Introduction to semiconductor materials

1. Introduction

This section briefly introduces the mechanism of conduction in a class of materials called semiconductors. Semiconductors are materials consisting of elements from group IV of the periodic table and having electrical properties falling somewhere between those of conducting and of insulating materials.

2. Atomic structure and Valence orbit

The term “Valence” is used to indicate that the potential required to remove any one of the last orbit electrons is lower than that required for any other electron in the structure (the internal orbits).

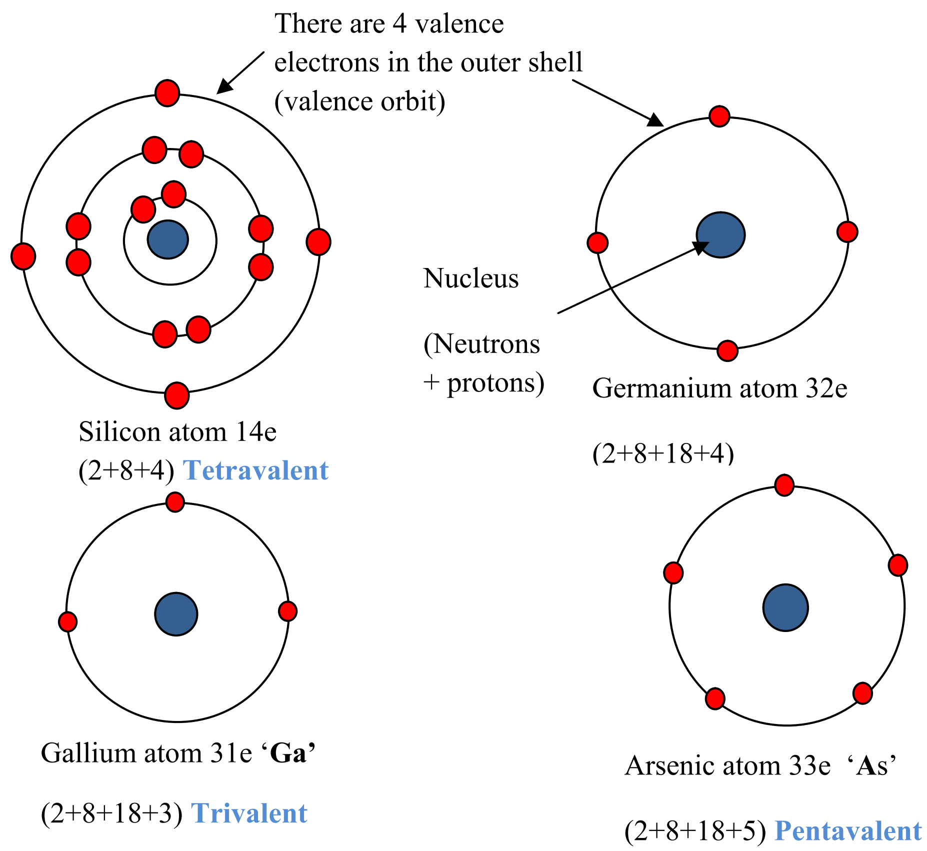

Fig.1.1: Valence orbit

3. Atomic bonding and covalent bond

- Atoms are bond together (**Covalent bonding**) to form a crystalline structure.
- The center atom shares an electron with each of the four surrounding atoms creating a **Covalent bond** with each.
- The surrounding atoms are in turn bounded to other Atoms, and so on.

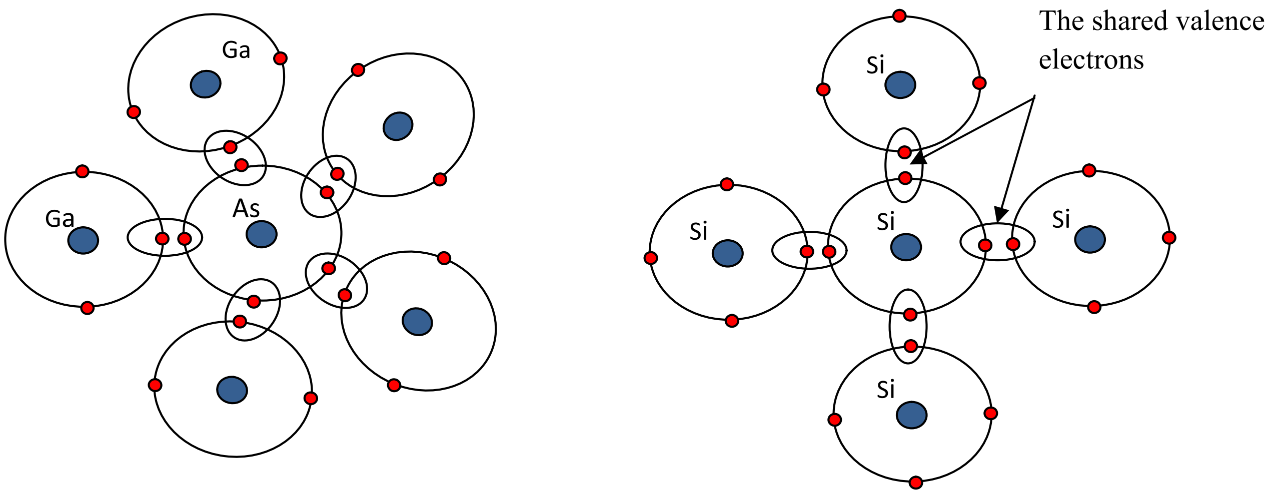

Fig.1.2: Atomic bonding

4. Classes of materials

a) Conductor: A conducting material is characterized by a large number of conduction-band electrons (overlapping between conduction band and valence band). (See Fig.1.3)

b) Insulator: Because of its wide energy gap, electrons are unable to reach conduction level.

c) Semiconductor materials: Semiconductors are a special class of elements having conductivity between that of a good conductor and that of insulator. The most used in the construction of electronic devices are Germanium (Ge), Silicon (Si) and Gallium Arsenic (Ga As).

As an example, consider the conductivity of three common materials. Copper, a good conductor, has a conductivity of 0.59×10^{6} S/cm; glass, a common insulator, may range between 10^{-16} and 10^{-13} S/cm; while silicon (semiconductor), has a conductivity that varies from 10^{-8} to 10^{-1} S/cm. We can see, then, that the name *semiconductor* is an appropriate one.

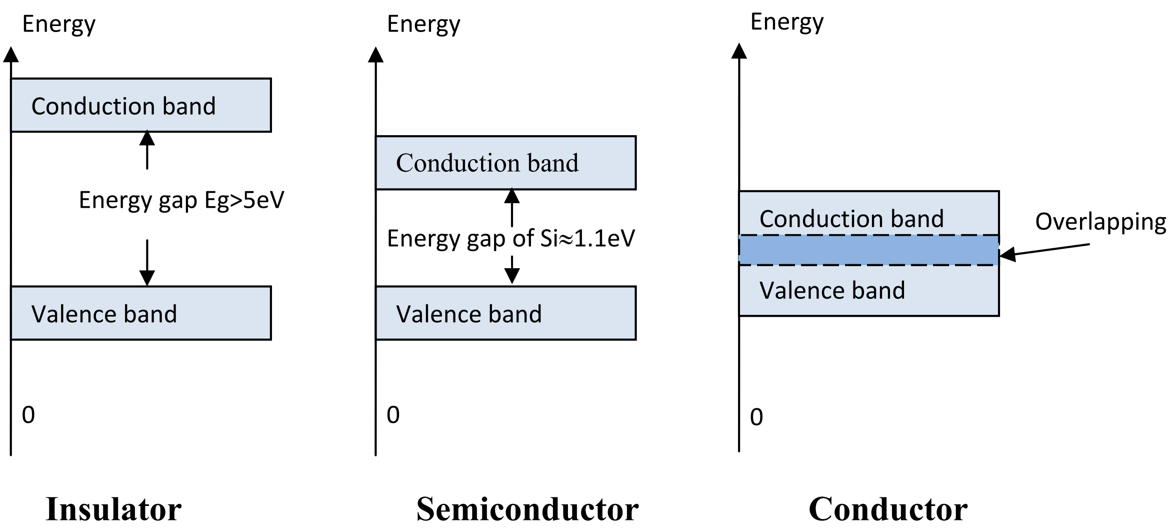

Fig.1.3: Energy diagram for the three types of solids

5. Intrinsic semiconductor

An Intrinsic Semiconductor is a pure semi-conductive material.

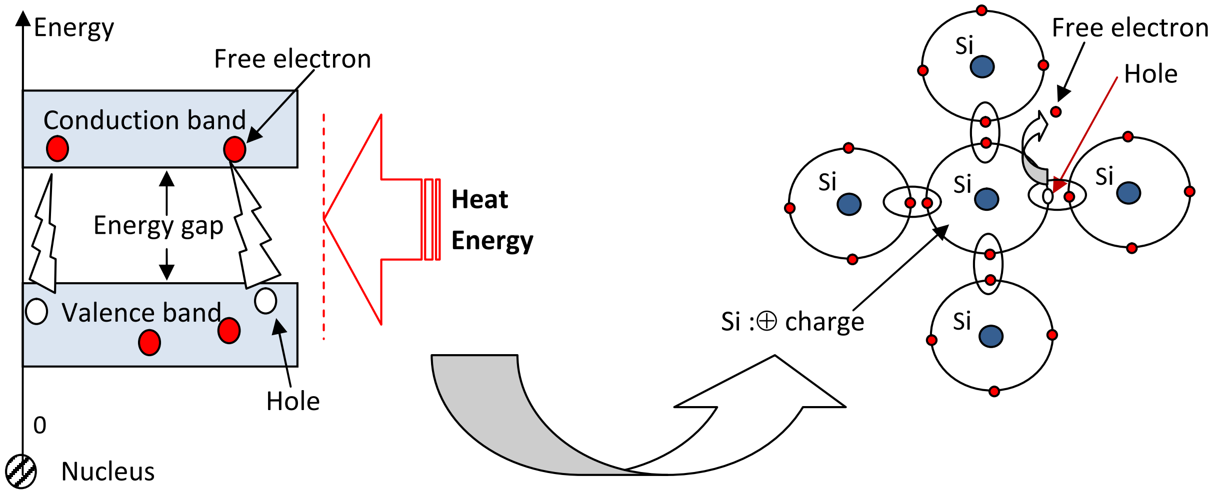

Fig.1.4: Intrinsic semiconductor

An **intrinsic** (pure) silicon crystal at room temperature has sufficient heat (thermal) energy for some valence electrons to jump the gap from the valence band into the conduction band, becoming ***free electrons*** (***These free electrons enable current flow in the semiconductor***). A vacancy is left in the valence band; this vacancy is called a ***hole.*** (***electron-hole pair***)

This type can't conduct current well this is because of the limited number of free electrons in the conduction band.

6. Extrinsic semiconductor (Doped materials)

Doping is the process of adding impurity atoms to a semiconductor in order to modify its conductive properties, as result to this process we get an extrinsic (impure) material.

There are two extrinsic materials: n-type and p-type

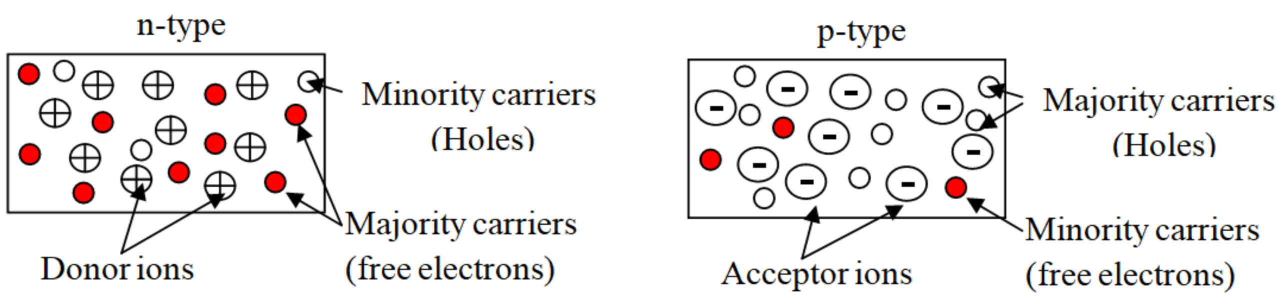

Fig.1.5: Extrinsic semiconductors

n- type:

An n-type is formed by the addition of **Pentavalent** impurity atoms (do**N**or) to the intrinsic semi-conductive material. The majority carriers (transporters) are the free electrons.

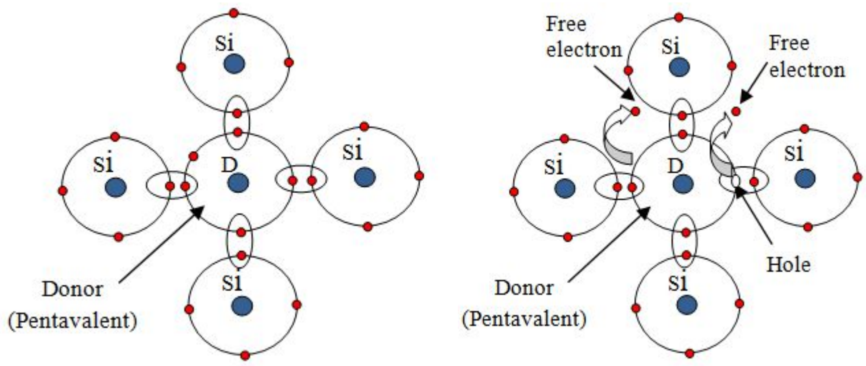

Fig.1.6: n- type semiconductor

Note that the four covalent bonds are still present

p- type:

A p-type is formed by the addition of **Trivalent** impurity atoms (acce**P**tor) to the intrinsic semi-conductive material. The majority carriers are the holes.

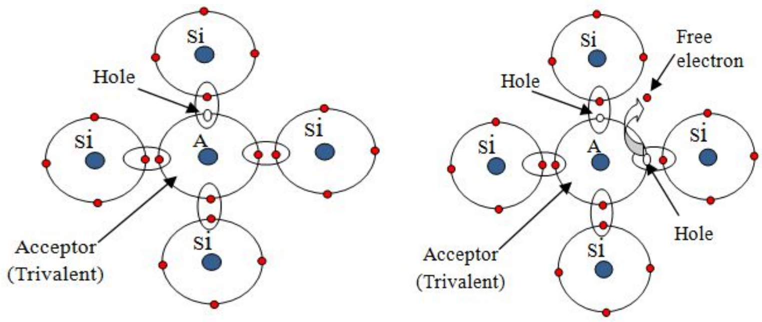

Fig.1.7: p- type semiconductor

7. pn junction :

A pn junction is the boundary between p-type and n-type semiconductors.

At the instant of junction formation, free electrons in the n region begin to diffuse across the junction and fall into holes near the junction in the p region.

⇒ Creation of very thin Depletion region.

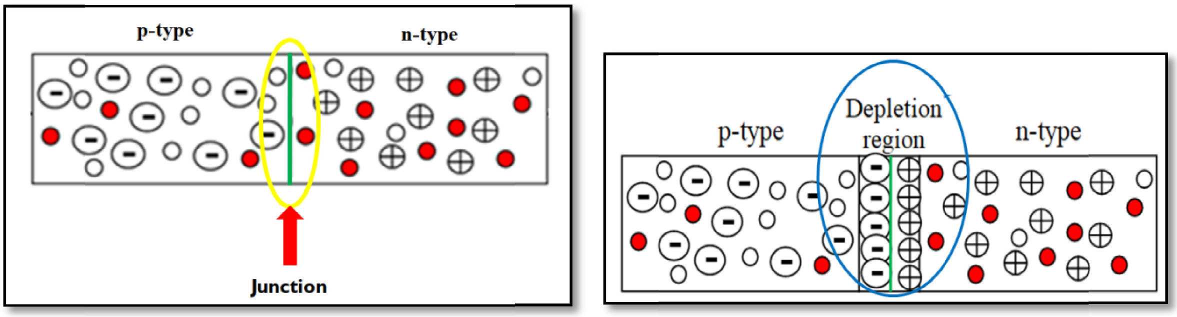

Fig.1.8: pn junction

a. No applied bias :

The voltage applied across the diode is =0.

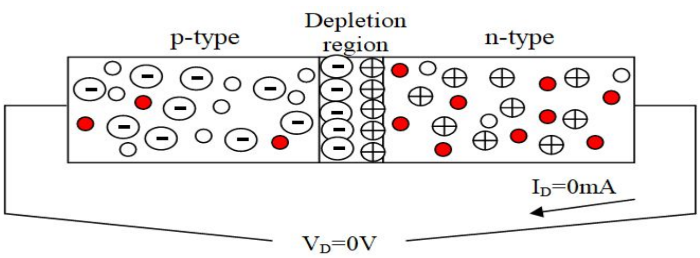

Fig.1.9: No bias condition

Current through the junction =I_D= 0

b. Reverse-Bias condition

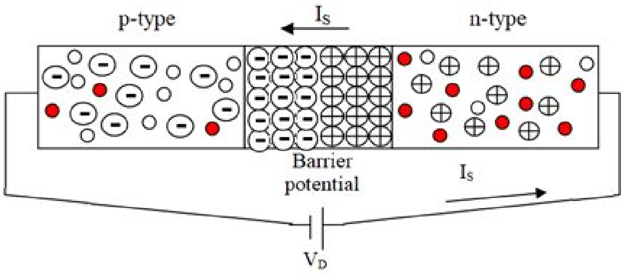

Fig.1.10: Reverse-Bias condition

Holes get attracted to the negative terminal of the source and Electrons get attracted to the positive terminal of the source.

The number of uncovered positive ions in the depletion region of the n type will increase due to the large number of free electrons down to the positive potential of the applied voltage. For the same reasons the number of uncovered negative ions will increase in p-type material.

The current that exists under reverse-bias condition is called the reverse saturation current, Is.

The only current that flows under reverse bias is the very small reverse saturation current, so that the diode current, $\mathbf{I_D}$:

$\mathbf{I_D = -I_S}$

$\mathbf{I_S}$ is the minority-carrier flow, I majority ≈0A.

Reverse biasing ⇒ pn junction acts as an insulator.

c. Forward- Bias condition

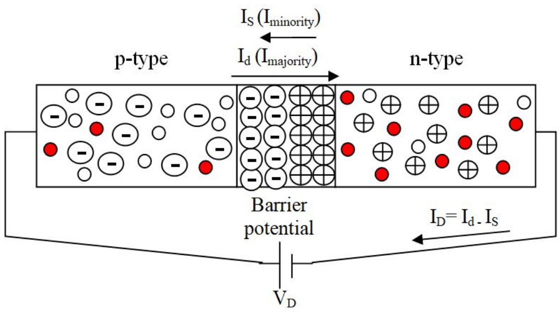

Fig.1.11: Forward-Bias condition

The application of a forward-bias potential V_D will pressure electrons in n-type material and holes in the p-type material to combine with the ions near the boundary and reduce the width of the depletion region (***Barrier potential***).

The diffusion (junction crossing) of majority carriers is aided by the external voltage source. This current across the junction flows opposite to the reverse saturation current and is called **diffusion current, I_d**.

The effect of barrier potential in the depletion region is to oppose forward bias. This is because the negative ions near the junction (in p-region) tend to prevent electrons from moving through the junction into p region.

⇒So, barrier potential is like a battery connected in a direction to oppose the forward bias voltage.

Forward biasing ⇒ pn junction acts as a conductor

The diffusion current increases as a function of the applied voltage, according to the following equation:

$$I_d = I_s\,(e^{VD/nVT}) \quad \text{and} \quad I_D = I_d - I_S$$

$$\Rightarrow \quad I_D = I_s\,(e^{VD/nVT} - 1)$$

Where:

I_s is the reverse saturation current.

V_D is the applied forward-bias voltage across the diode

n is an ideality factor.

VT is the thermal voltage.

The quantity **VT (= kT /q)** is constant at a given temperature and is approximately equal to 26 mV at room temperature.

Where:

k = 1.381×10^{-23} J/K is Boltzmann's constant,

q the charge of one electron (q= 1.6×10^{-19} C).

T is the temperature of the material in Kelvin (K). (T_K=273°+T_C)

Since the saturation current (**I_s**) is typically very small (10^{-9} to 10^{-15} A)

and For VD>>0, $I_D \approx I_s\,e^{VD/nVT}$