Micro-Electronics

UNIT I

Electronics is a branch of engineering which deals with the flow of Electrons through vacuum, gas or Semi-conductor.

Valence electrons : The electrons in the outermost orbit of an atom are known as valence electrons.

- The outermost orbit can have a maximum of 8 electrons.
- The valence electrons determine the physical and chemical properties of a material.

Free Electrons: The electrons which are not bound to any particular atom and free to move in the crystal are known as free electrons.

Energy Band Diagram:

- The range of energies possessed by valence electrons is called valence band.
- The range of energies possessed by free electrons is called conduction band.
- Valence band and conduction band are separated by an energy gap in which no electrons normally exist , this gap is called forbidden gap.

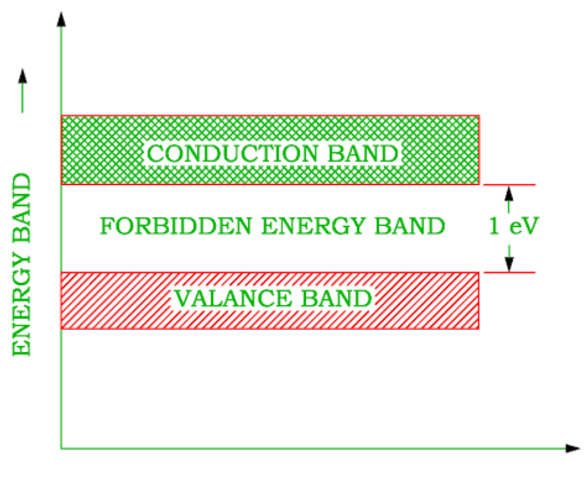

FIG B : ENERGY BAND DIAGRAM FOR SEMI CONDUCTOR

Fig :1

Based on the width of the forbidden gap, materials are broadly classified as conductors, Insulators and semiconductors.

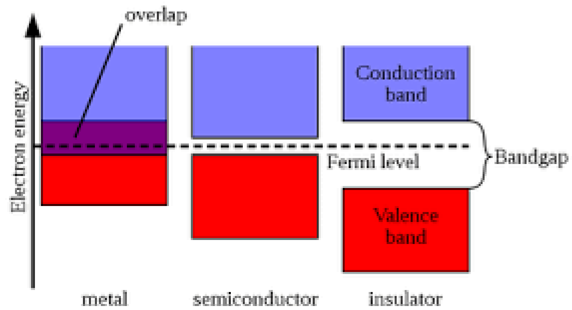

Fig: 2

Conductors:

- Conductors are those substances, which allow electric current to pass through them.
  Examples: Copper, Al, Silver etc
- In terms of energy bands, conductors are those substances in which there is no forbidden gap.
- Valence and conduction band overlap as shown in the figure. For this reason, very large number of electrons are available for conduction even at extremely low temperatures.

Insulators:

- Insulators are those substances, which do not allow electric current to pass through them. Example: Rubber, glass, wood etc.
- In terms of energy bands, insulators are those substances in which the forbidden gap is very large around 6eV (electron volts). Thus valence and conduction band are widely separated as shown in the figure.

- Therefore insulators do not conduct electricity even with the application of a large electric field or by heating or at very high temperatures.

Semi-Conductors:

- Semiconductors are those substances whose conductivity lies in between that of a conductor and Insulator. Example: Silicon, germanium, Gallium, Arsenide etc.
- In terms of energy bands, semiconductors are those substances in which the forbidden gap is narrow. Thus valence and conduction bands are moderately separated as shown in figure.

- In semiconductors, the valence band is partially filled, the conduction band is also partially filled, and the energy gap between conduction band and valence band is narrow. Therefore, comparatively smaller electric field is required to push the electrons from valence band to conduction band. At low temperatures the valence band is completely filled and conduction band is completely empty. Therefore, at very low temperature a semi-conductor actually behaves as an insulator.

Classification of semiconductors

Semiconductors are classified into two types.

a) Intrinsic semiconductors.

b) Extrinsic semiconductors.

a) Intrinsic semiconductors:

A semiconductor in an extremely pure form is known as intrinsic semiconductor.

Example: Silicon, germanium.

- Both silicon and Germanium are tetravalent (having 4 valence electrons).
- Each atom forms a covalent bond with the electrons of neighboring atom. The structure is shown below

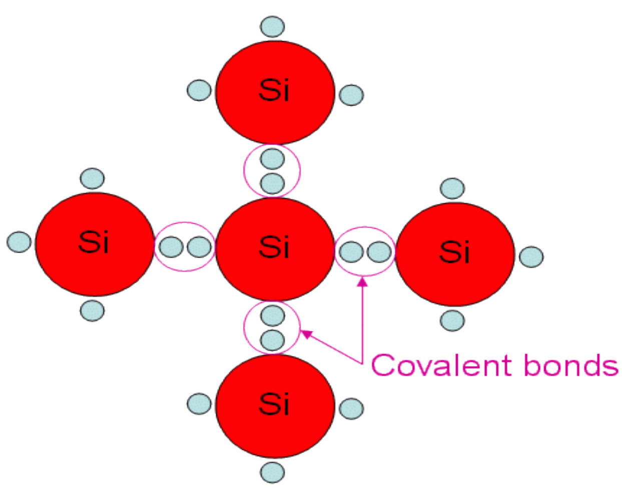

Fig:3

At low temperature

At low temperature, all the valence electrons are tightly bound to the nucleus hence no free electrons are available for conduction.

The semiconductor therefore behaves as an Insulator at absolute zero temperature.

At room temperature

At room temperature, some of the valence electrons gain enough thermal energy to break up the covalent bonds.

This breaking up of covalent bonds sets the electrons free and are available for conduction.

When an electron escapes from a covalent bond and becomes free electron a vacancy is created in a covalent bond. Such a vacancy is called a Hole. It carries positive charge and moves in a direction opposite to that of an electron.

Numbers of holes are equal to the number of electrons since, a hole is nothing but an absence of an electron.

b) Extrinsic Semiconductors:

- When an impurity is added to an Intrinsic semiconductor its conductivity changes.
- This process of adding impurity to a pure semiconductor is called Doping and the impure semiconductor is called as an extrinsic semiconductor.
- Depending on the type of impurity added, extrinsic semiconductors are further classified as n-type and p-type semiconductor.

N type Semiconductor:

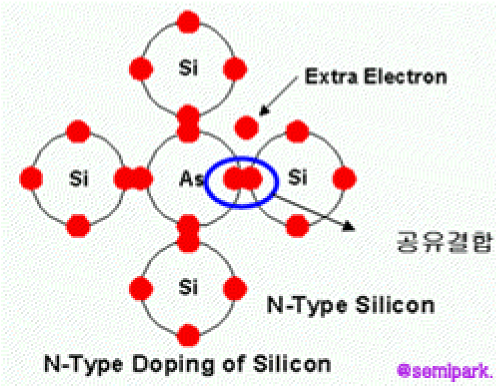

Fig:4

When a small amount of pentavalent impurity is added to a pure semiconductor it is called as n-type semiconductor.

Addition of Pentavalent impurity increases the number of free electrons in a semiconductor crystal.

Typical examples for Pentavalent impurities are Arsenic, Antimony and Phosphorus etc. Such impurities which produce n-type semiconductors are known as Donor impurities because they donate free electrons to the semiconductor crystal.

To understand the formation of n-type semiconductor, consider a pure silicon crystal with an impurity say arsenic added to it as shown in Fig:4.

We know that a silicon atom has four valence electrons and Arsenic has five valence electrons. When Arsenic is added as impurity to silicon, the four valence electrons of silicon make covalent bond with four valence electrons of Arsenic.

The fifth valence electron finds no place in the covalent bond thus, it becomes free and travels to the conduction band as shown in figure. Therefore, for each arsenic atom added, one free electron will be available in the silicon crystal. Though each arsenic atom provides one free electron yet an extremely small amount of arsenic impurity provides enough atoms to supply millions of free electrons.

Due to thermal energy, further hole election pairs are generated but the number of free electrons are very large in number when compared to that of holes. So in an n-type semiconductor electrons are majority charge carriers and holes are minority charge carriers. Since the current conduction is pre-dominantly by free electrons it is called as n-type semiconductor.

P Type Semiconductor:

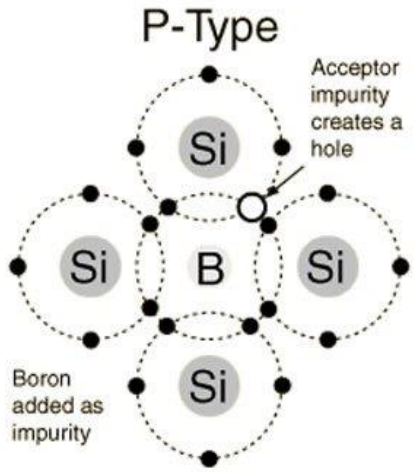

Fig:5

When a small amount of trivalent impurity is added to a pure semiconductor it is called a p-type semiconductor.

The addition of trivalent impurity increases the number of holes in the semiconductor crystal. Example: Gallium, Indium or Boron etc.

Such impurities which produce p-type semiconductors are known as acceptor impurities because the holes created can accept the electrons in the semi conductor crystal.

To understand the formation of p-type semiconductor, consider a pure silicon crystal with an impurity say gallium added to it as shown in figure 1.7.
We know that silicon atom has 4 valence electrons and Gallium has three electrons.

When Gallium is added as impurity to silicon, the three valence electrons of gallium make three covalent bonds with three valence electrons of silicon. The fourth valence electron of silicon cannot make a covalent bond with that of Gallium because of short of one electron as shown in the figure. This absence of electron is called a hole. Therefore for each gallium atom added one hole is created, a small amount of Gallium provides millions of holes.

Due to thermal energy, further hole-electron pairs are generated, but the number of holes are very large compared to the number of electrons. Therefore, in a p-type semiconductor holes are majority carriers and electrons are minority carriers. Since the current conduction is predominantly by holes it is called as p-type semiconductor.

Diffusion current :

- The directional movement of charge carriers due to their concentration gradient produces a component of current known as Diffusion current.

- The mechanism of transport of charges in a semiconductor when no electric field is applied called diffusion. It is encountered only in semiconductors.

Drift Current :

- The current flowing due to an applied electric field is known as Drift Current.