can be explained by the kinetic theory of gases. This is referred to as the electron gas theory of gases. The valance electrons are supposed to be completely detached from the atoms. The basis for the electron gas theory is the picture of a conductor as a lattice (regular arrangement which remains fixed) of positive ions, through which an electron cloud or gas can move. The number of electrons in such a gas is equal to the number of valance electrons. If for the mono-valent metals one assumes that the number of free electrons in a given volume is equal to the number of atoms in the same volume, the former can be found by knowing the Avogadro's number. When not affected by external electric fields the valance electrons oscillate equally in all directions among the atoms just like the molecules in a gas. The statistics of this random electron velocity will be analogous to the statistics of the molecular motion in a gas.

In the absence of an electric field, the random velocities of the electrons will be determined by the temperature of the conductor. The temperature of the electrons need not be the same as that of the conductor. This temperature is a measure of kinetic energy of the electron.

Q 2 (b) Explain the term superconductivity. Mention its applications in electrical and electronic engineering.

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

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.

Q 3 Explain the phenomena of polarization. What are the different types of polarization?

Answer

Polarization:

A dielectric consists of molecules the atomic nuclei of which are effectively fixed, relative to each other. In the absence of any external field the electrons are distributed symmetrically round the nucleus at any instant. When an electric field is applied the electrons of the atoms are acted upon by this field. This causes a movement of the electrons which are displaced in a direction opposite to that of the electrons which are displaced in a direction opposite to that of the field. This movement is opposed by the attractive forces between nuclei and electrons. The resultant effect is to separate the positive & negative charges in each molecule so that they behave like electric dipoles. The strength of each dipole is given by the dipole moment, which in its simplest form, consists of two equal point charges of opposite sign $\pm Q$ separated, by a distance d.

When the dipoles are created the dielectric is said to be polarized or in a state of polarization considers the dielectric to be composed of a large number of elementary cylinders each of length l in the direction of the applied field and of cross section δA. Let a uniform field of strength E be applied normal to the plates. This polarizes the dielectric inducing dipoles in each elementary cylinder, and charges δq appears on either end of the cylinder. The charge density, σ on the the surface δA of the cylinder is given by

$$\sigma = \frac{\delta q}{\delta A}\left(\frac{c}{m^2}\right) = l\frac{\delta q}{\delta A} = \frac{m}{\delta V}$$

Where m is the dipole moment and δV is the volume of the elementary cylinder. If the number of dipoles per unit volume be N i.e. if $N = \frac{I}{\delta V}$ then σ =Nm. The product Nm is called the polarization (P) of the dielectric and is the total dipole moment established within unit volumes of the insulating medium. Thus a dielectric subject to a homogeneous field carries a dipole moment P per unit volumes which may be written as

$$P=Nm.$$

Polarization are of three types.

(i) Electric polarization
(ii) Ionic polarization.
(iii) Dipolar polarization.

Electric polarization or polarization density is the vector field that expresses the density of permanent or induced electric dipole moments in a dielectric material. The SI unit of measure is coulombs per square metre.

The electric polarization **P** is defined as the difference between the electric fields **D** (induced) and **E** (imposed) in a dielectric due to bound and free charges, respectively. In cgs, $p = \frac{D - E}{4\pi}$ which can be written in terms of the electric susceptibility(χ_e) as $P = \chi_e E$

In MKS, $P = \in_0 \chi_e E$

where $\in_0$ is the permittivity of free space.

Ionic polarization is polarization which is caused by relative displacements between positive and negative ions in ionic crystals (for example, NaCl).

If crystals or molecules do not consist of only atoms of the same kind, the distribution of charges around an atom in the crystals or molecules leans to positive or negative. As a result, when lattice vibrations or molecular vibrations induce relative displacements of the atoms, the centers of positive and negative charges might be in different locations. These center positions are affected by the symmetry of the displacements. When the centers don't correspond, polarizations arise in molecules or crystals. This polarization is called **ionic polarization**.

Ionic polarization causes ferroelectric transition as well as dipolar polarization. The transition which is caused by the order of the directional orientations of permanent dipoles along a particular direction is called **order-disorder phase transition**. The transition which is caused by ionic polarizations in crystals is called **displacive phase transition**

Dipolar polarization is a polarization that is particular to polar molecules. This polarization results from permanent dipoles, which retain polarization in the absence of an external electric field. The assembly of these dipoles forms a macroscopic polarization.

When an external electric field is applied, the distance between charges, which is related to chemical bonding, remains constant in the polarization; however, the polarization itself rotates. Because this rotation completes not instantaeously but in the delay time τ, which depends on the torque and the surrounding local viscosity of the molecules, dipolar polarizations lose the response to electric fields at the lowest frequency in polarizations. The delay of the response to the change of the electric field causes friction and heat

Q 4 (a) What are the important requirements of good insulating material? Give two examples and their uses.

Answer

<u>Important requirements of good insulating materials:-</u>

The requirement of good insulating materials can be classified as electrical, mechanical, thermal and chemical. Electrically the insulating materials should have high resistivity to reduce the leakage current and high dielectric strength to enable it to with stand higher voltage with out being punctured or broken down. Also the insulator should have small dielectric loss.

Insulators should have low density; a uniform viscosity for liquid insulators ensures uniform thermal and electrical properties.

Liquid and gaseous insulators are used also as coolants. For example, transformer oil, Hydrogen and Helium are used for both insulation and cooling purposes. For such materials, good thermal conductivity is desirable. The insulators should also have small thermal expansion to prevent mechanical damage. It should be none ignitable or if ignitable, it should be self-extinguishable.

Chemically, the insulators should be resistance to oils, liquids, gas fumes, acids and alkalis. It should not deteriorate by the action of chemicals in soils or by contact with other metals. The insulators should not absorb water particles, since water lowers the insulation resistance and the dielectric strength.

Insulating materials should have certain mechanical properties depending on the use to which they are put. Thus when used for electric machine insulation the insulator should have sufficient mechanical strength to withstand vibration. Good heat conducting property is also desirable in such cases. Example of insulating materials are mica & porcelain. Mica sheets are used for the insulating leaves between commutator segments.

Porcelain insulators are used for transmission line insulators, conductor, rail support on railways etc.

Q 4 (b) What is piezo electricity? Explain.

Answer

<u>Piezoelectricity</u>

When an electric field is applied to a substance it become polarized, the electrons and nuclei assume new geometric positions and the mechanical dimensions of the substance are altered. The 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 centre of symmetry, the phenomenon being known as piezoelectricity.

Examples of Piezoelectric materials:-

Rochelle salt, quartz and $BaTi0_3$ exhibit piezoelectric properties. The change in crystal dimensions under the action of an electric field differs for different directions with respect to the crystals axis of symmetry. Therefore, different deformations will be obtained from a crystal of rods and plates having different orientation are cut from the crystal and placed between the condenser plates.

Application of piezoelectric materials:-Piezoelectric materials serve as a source of ultra sonic waves. At sea, they may be used to measure depth, the distance to shore, the position of icebergs, submarines and the like.

Q5 (b) What are permanent magnet materials? Explain

Answer

Material for making permanent magnets

For permanent magnets "hard" magnetic materials, which have high remanence, are usually prefer. Silicon iron and nickel iron alloys are unsuitable for making permanent magnets because of the narrow hystereses loop of these material.

Materials in which carbon has been deliberately added give a hysterises loop which embrace maximum possible area. Such materials were the earliest ones the be used for permanent magnets because of their large retentivity and coercivitly. The manufacture of permanent magnet steel which are now used is a very specialized process. Tungsten is an important constricting of such steels.

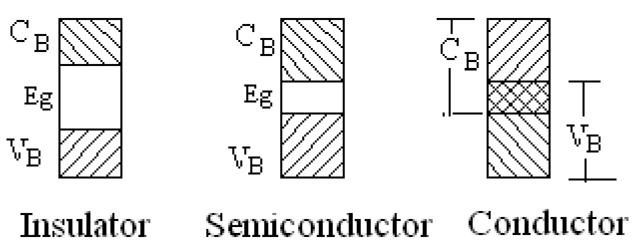
Many other alloys having high coercivity have been made in the laboratory. These include alloys of iron and platinum, Cobalt and platinum etc.

Q6 (a) Distinguish between conductor, semiconductor and insulators with the help of energy band-diagram.

Answer

<u>Difference between conductor , semiconductor and insulator.</u>

With reference to different band structures shown in fig. below we can broadly divide solid into conductors, semiconductors, and insulators. Conductors contain a large number of electrons in the conduction band at room temperature. No energy gaps exist and the valence and conduction bands overlap.



Insulator is a material in which the energy gap is so large that practically no electron can be given enough energy to jump this gap.

These materials might conduct little electricity if their temperature are raised to very high values enabling a number of electrons to join the conduction band. A semiconductor is a solid with a energy gap small enough for electron to cross easily from the valence band to the conduction band. At room temperature sufficient energy is available for a valence

electrons to bridge the energy gap to the conduction band, thus the material sustains some electric current.
The energy distribution of electrons in a solid are governed by the laws of Fermi – Dirac statistics.
The Fermi level is such that at any temperature, the number of electrons with greater energy than the Fermi energy is equal to the number of unoccupied energy levels lower than this. In conductors, the Fermi level is situated in a permitted band (since the valence band and conduction band overlap with no energy gap.). In insulators, it lies in the centre of the large energy gap while in semiconductors it lies in the relatively small energy gap.

Semiconductors are of two types:

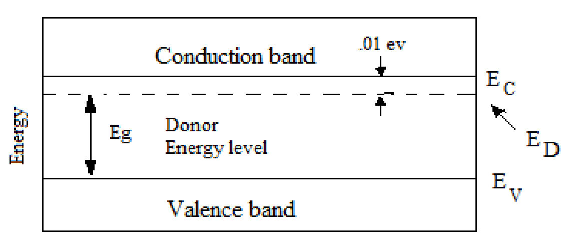
i. Intrinsic semiconductors:

An intrinsic semiconductor is one which is made of the semiconductor material in its extremely pure form.
In a semiconductor the energy gap is so small that even at ordinary room temperature, there are many electrons which posses sufficient energy to jump across the small energy gap from the valence to the conduction band. However , when each electron gets liberated into conduction band , a positively charge hole is created in the valence band, when an electric field is applied to intrinsic semiconductor at a temperature greater than 0^0K, conduction electrons move to the anode and the holes in the valence band move to the cathode. Hence semiconductor current consists of movement of electrons and holes in opposite direction.

ii. Extrensic semiconductor :

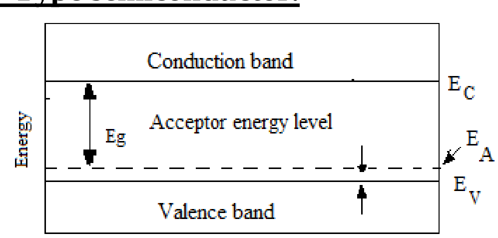
Those intrinsic semiconductors to which some suitable impurity or doping agent is added in extremely small amount are called extrinsic semiconductors. Usually the doping agents are pentavalent. Antimony, arsenic atoms or trivalent atom (gallium, aluminium, boron).
Pentavalent doping atom is known as donor atom because it donates or contributes one electron to the conduction band of pure germanium. Trivalent doping atom known as accepter atom because it accepts one electron from the germanium atom.
Depending upon the impurity added, extrinsic semiconductors can be further subdivided into two classes:

<u>N-type semiconductor.</u>



Energy band diagram of n-type semiconductors

<u>P- Type semiconductor.</u>



Energy band diagram of p-type semiconductors

-

If to pure germanium, a small amount of pentavalent impurity i.e. antimony is added.Four of the five valence electrons will occupy covalent bonds, and the fifth will be nominally unbound and will be available as a carrier of current. These are called N-type semiconductor.

In this type of semiconductor electron are the majority carriers.

If a trivalent impurity such as boron, Gallilium etc. is added to an intrinsic semiconductor, only three of the covalent bonds can be filled, and the vacancy that exists in the fourth bond constitutes a hole. These are called P type semiconductor in which holes are the majority carriers.

Q6 (b) Explain Einstein's relation between diffusion constant and mobility.

Answer

Einstein relation:

There exists an important relation between the diffusion constant and the mobility. This is known as the Einstein relation and may be deduced as follows:

Consider a semiconductor in which there exists an electric field E_x and a concentration gradient such that the current is zero. Under these conditions the system is in thermal equilibrium and the Boltzmann statistics applies. Consider a potential V(x) producing at x an electric field E(x)= -dV/dx.

The Boltzmann expression for the density of holes as a function of x in thermal equilibrium is $p(x)= Ce^{-eV/KT}$

Where C is a constant.

The gradient gradient of the hole density is therefore given by

$$dp/dx = (-e/KT)p.(dv/dx)$$
$$= (e/KT)p.E$$

The hole current vanishes in thermal equilibrium.

Therefore,

$$O=peu_p\, E_x-eD_p\ dp/dx$$
$$=peu_p\, E_x-(e^2/KT)D_p\ .\ Ex$$
$$Dp = (KT/e)\ Up \text{ (The Einstein relation)}$$

Mobility: Average drift velocity of the electrons in an applied field is proportional to the field, the absolute magnitude of the proportionality factor eq/m, called the mobility of the electrons, which is denoted by μ. The mobility may thus be defined as the magnitude of the average drift velocity per unit field.

The mobility of the electrons can be determined by knowing the conductivity of the material and estimating the number of free electrons. Unit of mobility is m^2/volt.sec.

Diffusion: Although the mobility of the carriers in a semiconductor is greater than that of the electrons in a metal, the conductivity in the former is much less than that in the latter because of the too few current carriers. The conductivity is so less that the random movement of the carriers due to unequal carrier densities plays a greater part in conduction than the drift due to the applied fields. Diffusion arises essentially from density difference and the resulting current are called diffusion currents .

The defining equation for diffusion currents in one direction are

$J_n = eD_n \frac{\partial n}{\partial x}$ for electrons

$J_P = -eD_P \frac{\partial P}{\partial x}$ for holes

Where J_n = diffusion current density of electrons

J_P = diffusion current density of holes

D_n =diffusion constant of electron

D_P = diffusion constant of holes

$\frac{\partial n}{\partial x}$ = gradient of electron density

$\frac{\partial P}{\partial x}$ =gradient of hole density.

Therefore, the diffusion current due to the random motion of carriers from the dense to the less dense regions is proportional to the gradient or rate of increase of carrier density with distance.

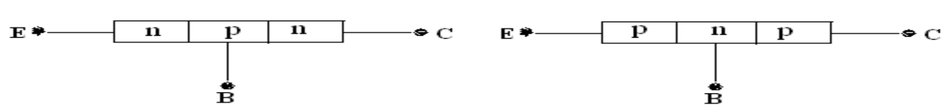
The coefficient of proportionality is called the diffusion constant and is denoted by D.

Q7 (b) What is junction transistor? Describe in brief working of two types of transistor.

Answer

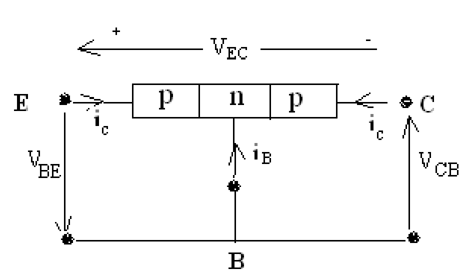
Junction Transistor:

The junction transistor consists of two p-n junctions combined in one crystal as shown in fig. below.

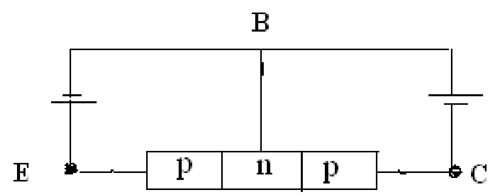


There are two main forms of junction transistors depending upon whether the middle section is on an n material or a p material. The middle sector is called the base and the outer regions are called the emitter and the collector respectively.

The transistor is a 3-terminal device and its properties may be specified in terms of characteristic curves connecting the three currents and the three voltages shown in fig. below.



In a transistor there is zero resultant current of electrons and holes across each junction. If the collector is joined directly to the base and a small positive voltage is applied between emitter and base then a current flows just as in a p-n junction diode in the forward direction. Similarly if the emitter is joined to the base and a negative voltage is applied between collector and base, a current flow in the reverse direction, showing a saturation of collector current.
If these voltages with the same polarity are applied simultaneously as shown in fig. below.



The potential barrier between base and emitter is reduced and the flow of holes across the barrier greatly increased. There is an increased flow of electrons from base to emitter but since the hole density in the p- region is much greater than the electron density in the n-region, the current may be considered to be mainly due to the holes. The holes enter the n-region and diffuse through it, and combine with the electrons in that region since the base region is made sufficiently thin, a large number of holes reach the collector and base junction and very few arrive at the base terminal. At the collector base junction, holes fall easily in to the collector region on account of the field at the junction. Thus the collector current is very nearly equal to the emitter current and the base current is nearly zero. V_{CB} has little effect on the current as long as its magnitude is above some minimum value and the base is sufficiently thin. A small change in V_{EB} causes a change in I_C resulting in an almost equal change in I_C.

Q8 (b) What is a Wire Round Resistor? Describe different types of wire wound resistor in brief?

Answer

Wire -Round Resistors

Wire wound power-type resistors are generally capable of dissipating appreciable amount of power. The resistance (80% nickel and 20% chromium) wire corresponding to the required value of resistance is wound on a ceramic former capable of withstanding thermal shocks. There are 4 main types of constructions:

Open wound

These consist of a simple solenoid winding on a ceramic tube or rod. Some formers have grooves depending on the wire used and expansion expected when dissipating full power. Such resistors are also constructed by a double spiral or coiled coil-process, in which the resistance wire is first helically wound on a braided core of glass fibres or similar material and this in turn is wound on a grooved ceramic rod.

Cement coated

These resistors have a layer of suitable cement to provide mechanical protection.The cement coating, though less expensive, is not moisture proof.

Lacquered
These resistors have a moisture proof layer of lacquer or organic varnish. A temperature limitation of 150 °c limits the maximum voltage.
Vitreous enameled
These resistors have a covering of vitreous enamel over the resistance wire. This provides excellent protection against moisture and ensures good mechanical protection to the wires. Resistors of this type are suitable for use under extreme conditions of temperature and humidity provided the enamel remains ungrazed.

Q9 (a) What are the various methods by which junction are fabricated from pure single crystal semiconductor? Describe any two methods.

Answer
From pure single crystal semi-conductors, junctions are fabricated by one of the following methods-

- Grown junction
- Alloyed junction
- Diffused junction
- Epitaxial diodes

Grown junction: this technique is historically the most important. The first devices were built using this technique. A single crystal is grown from an initially n-type doped melt. After the crystal; has been pulled sufficiently to ensure crystal uniformity, the melt dopant is changed p-type by compensating with an acceptor impurity. The resulting crystal is partly n-type and partly p-type, a junction occurring at the plane of 0 net impurity, as usual. Subsequent cutting of the crystal into discs containing a pn junction can provide material for many individual diodes. The junction formed by this process is usually gradual and must be treated as a graded junction. The difficult with the method is the size location of the junction in the crystal.

Alloyed junction A small n-type single crystal die has a dot of either a pure acceptor metal, such as In or Al or a metal heavily doped with p-type impurities placed on top of it and the unit is heated in a none of the above – oxidizing atmosphere. When the furnace temperature is raised above the melting point of the euitectic alloy formed between the semiconductor and metal, the metal melts and dissolves some of the n-type material forming an alloy.

The thickness of dissolved layer is dependent on temperature and the duration of the process. On cooling, the molten region crystallizes out as a p-type compensated region with the same crystalline structure as the semiconductor. The remainder of the metal forms a convenient ohmic contact; the header to which the n-type chip is soldered forms the other contact the diode.

Text Book

Introduction to Electrical Engineering Materials by C.S. Indulkar and S. Thiruvengadam, 4th Edition, Reprint 2006 Edition, S. Chand and Company, New Delhi