MODULE – 2

ELECTRICAL PROPERTIES OF MATERIALS

2.1Introduction

Conductors are nothing but a material having ability to conduct electricity (or) conduct free electrons. It has high thermal and electrical conductivity.

Examples: Al, Ag, Cu, Alloys etc.

The resistance of the conductor is the order of $10^{-8}\Omega$. This conductivity is mainly based on the available free or valence electrons in the material.

Valence electrons

The electrons in the outer most orbit of an atom in the material are known as valence electrons. It is loosely bounded with the nucleus.

In band theory, the conduction and valence bands are overlap with each other, and there is no band gap.

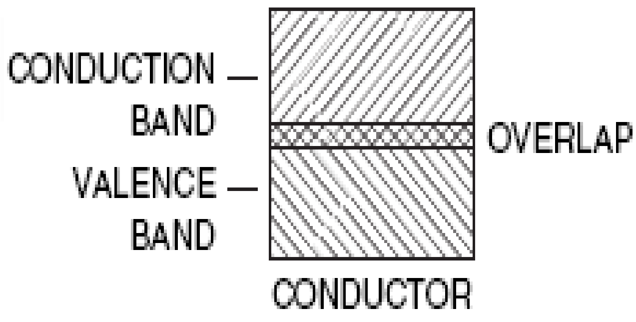


Fig 2.1

Classification of conducting materials

The conducting materials based on their conductivity, are classified into the major categories.

- Zero resistivity materials
- Low resistivity materials and
- High resistivity materials.

(i) Zero resistivity materials

Superconductors like alloys of aluminum, zinc, gallium, nichrome, niobium, etc., are a special class of materials that conduct electricity almost with zero resistance below transition temperature. These materials are known as zero resistivity materials.

They are used for saving energy in the power systems, super conducting magnetism memory storage elements etc.,

(ii) Low Resistivity Materials

The metals like silver, aluminum and alloys have very high electrical conductivity. These materials are known as **low resistivity materials.**

They are used as conductors, electrical contact, in electrical devices, electrical power transmission distribution, winding wires in motors and transformers.

(iii) High Resistivity Materials

The materials like tungsten, platinum, nichrome etc., have resistivity and low temperature co-efficient of resistance. These materials are known as **high resistivity materials.**

Such metals and alloys are used in the manufacturing of resistors, heating elements, resistance thermometers etc. The conducting properties of a solid are not a function of the total number of the electrons of the atoms can take part in conduction. These valence electrons are called **free electrons or conduction electrons.**

Basic Definitions

2.1.1.Current

The rate of flow of charges across any cross sectional area of a conductor is called current. The rate of flow of charges is not uniform and it varies with respect to time.

$$I = \frac{q}{t} \Longrightarrow I = \frac{dq}{dt}$$

2.1.2. Ohm's Law

At constant temperature, the steady current flowing through a conductor is directly proportional to the potential difference (voltage) between its ends.

$$V \propto I$$

$$V = IR$$

2.1.3. Resistivity

Resistance of a conductor (metal) is directly proportional to the length and inversely proportional to the area of cross section.

$$R \propto \frac{L}{A}$$

$$R = \rho \frac{L}{A}$$

$$\rho = \frac{RA}{L} \,(\Omega m)$$

Where, ρ is the electrical resistivity and it's inversely proportional is called electrical conductivity.

$$\sigma = \frac{1}{\rho} \qquad (\Omega^{-1}m^{-1})$$

2.1.4. Current Density

The current per unit area of cross section of a current carrying conductor is known as current density. It is perpendicular to the flow of charges.

$$J = \frac{I}{A}(Am^{-2})$$

2.1.5. Drift Velocity

The average velocity is required to drift the free electrons in the conductor towards the application of an electrical field is called drift velocity.

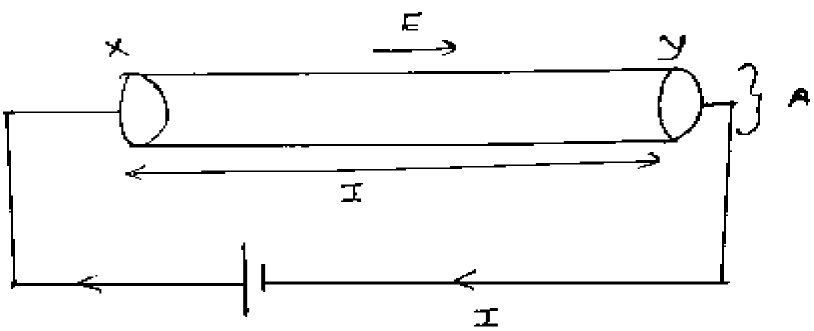
$$V_d = \frac{\lambda}{\tau_c}$$

2.1.6. Electrical Field

In a uniform cross section of a conductor, potential drop per unit length is known as electrical field.

$$E = \frac{V}{L}(Vm^{-1})$$

2.1.7. Relationship between Current Density and Drift velocity



Movement of free electrons in a metal rod

Consider a conductor 'XY' of length (l) and area of cross section 'A'. An electric field 'E' is applied between its ends. Let 'n' be the number of free electrons per unit volume and V_d is the drift velocity.

The number of free electrons in the conductor is = nAl

The charge of an electron = e

Total charges passing through the conductor is

$$q = (nAl)e \quad \ldots\ldots\ldots..(1)$$

The time taken by the charges pass through the conductor is

$$t = \frac{l}{V_d} \quad \ldots\ldots\ldots\ldots..(2)$$

$$\therefore Current\ I = \frac{q}{t} \quad \ldots\ldots\ldots\ldots..(3)$$

Substitute equations (1) and (2) in equation (3), we get,

$$I = \frac{nAle}{{}^{l}/_{V_d}}$$

$$= \frac{nAleV_d}{l}$$

$$I = nAeV_d$$

$$\frac{I}{A} = neV_d$$

$$J = neV_d \quad ..(4)\left(\because\ J = {}^{I}/_{A}\right)$$

From this expression we obtained, the current density is directly proportional to the drift velocity and number of free electrons in the conductor.

2.1.8. Electron theory of solids

The electron theory of solids aims to explain the structures and properties of solids through their electronic structures. The electron theory is applicable to all solids both metals and non-metals. The electron theory of solids explains the following concepts,

- Structural, electrical and thermal properties of solids.
- Elasticity, cohesive force and binding in solids.
- Behavior of conductors, semiconductors and insulators etc.,

There are three types of electron theories have been proposed. They are,

- Classical Free Electron theory
- Quantum Free Electron theory
- Brillouin Zone theory (or) Band theory.