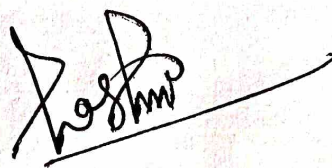


SUBJECT – EEM

BRANCH – ELECTRICAL

SEMISTER – 3rd SEM

PREPARED BY – PRABHAT RASHMI MALLIK

A handwritten signature in black ink, appearing to read 'Prabhat Rashmi', with a long horizontal line extending from the end of the signature.

Lect.(Electrical)

Introduction :-

- ⇒ Materials which are used commercially for conducting electricity can be classed as conducting materials.
- ⇒ Materials which are used for preventing the flow of electricity can be classed as non-conducting or insulating materials.
- ⇒ conducting materials have very low values of resistivity as compared to insulating material.
- conducting materials can further be subdivided into low resistivity and high resistivity materials.

Resistivity and Factors affecting Resistivity :-* Resistivity :-

We know from ohm's Law

$$V = IR$$

where V = value of the voltage between the terminals of a current carrying conductor.

I = current flowing through the conductor.

R = Resistance of the conductor.

The resistance ' R ' of any given material is directly proportional to its length ' l ' and inversely proportional to its cross-sectional area ' a '.

Thus $R \propto \frac{l}{a}$ or $R = \rho \frac{l}{a} \Omega$

Where ' ρ ' = coefficient of proportionality and is called the resistivity or specific resistance of the material.

R = Resistance of the material in Ω ,

ρ = Resistivity of the material in $\Omega\text{-m}$.

a = Area of cross-section of the material in sq-m .

l = Length of the material in metres.

Factors Affecting Resistivity :-

The resistivity of a material is not constant. The factors which affect the value of resistivity of a material are :- Temperature, alloying and mechanical stressing.

(i) Effect of Temperature on Resistivity :-

The most important factor which affects the value of resistivity is the temperature. The resistance of most of the conducting materials increases with temperature.

$\Rightarrow$ The change in resistance of a material per ohm per degree change in temperature is called the "temperature coefficient of resistance" of that material.

The resistance of a conductor changes with temperature according to the Law :-

$$R_t = R_0(1 + \alpha t) \quad \text{--- (1)}$$

Where, R_t & R_0 = The resistances of the conductor at t degrees & zero degree centigrade
 α = Temp. coefficient of resistance.

If the resistance of the same material at any other temp. t_1 degrees centigrade be R_{t_1} , then acc. to expression

$$R_{t_1} = R_0 (1 + \alpha t_1) \quad \text{--- (2)}$$

Dividing expression (2) by expression (1), we get

$$\begin{aligned} \frac{R_{t_1}}{R_t} &= \frac{R_0 (1 + \alpha t_1)}{R_0 (1 + \alpha t)} = \frac{1 + \alpha t_1}{1 + \alpha t} = \frac{1 + \alpha t + \alpha t_1 - \alpha t}{1 + \alpha t} \\ &= \frac{1 + \alpha t}{1 + \alpha t} + \frac{\alpha(t_1 - t)}{1 + \alpha t} \\ &= 1 + \frac{\alpha(t_1 - t)}{1 + \alpha t} \end{aligned}$$

$$\therefore R_{t_1} = R_t \left[1 + \frac{\alpha}{1 + \alpha t} (t_1 - t) \right] \quad \text{--- (3)}$$

This means that the resistance at any temperature t_1 degrees can be calculated if the resistance at t degrees is known. (संज्ञा)

(ii) Effect of alloying on resistivity :-

$\Rightarrow$ Alloying is another factor which affects the resistivity of a material. By adding some impurities (a small % of some other material) to a metal its resistivity can be increased.

$\Rightarrow$ Alloys have higher resistivity than the pure base metal. At the same time, when a metal is alloyed, it also acquires properties like higher mechanical strength which are needed for certain applications.

Ex :- When copper is alloyed with zinc, the alloyed material is called brass (60% copper, 40% zinc).

→ By alloying copper with zinc its resistivity is increased i.e. conductivity is decreased by about 4 times. But the tensile strength of brass is much more than that of copper and therefore may be used for making structural products such as rods, heavy plates, plug points, socket outlets etc.

(ii) Effect of mechanical stressing on Resistivity :-

⇒ The resistivity of a material also changes under the influence of mechanical treatment. The fabrication of conductor from the ingot to the final stage comprise initially hot working & finally cold-working.

⇒ Cold-working operation (stressing) distorts the crystal structure of the metal. This generally tends to harden the material, increase its tensile strength and increase slightly its resistivity. This is useful for overhead conductors.

⇒ Mechanical stressing increases the resistivity & decreases the conductivity.

✓ Classification of conducting materials

Low Resistivity :-

⇒ Low resistivity materials are used in house wiring as conductors for power transmission and distribution, in the winding of transformer and machines like motors and generators.

⇒ Low resistivity materials are used in all such applications where power loss and voltage drop should be low.

→ copper & aluminium are examples of commercially acceptable low resistivity materials. A low resistivity material, besides possessing low value of resistivity, should also possess the following additional properties for reasons mentioned :-

- (a) Low Temp. coefficient :- This means the change of resistance with change in temp. should be low. This is necessary to avoid variation in voltage drop and power loss with changes in temp.
- (b) Sufficient mechanical strength :- The overhead line conductors used for transmission and distribution of electrical power are subject to stresses due to wind and their own weight. The conducting materials used for the windings of T/Fs, motors and generators develop mechanical forces when loaded, which can become very large if a high current flows due to a short ckt.
- (c) Ductility :- It is that property of a material which allows it to be drawn out into a wire. Conductors are required in different sizes and shapes. The conducting material should be ductile enough to enable itself being drawn into different sizes and shapes.

(d) Solderability :- conductors have often to be jointed. The joint should offer minimum contact resistance. A simple joint would be to twist the conductors with the material to which it is to be jointed. But this gives high contact resistance. Minimum contact resistance results if the joint is soldered. (So while selecting conducting material, this point should be kept in view.)

(e) Resistance to corrosion :- The conducting material should be such that it is not corroded when used in out-door atmosphere.

∴ High Resistivity Materials

⇒ High resistivity materials are used for making resistance elements for heating devices, starters for electric motors, resistance used in measuring instruments, rheostats and filaments for lamps.

⇒ High resistivity materials are used in all such applications where a large value of resistance is required.

⇒ If low resistivity materials were used for such application the length of the wire would be too large which would increase to a large extent

the overall size of the equipment.

⇒ A high resistivity material besides possessing high value of resistivity should also possess the following additional properties for reasons mentioned :-

(a) Low Temp. coefficient :- High resistivity materials are often used as shunts in electrical measuring instruments, in making wire-wound resistance. The element should have negligible temp. coefficient of resistance as otherwise the accuracy of measurements will be reduced.

(b) High Melting point :- In applications like rheostats and starters for electrical motors the material of the resistance element should be able to withstand high temp. for a long time without melting. The consideration of high melting point is important for resistance materials used in electrical heating devices like room heaters, furnaces etc.

(c) No tendency for oxidation :- Materials used as high resistance elements in heating appliances should be able to withstand high temperature for a long time without oxidation.

This is because if an oxide layer is formed on the heating element, the amount of heat radiation will reduce.

(d) Ductility : — High resistance materials are required in the shape of very thin wires in the case of precision wire-wound resistors and in the shape of thick wires in the case of the elements used in ovens, heaters, starters, etc.

(e) High Mechanical Strength : — High resistivity materials to be used for applications where the wire must be very thin are required to have high tensile strength as otherwise they may break during the subsequent operation.

Low Resistivity materials and Their Applications:

Copper :-

⇒ Amongst all the conducting materials, copper is most widely used metal because of its high conductivity (i.e. low resistivity).

⇒ Silver has the lowest resistivity but because of its high cost it is not used as a conducting material.

- Properties:
- ⇒ Pure copper is one of the best conductors of electricity and its conductivity is highly sensitive to impurities.
 - ⇒ It is reddish-brown in colour.
 - ⇒ It is malleable and ductile.
 - ⇒ It can be welded at red heat.
 - ⇒ It is highly resistant to corrosion.
 - ⇒ Melting point at 1084°C .
 - ⇒ Electrical resistivity is $1.682 \mu\Omega\text{cm}$.
 - ⇒ Its tensile strength varies from 3-4.7 tonnes/cm².
 - ⇒ It forms important alloys like bronze and gun-metal.

uses: - wires, cables, windings of generators and T/F₂, overhead conductors, busbars etc.

⇒ Hard drawn (cold-drawn) copper conductor is mechanically strong with tensile strength of 40 kg/mm^2 . It is used for overhead line conductors and busbars.

⇒ Annealed copper (soft copper) conductor. It is mechanically weak, tensile strength 20 kg/mm^2 , easily shaped into any form.

⇒ Low - resistivity Hard copper. → It is used in power cables, windings and coils as an insulated conductor. It has high flexibility and high conductivity.

Silver :-

It is best known electrical conductor.

Properties :-

⇒ It is very costly.

⇒ It is not affected by weather changes.

⇒ It is highly ductile and malleable.

⇒ Its resistivity is $165 \mu \Omega \text{ cm}$.

Uses :- used in special contact, high rupturing capacity fuses, radio frequency conducting bodies, leads in valves and instruments.

Gold :-

⇒ Gold is the best known electrical conductor.

⇒ Gold is generally found in veins among rocks and ores of other metal.

⇒ Melting point at 1063°C and boiling point 2700°C

⇒ It is malleable and ductile.

⇒ It is largely used as alloy to make coins and jewellery.

⇒ Its good corrosion resistance property makes it alloy very much useful as contact materials in electrical field.

Aluminium :-

properties :-

- ⇒ pure aluminium has silvery colour and lustre.
- ⇒ It offers high resistance to corrosion. Its electrical conductivity is near to that of copper.
- ⇒ It is ductile and malleable.
- ⇒ Its electrical resistivity is $2.669 \mu\Omega \text{ cm}$ at 20°C .
- ⇒ It is good conductor of heat and electricity.
- ⇒ Its specific gravity is 2.7.
- ⇒ Its melting point is 658°C .
- ⇒ It forms useful alloys with iron, copper, zinc.
- ⇒ It can not be soldered or welded easily.

uses :- overhead transmission line conductor, busbar, ACSR conductor.

Steel :-

- ⇒ Steel contains iron with a small percentage of carbon added to it. ~~From~~ Steel itself is not very strong but when carbon is added it assumes very good mechanical properties.

⇒ With the addition of a small percentage of carbon tensile strength of steel increases but at the same time its ductility decreases.

⇒ Steels are classified as follows :-

Mild steel containing carbon about 0.25%.

Medium " " " " 0.45%.

High carbon " " " " 0.70%.

⇒ The resistivity of steel is 8 to 9 times higher than that of copper. Due to this reason steel is not generally used as conducting material.

⇒ Galvanised steel wires are used as overhead telephone wires and as earth wires.

Stranded conductors :-

⇒ When a single conductor of large cross-section is used, it becomes rigid in construction, and is liable to kinks and breaks while handling.

⇒ To avoid this conductors are made of a no. of thin wires, bunched together, called strands.

⇒ Stranding makes the conductor flexible and eliminates to a large extent the risk of its breaking through the insulation.

> A stranded conductor is made by twisting the wire (strands) together to form layers.

> Generally, stranding is done in opposite directions for successive layers. This means, if the wires of one layer are twisted in left-hand direction, the next layer of wires will be twisted in the right-hand direction and so on.

> A standard stranding consists of 6 wires around 1 wire, then 12 wires around the previous 6, then 18 wires around the 12, then 24 wires around the 18 and so on.

> The no. of layers to be provided will depend upon the no. of wires to be provided.

⇒ Note that the central wire is not counted as a layer

⇒ If 3 stranded wires are put in the centre, 9 wires will be in the 1st layer then 15 wires in the 2nd layer & so on. In each of the above cases, the increase in the no. of wires in each successive layer is 6.

NO. OF wires in the centre	1 wire	3 wires	4 wires
NO. OF wires in the n th layer from centre.	$6n$	$3+6n$	$4+6n$
Total no. of wires in a stranded conductor having n layers.	$1+3n(1+n)$	$3(1+n)^2$	$(4+3n)(1+n)$
diameter over the n th layer in cm,	$(1+2n)d$	$(2.155+2n)d$	$(2.414+2n)d$
where d indicates the diameter of each wire in cm.			

Stranded conductors are expressed as :-

7/2.24, 19/2.50, 37/2.06, 61/2.50 etc.

⇒ The first number i.e. 7, 19, 37, 61 etc. indicate the total no. of wires in the stranded conductor and the second number i.e. 2.24, 2.50, 2.06, 2.59 etc. represent the diameter of each wire in mm.

⇒ A 37/2.06 stranded conductor has 1 wire at the centre, 6 wires in 1st layer, 12 wires in 2nd Layer and 18 wires in the 3rd Layer. Therefore total no. of layers, $n = 3$

$$\begin{aligned}\text{Total no. of wires} &= 1 + 3n(1+n) \\ &= 1 + 3 \times 3(1+3)\end{aligned}$$

$$= 37$$

$$\begin{aligned}\text{Overall diameter} &= (1 + 2n)d \\ &= (1 + 2 \times 3) \times 2.06 \text{ mm} \\ &= 14.42 \text{ mm}\end{aligned}$$

Bundle conductors :-

⇒ The adoption of bundled conductors in extra high tension power transmission enables stranded conductors to be employed and gives an increased current carrying capacity compared with a single conductor of equivalent cross-sectional area.

∴ Since the voltage stress at the conductor surface is reduced by using bundled conductors,

Corona loss is smaller and the line is less liable to cause radio interference.

Low Resistivity, Copper, Alloys :-

Brass :- When copper is alloyed with zinc (60% copper, 40% zinc), it is called brass. Brass has high tensile strength but has lower conductivity than copper.

It is weldable and solderable and is fairly resistant to corrosion. Due to these reasons Brass has gained wide application as a current carrying and structural material in plug-point socket-outlets, switches, lamp holders, fuse holders, knife switches and rheostats etc.

Bronze :- Copper when alloyed with tin (8% to 16%) and a very small % of a 3rd element like cadmium, Beryllium, Silicon is called Bronze.

Bronzes are given their name based on the 3rd element to which is added to copper and tin to form the alloy.

For example :- When the 3rd element is phosphorous, the alloy is called phosphor bronze. If the 3rd element is silicon or cadmium, the alloy is called silicon bronze or cadmium bronze respectively.

Beryllium copper Alloy

⇒ The copper alloy containing beryllium is also called Bronze. It has high conductivity and mechanical strength.

⇒ Its hardening and elasticity property can be changed by giving appropriate heat treatment.

⇒ It is used for making current carrying brush holders, coil springs, knife switch blades.

High Resistivity Materials and their applications :-

Tungsten :→

properties :-

⇒ It is grayish in colour when in metallic form.

⇒ It has a very high melting point (3300°C).

⇒ It is a very hard metal and does not become brittle at high temp.

⇒ It can be drawn into very thin wires for making filaments.

⇒ Its resistivity is about twice that of aluminium.

⇒ In its thinnest form, it has very high tensile strength.

⇒ It oxidizes very quickly in the presence of oxygen even at a temp. of a few hundred degrees centigrade.

> In the atmosphere of an inert gas like nitrogen or argon, it will reliably work up to 2000°C .

Uses :- It is used as filaments of electric lamps and as a heater, radars, contact points etc.

Carbon :-

Carbon is mostly available as graphite which contains about 90% of carbon. Amorphous carbon is found in the form of coal, coke, charcoal, petroleum etc.

Properties :-

- => carbon has very high resistivity about $4600 \text{ } \Omega \cdot \text{cm}$.
- => It has -ve temperature coefficient of resistance.
- > It has a pressure sensitive resistance material and has low surface friction.
- > The current density is $55 \text{ to } 65 \text{ A/cm}^2$.
- > This oxidizes at about 300°C and is very weak.
- > It has very good abrasive resistance.
- => It withstands arcing and maintains its properties at high temp.

Platinum :-

- => It is grayish-white metal.
- => It is non-corroding.
- => It is resistant to most chemicals.
- => It can be drawn into thin wires & strips.
- => Melting point is 1775°C .

- ⇒ Its resistivity is $10.5 \mu\Omega \cdot \text{cm}$.
- ⇒ It is not oxidized even at high temp.

Uses :- heating element in laboratory, ovens & furnaces, contact material, vacuum tubes,

Mercury :-

- ⇒ It is good conductor of heat & electricity.
- ⇒ It is a heavy silver-white metal.
- ⇒ It is the only metal which is liquid at room temp.
- ⇒ Its electrical resistivity is $95.8 \mu\Omega \cdot \text{cm}$.
- ⇒ It expands & contracts in regular degrees when temp changes.

Uses :- Mercury vapour lamps, gas filled tubes, for making contacts, tubes, valves etc.

Superconductivity :-

- ⇒ The resistivity of most metals increases with increase in temp. and vice-versa. There are some metals and chemical compounds whose resistivity becomes zero when their temp. is brought near 0°Kelvin (-273°C).
- ⇒ At this state such metals or compounds are said to have attained superconductivity.
- ⇒ For ex: - Mercury becomes superconducting at approximately 4.5 Kelvin (-268.5°C).

⇒ The transition from normal conductivity to superconductivity takes place almost suddenly, it occurs over a very narrow range of temp about 0.05°K .

⇒ The temp. at which the transition takes place from the state of normal conductivity to that of superconductivity is called transition temp.

⇒ There are 2 types of superconductors commonly known: Type 1 & Type 2 superconductors.

Type 1 superconductors are soft superconductors. They are usually pure specimens of some elements i.e. metals. They have very little use in technical applications.

⇒ Whereas Type-II superconductors are hard superconductors. They are usually alloys of metals with high value of resistivity in normal state. They are very useful as compared to type 1 ~~cond~~ materials.

Superconducting materials ⇒

⇒ Many metals & compounds have superconducting properties at very low temps. Superconductivity has been observed to occur in poorer metallic conductors such as tin, lead & tantalum.

⇒ It has been found that superconductors may not only be pure metals but various alloys and chemical compounds as well. At present about 30 supercondⁿ metals & more than 600 supercondⁿ alloys are already known.

Application of Superconductor materials

(1) Electrical m/c :- At present utilizing the superconductivity to develop electrical m/c's & T/F's. In addition to superconducting magnets which are already being produced.

(2) Power cables :- S/c materials if used for power cables will enable transmission of power over very long distances using a diameter of a few cm without any power loss or drop in voltage.

(3) Electromagnets :- For designing electromagnets using superconductivity for use in laboratories & for low temp. devices like the maser.

(4) Future prospects :-

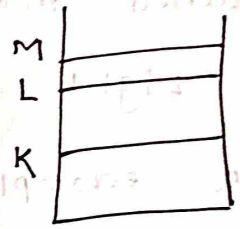
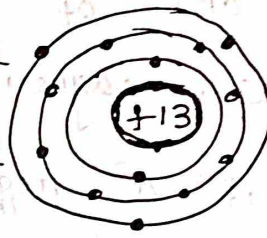
Semiconducting Materials

Introduction :-

"A semiconductor materials is one whose conductivity lies between that of a conductor and an insulator. The 2 most commonly used semiconductor materials are germanium and silicon."

Electron Energy and Energy Band Theory

⇒ An electron revolving around the nucleus of an atom has potential energy, centrifugal energy, rotational energy and magnetic energy, all of which together determine the total energy or the energy level of an electron. This value is measured in electron volts, (eV).

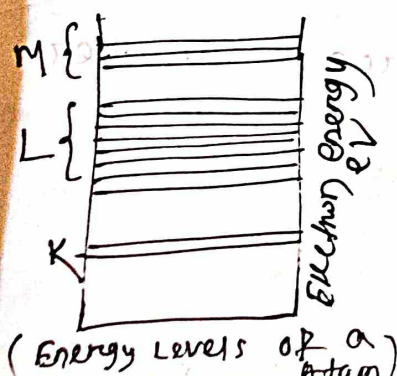


(The Bohr Model of an Atom) (Simplified Energy Level representation of the shells)

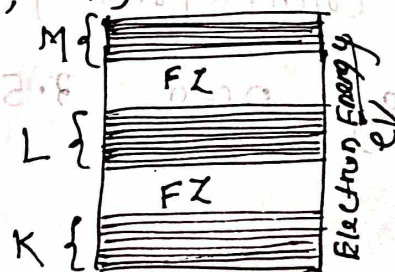
⇒ The electron volt is defined as that amount of energy gained or lost when an electron moves with or against a potential difference of 1 volt.

⇒ The larger the orbit in which an electron revolves, the greater is its energy. Electrons with least energy are on the K level i.e. the orbit closest to the nucleus. Each succeeding level contains electrons with higher energies.

⇒ Fig (1) represents the actual energy levels of an atom, each electron now occupies an energy level different from that of any other. In this Fig the energy levels have been grouped into energy bands.



⇒ Fig (2) shows a more general method of representing energy bands. The areas betⁿ them are called energy gaps; they are also called forbidden zones.



(Energy Levels grouped as Bands)

Excitation of Atoms $\Rightarrow$

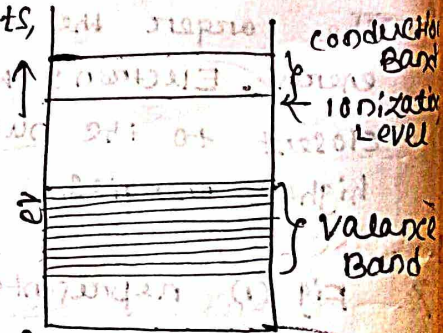
$\Rightarrow$ When each electron in an atom is in its normal orbit, the atom is said to be in an unexcited state.

$\Rightarrow$ To move an electron further away from the nucleus requires addition energy. The additional energy can be obtained from any of the following sources:-
Light, Heat, Magnetic, Kinetic, Electrostatic.

$\Rightarrow$ For example if a required amount of heat energy is absorbed by electron, it will jump to a higher energy level.

$\Rightarrow$ When the electron is in the higher energy level, the atom is said to be in an excited state.

$\Rightarrow$ The quantum of energy, in electron volts, required to move an electron from one energy level to a higher energy level varies from material to material.



$\Rightarrow$ For ex:- an atom of one type of material may require a quantum of energy corresponding to 1.9 eV, whereas another material may need 3.5 eV.

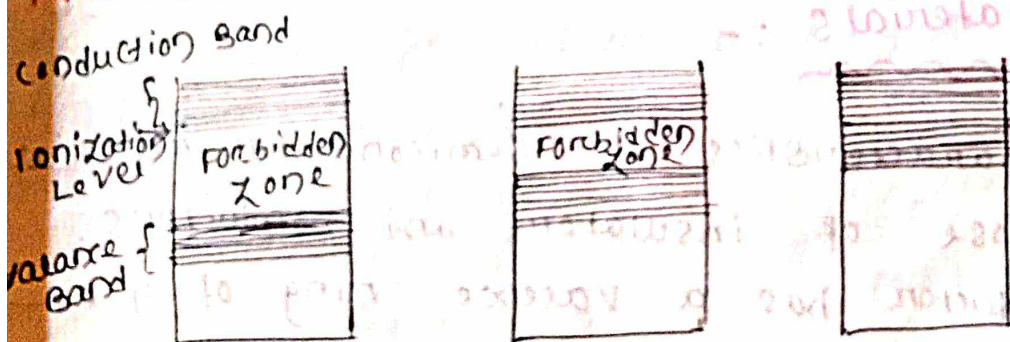
Fig, when the required amount of light or heat energy is absorbed by a valence electron, it will leave the valence band & may move up to the ionization level.

=> If it does, it is released from the attractive forces of the nucleus. Then it is free to float around between the atoms and to conduct.

=> An electron above the ionization level is said to be in the conduction band and is called a free electron.

=> The word "ionization Level" is used because when an electron leaves the valence band, the remaining atom is no longer neutral but has a +ve charge and is called a positive ion. The atom is said to be ionized.

Insulators, semiconductors and conductors



(a) insulator (b) semi-conductor (c) conductor

Fig(a) shows the ionization level of an insulator. The forbidden zone betⁿ the valence band and the conduction band is quite large. This indicates that electrons in the valence band require large amount of additional

energy to move up and become free. As long as the valence electrons are unable to move up to the conduction band there can be no electron flow.

⇒ Fig (b) shows that in the case of semiconductors the forbidden zone is reduced. Thus the valence electrons require less energy to free themselves from the attraction of the nucleus.

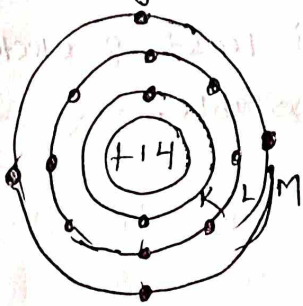
⇒ Fig (c) shows that in a conductor there is no gap between the valence band and the conduction band. Indeed in the better conductors the conduction and valence bands may even overlap. Electrons from the valence ring may be moved into the conduction zone by a small amount of energy thus becoming free.

Semiconductor Materials :-

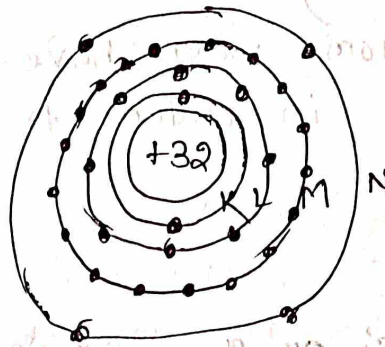
⇒ The electrical characteristics of semiconductor materials fall between those of insulators and conductors. Thus a semiconductor has a valence ring of 4 as compared to valence rings of 8 electrons for the best insulators and 1 electron for the best conductors.

⇒ The 2 most widely used semiconductor materials are Silicon (Si) and Germanium (Ge).

The atomic structure of silicon and germanium is shown in fig.



(Si)



(Ge)



(b) simplified Si and Ge atoms.

(a) Shell arrangements for Si & Ge

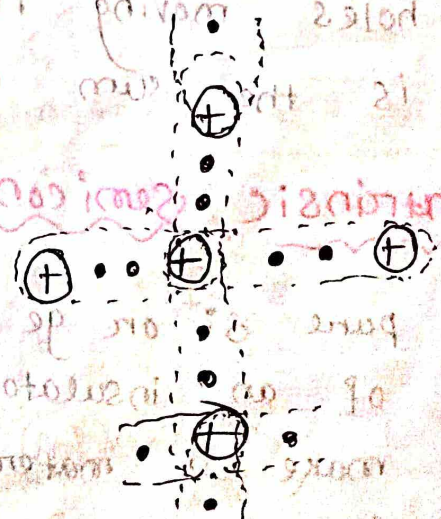
→ In the silicon atom K and L shells are full but M shell contains only four electrons. According to $2n^2$ formula, the M shell can contain 18 electrons however, the M shell in silicon is the valence shell and thus can never contain more than 8 electrons.

In the germanium atom the K, L & M shells are filled and the N shell is the valence shell containing 4 electrons.

Covalent Bonds :-

A covalent bond results from sharing of pairs of valence electrons by 2 or more atoms.

The atoms of materials having 4 or more than 4 electrons



(sets of covalent or sharing)

revolving in their outermost orbits must share their electrons with the neighbouring atoms as shown in fig.

⇒ This is because an atom must have at least 8 electrons in the outer most orbit in order to be stable.

Intrinsic Semiconductors :-

⇒ If a crystal, say Si or Ge, does not contain any impurity atoms i.e. if it contains only one type of atoms, it is called an intrinsic material.

⇒ If its temp. is brought down to 0°K (i.e. -273°C) this intrinsic material will act as a good insulator and very little current will flow through it.

⇒ When an electron is freed from the atom of an intrinsic material it breaks a covalent bond and leaves behind a vacancy (called a hole).

⇒ When a voltage is applied to an intrinsic material at a temp. above 0°K , it acts as a conductor.

⇒ If a voltage is applied to a semiconductor containing free electrons and holes, current consisting of 2 parts will flow, free electrons moving in one direction and holes moving in the opposite direction. The total current is the sum of the 2 parts.

Extrinsic Semiconductor :-

⇒ pure Si or Ge exhibits characteristics closer to that of an insulator than a semiconductor. In order to make a material conducting, a small quantity of impurity must be added to it. The addition of impurity is called "doping".

→ A material which has been doped is called an extrinsic material. The extent to which the impurity has been added is called the doping level. Extrinsic semiconductors are of 2 types i.e. N-type & P-type.

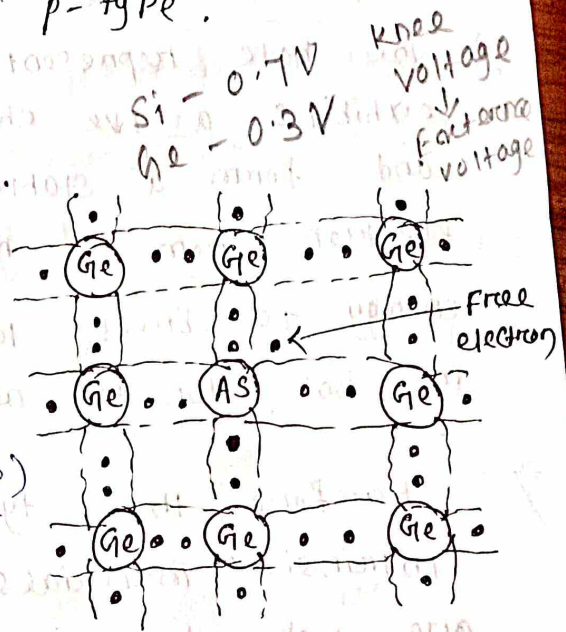
N-Type Materials →

→ One category of impurities has 5 valence electrons and is called the pentavalent group. Some of the impurities of this group are Bismuth, Antimony, Arsenic, phosphorus. (BAAP)

→ When a pentavalent impurity is added to an ^{Ex}trinsic material (i.e. Ge or Si) only four of its valence electrons lock into the covalent bond formation of the atomic structure.

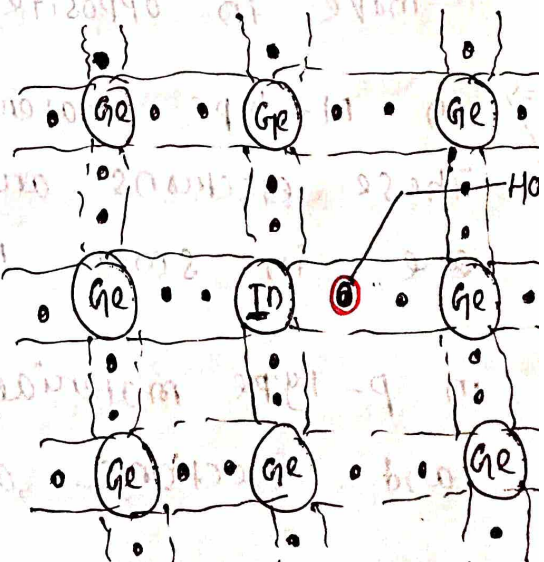
⇒ The 5th valence electron of the impurity atom is free to wander through the crystal.

⇒ Pentavalent atoms provide (or donate) an extra electron they are called donor impurities. A material doped with a donor impurity has excess of electrons in its structure and is, therefore, known as -ve or N-type material.



P-Type Materials →

⇒ Another category of impurities has 3 valence electrons and is called the trivalent group. Some of the impurities of this group are Boron, Aluminium, Gallium, Indium. (BIGA)



(Indium impurity atom creates a hole in the covalent bond)

⇒ Since the impurity has 3 valence electrons, there is a hole in the covalent bond structure created by the lack of an electron.

⇒ The hole represents an incomplete covalent bond and exhibits a +ve charge. In order to complete the bond and form a stable 8 electron structure a valence electron from a nearby atom gains sufficient energy to break loose from its bond and jump into the hole due to attraction from it.

⇒ Therefore, this type of impurity is known as 'acceptor'. Intrinsic materials doped with a trivalent impurity are referred to as positive or p-type because the lack of electrons for the covalent bond structure causes an attraction to nearby electrons.

Majority & Minority carriers

⇒ In n-type material, conduction takes place through the electrons created mostly by the doping and a small no. created by thermal generation.

⇒ The small no. of holes created by thermal generation move in opposite direction.

⇒ In n-type material, the no. of free electron is large. These electrons are called majority carriers. Holes are in small no.s and are called minority carriers.

⇒ In p-type material, the holes are majority carriers and electrons are minority carriers.

Semi-conductor Materials :-

⇒ Semiconductors, differ from conductors and insulators in that they have a narrow forbidden gap. The semiconductor elements are listed below :-

Boron, carbon, silicon, Germanium, phosphorus, Arsenic, Antimony, sulphur, selenium, Tellurium..

⇒ The resistance of a semiconductor material can be controlled by changes in temp. and by adding impurities.

⇒ The resistance of semiconductor materials can also be controlled by the following factors.

- (i) voltage (ii) Electric field.

Application of semiconductor Materials :-

Rectifiers :-

(i) Germanium & silicon Rectifiers :-

⇒ A p-type and a n-type material are joined together to form a junction called the p-n junction.

⇒ When an external voltage is applied across the 2 materials a flow of current results if the +ve and -ve terminals of the voltage source are connected respectively to the extreme ends of the p & n materials. It is called Forward Bias.

⇒ If the applied voltage is reversed i.e. the +ve of the supply voltage is connected to the n side and the -ve of the supply voltage is connected to the p-side, there is no flow of current.

This is called reverse biasing.

⇒ Thus the p-n junction offers high conductivity when forward biased and no conductivity when reverse biased.

⇒ Thus semiconductors can be used as Rectifiers. Semiconductor p-n junction diodes have almost replaced thermionic valves as rectifiers.

⇒ Modern p-n junction rectifiers use germanium or silicon as the semiconductor material.

(2) Copper - oxide ~~and selenium~~ Rectifiers :-

⇒ The earliest semiconductor to be used was copper oxide. Its application was in copper oxide rectifier.

⇒ copper oxide rectifier is a plate of 99.98% pure copper on which a film of cuprous oxide is produced by a special process.

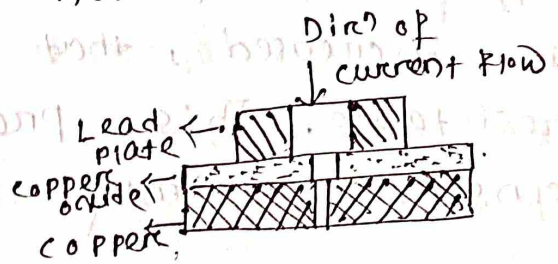
⇒ one side of the plate is cleaned of cuprous oxide and an electrode is soldered directly to the copper. The 2nd electrode is soldered to the cuprous oxide film.

⇒ When +ve potential is applied to the oxide layer and -ve to the copper, it corresponds to forward biasing a p-n junction.

⇒ To have a good contact with copper oxide, a lead plate is pressed against it. The 2 terminals of the rectifiers are the copper plate and lead plate.

The oxide will be in between the plates as shown in fig. This rectifier will allow the current to flow only from oxide to copper and will not allow flow from copper to oxide.

The single unit can sustain 8V.
The life of copper oxide rectifiers is 12 to 15 years & η is 70%.



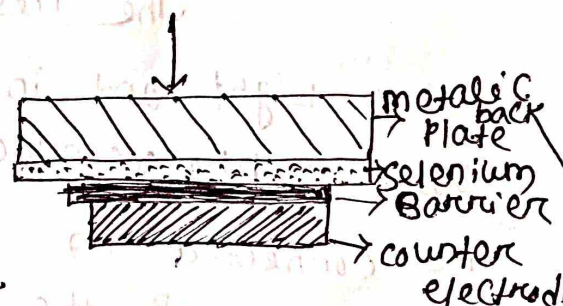
These types of oxide rectifiers are [copper oxide rectifier] mostly used for meters, battery, cell charging, X-ray works, measuring instruments, railway signaling, telecommunication systems etc.

Selenium Rectifiers :-

In this type, a film of 0.5mm thickness is deposited on one side of the metallic back plate (iron or aluminium).

By means of chemical treatment, a film of "blocking" or "barrier" layer is formed betⁿ selenium and counter electrodes. The rectifier construction is as shown in fig.

A single unit can sustain 6V. The normal current density is about 0.04 A/cm² for Full wave Rectification.



The power η is 50 to 75%.

[selenium rectifier]

Application :- Battery charging, telephone ckt's, control ckt's, meters, electroplating.

Temperature - sensitive Elements (Thermistors) :-
⇒ If the temperature of a semiconductor material is increased, that causes a decrease in its resistance. This property is used in temperature sensitive elements which are called as "Thermistors".

⇒ The thermistors are thermally sensitive materials (resistors). They are made from oxides of certain metals such as copper, manganese, cobalt, iron and zinc.

⇒ Application of Thermistors :- Temp. measurements and control. They sense temp. variations and convert these variations into an electrical signal which is then used to control heating devices. voltage regulation & Time Delay ccts.

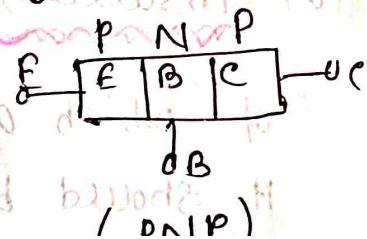
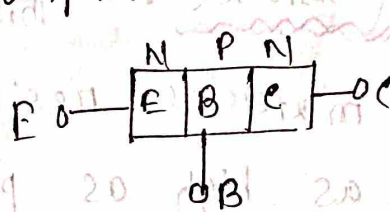
Photoconductive cells :-
The resistance of semiconductor material is low under light and increase in darkness. This phenomenon is used in photoconductive cells where a semiconductor material is connected in series with a voltage source. The resistance of the semiconductor varies with the intensity of light and thus the current in the ckt is controlled.

⇒ Photoconductive cells can be used in applications which require the control of a certain function or event according to the colour or intensity of light. It is also used for burglar alarms, flame detector, smoke detector and control for street lights.

Photovoltaic cells :- Photovoltaic cells are devices that develop an emf when illuminated. Thus they convert Light energy directly into electrical energy. No outside source of current flow as a photoconductive device.

Varistors :- The resistance of semiconductors varies with the applied voltage. This property is used in devices called varistors. It is used in voltage stabilizers and motor speed control.

Transistors :- The resistance of semiconductors depends to a large extent on the magnitude of electric field. The current in a semiconductor does not follow ohm's Law and increase far more rapidly than the voltage. This property has been used in the device called transistor. A transistor is a 2 junction 3 terminal device, the 2 junctions being formed by joining P, N and P material or N, P & N materials as shown in fig. Transistors have replaced the vacuum and gas tubes in performing many jobs including amplification of signals and switching ccts.



Insulating Materials

Introduction:

For safe operation of all electrical & electronics equipment insulator plays important role. Basically current carrying wires need to be covered with insulating material.

General Properties of Insulating Materials :-

The different properties of insulating material are :-

- (1) Electrical Properties.
- (2) Visual Properties.

(3) Mechanical "

(4) Thermal "

(5) chemical "

(6) Ageing

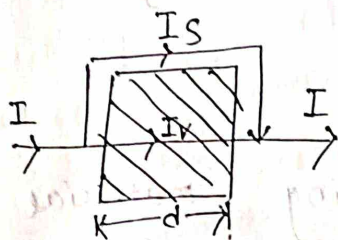
(1) Electrical Properties :- The various electrical properties are

(a) Insulation Resistance :- This is a property by virtue of which a material resists flow of electric current. It should be as high as possible. When subject to electrical pressure there will always be a flow of current however extremely small it may be, an insulation resistance is never ∞ .

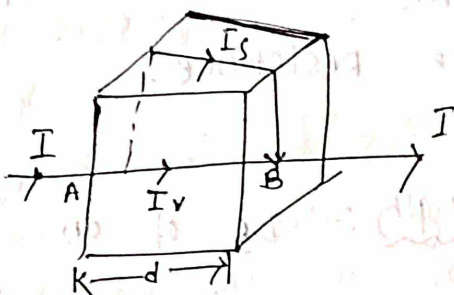
→ An insulator to which a voltage V , is applied will have a small current I flowing through it. The insulation resistance $R = \frac{V}{I}$

Insulation Resistance is of 2 types.

- (i) Volume resistance.
- (ii) Surface resistance.



(a)



(b)

(Volume resistivity and surface resistivity of a piece of insulating material)

⇒ In Fig (b) is shown a piece of insulating material in isometric view. The same is shown in cross-section in Fig (a).

⇒ If a potential difference is applied across the faces A & B, a current will flow. This current is likely to take path viz; straight through the material and around the material over the surface.

⇒ The current that flows right through the material is denoted by I_v in Fig (a). The current that flows over the surface is denoted by I_s .

(i) Volume Resistance:- The resistance offered to current I_v which flows through the material is called volume resistance. For a cube of unit dimensions this is called volume resistivity. This resistivity is the resistance offered to the flow of current through the body of the material & expressed in $\Omega\text{-m}$.

The volume resistance of an insulating material

$$R_v = \rho_v \frac{d}{a}$$

(ρ_v = volume resistivity in $\Omega\text{-m}$
 d = length of the current path through the material in m.
 a = cross-sectional area of the current path in sq. m .)

(ii) Surface resistance :- The resistance offered to current I_s which flows over the surface of the insulating material is called surface resistance.

(b) Dielectric strength :- D.S of an insulating material is the maximum potential gradient that the material can withstand without rupture. This value is expressed in volts or KV per unit thickness of the insulating material. (KV/mm).

(c) Dielectric constant :- Every insulating material has the basic property of storing charge (Q) when a voltage (V) is applied across it. The charge is proportional to the voltage applied i.e. $Q \propto V$.
or $Q = CV$.

Where C = capacity or capacitance of the material across which the voltage is applied.

⇒ Every insulating material behaves as a capacitor but only some are used as practical capacitors.

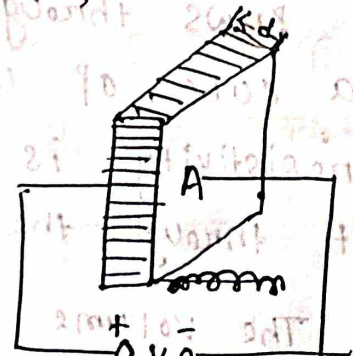
⇒ The property of insulating materials that causes the difference in the value of capacitance, is called the dielectric constant or permittivity (ϵ).

$$C \propto \frac{A}{d}$$

$$C = \epsilon \frac{A}{d}$$

A = Face area of insulation

d = distance betⁿ 2 faces



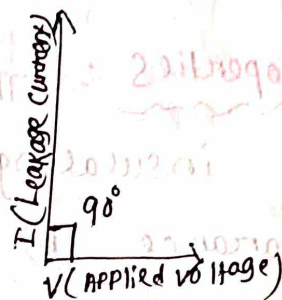
(An insulating material across which a potential V is applied)
 ϵ = Dielectric constant (permittivity)

Also $\epsilon = \epsilon_0 \epsilon_r$

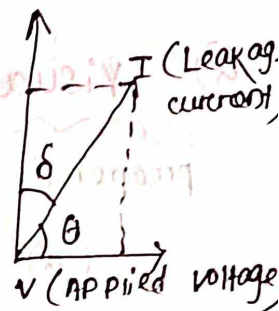
ϵ_r = Dielectric constant of material
 ϵ_0 = Dielectric constant or permittivity
 $= 8.854 \times 10^{-12}$ Farad/m. of vacuum

(d) Dielectric Loss :- when a perfect insulation is subjected to alternating voltage it is like applying alternating voltage to a perfect capacitor. In such a case there is no consumption of power.

$\Rightarrow$ In such cases the charging current would lead the applied voltage by 90° exactly in (a). This means that there is no power loss in the insulation.



(a)



(b)

(Phase Relation between Leakage current and Applied voltage in dielectrics)

$\Rightarrow$ In most insulating materials there is definite amount of dissipation of energy when an insulator is subjected to alternating voltage. It is this dissipation of energy is called dielectric loss.

$\Rightarrow$ In commercial insulators the leakage current does not lead applied voltage by exactly 90° in (b). The phase angle is always less than 90° . The complementary angle $\delta = 90^\circ - \theta$ is called dielectric loss angle.

$\Rightarrow$ For an insulator having a capacitance C and having a voltage V applied to it at a frequency f Hz the dielectric power loss

$$P = VI \cos \theta$$

$$= V \times \frac{V}{X} \cos \theta$$

$$= V^2 \times \frac{1}{X} \cos(90^\circ - \delta)$$

$$= V^2 \times \frac{1}{2\pi f C} \sin \delta$$

$\theta = 90^\circ - \delta$
 (Where X = capacitive reactance)
 $(\because \cos \theta = \sin \delta)$

$$\begin{aligned} \cos \theta &= \cos(90^\circ - \delta) \\ &= \sin \delta \\ \cos(90^\circ - \theta) &= \sin \theta \end{aligned}$$

In most insulators the angle δ is negligibly small ($\because \delta = 0$)

$$p = \frac{1}{\sqrt{1 - \tan^2 \delta}} \approx \tan \delta$$

From the above eqⁿ it is seen that power loss is dependent on $\tan \delta$ so long as the other factors like voltage, frequency & capacitance are constant. $\tan \delta$ is called the p.f of the insulator.

(2) Visual Properties :- The following are the visual properties of insulating materials.

(a) Appearance (b) colour (c) crystallinity.

(3) Mechanical Properties :-

(a) Mechanical Strength :- The mechanical strength of insulating materials depends upon a no. of factors given below :-

(i) Temperature Rise :- Temp. rises as a result of heat generation in the conductor and the dielectric loss in the insulator. High temp. can affect the mechanical strength of insulating materials.

(ii) climatic effects :- Humidity can affect mechanical strength of insulating materials.

(b) Viscosity :- Viscosity in liquid dielectrics will affect manufacturing processes.

(c) porosity :- High porosity insulating materials will increase the moisture holding capacity and affect electrical properties.

(d) Solubility :- in certain applications insulation can be applied only after it is dissolved in some solvent. In such cases the insulating material should be soluble in certain appropriate solvents. (9/19/19)

(4) Thermal properties :-

=> one of the major function of insulation is heat transfer. consider an underground cable under operation. This cable is recommended for operation with certain limitations of voltage and current. Suppose voltage is increased. If the insulating material is able to withstand the higher voltage stress, the change will cause increase of dielectric losses that will increase heat generation. Ultimately the temp. of the insulation will further increase. If the insulator starts losing its insulating properties, ultimately breakdown will occur.

=> 2ndly, if load current in the cable is increased, I^2R losses will increase, resulting once again in increased heat generation and failure as mentioned. This example signifies that in an apparatus heat transfer function decides :-

(i) The voltage rating and up to what safe limit the voltage can be raised.

(ii) Loading and overloading current limitation.

(iii) Ambient Temp & max^m temp an insulation can withstand.

Various thermal properties are :-

(a) Melting points, Flash points, Volatility :-

Melting point assumes importance in specific cases like non-draining compound impregnated paper insulated cable etc. It is desired that in the entire operating temperature range of cables the impregnating compound must not melt to avoid migration of oil.

Flash point will impose restriction in manufacturing processes to avoid possible hazards of apparatus catching fire.

Volatility assumes when a trapped gas is evolved from a volatile insulating material subjected to voltage stress, the break-down is very rapid.

A volatile material cannot be a good insulator.

(b) Thermal Conductivity :-

Heat generated due to I^2R losses and dielectric losses will be dissipated through the insulator itself. How effectively this flow of heat takes place, depends on the thermal conductivity of the insulator.

An insulator with better thermal conductivity will not allow temp. rise because of effective heat transfer through it to the atmosphere. This property assumes great importance in high voltage apparatus where thickness of insulation is more.

(c) Thermal Expansion :-

An insulator with a high coefficient of expansion poses problems. Repeated load cycles of an apparatus cause corresponding expansion and contraction of the insulator leading to the possibility of the formation of voids in it. When there are two insulating materials involved to form an insulation system different coefficients of expansion of the two will further increase the formation of voids. These voids have been found to be the major cause of insulation breakdown.

(d) Heat Resistance :-

This is a general property which desires that a dielectric should withstand temperature variation within desirable limits, without damaging its other important properties.

If an insulator has favourable properties at ambient temperature but is not able to retain these properties to desirable extent at higher temperature but is not able to retain these properties to desirable extent at higher temperatures upto which it has to operate, it is not a good insulator.