4.1. P-N JUNCTION

We know about P-type semiconductors and N-type semiconductors. But P-type and N-type semiconductors, taken separately, are of a very little use. If a piece of P-type semiconductor is joined to a piece of N-type semiconductor in such a manner that the crystal structure remains continuous at the boundary, then a new structure called P-N junction is formed. Such a PN-junction makes a versatile device which is called a semiconductor diode, P-N junction diode or simply crystal diode.

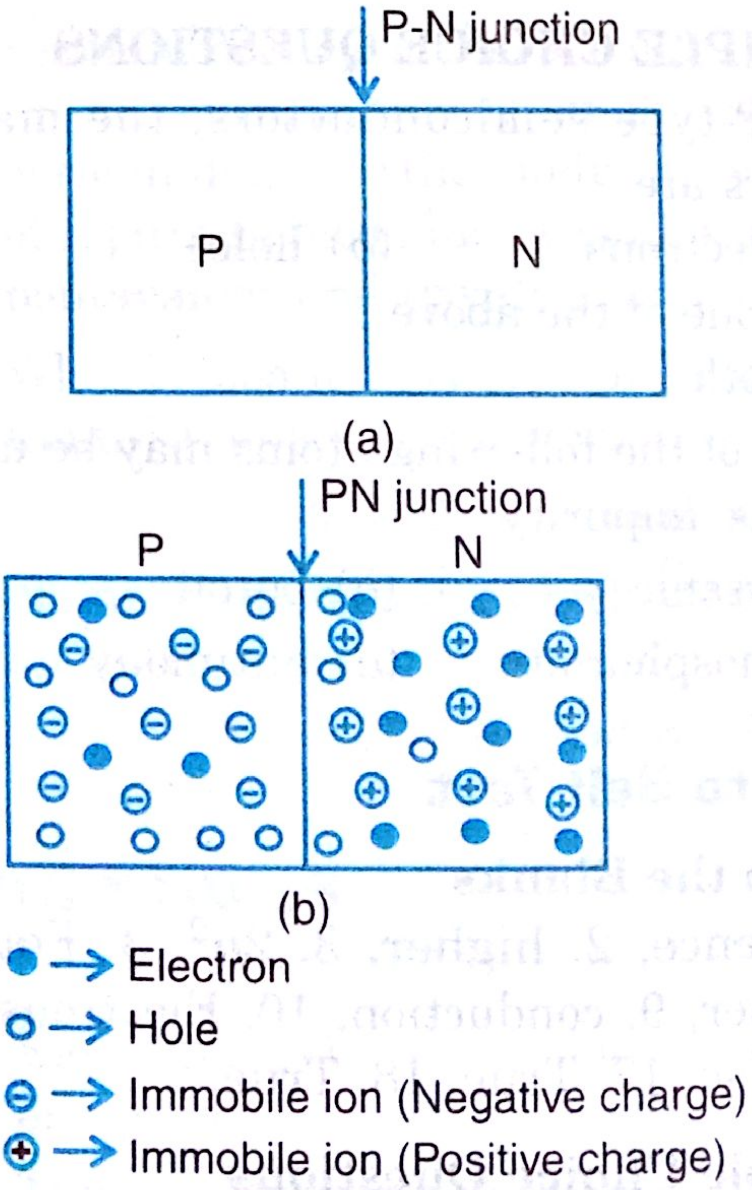


Fig. 4.1. PN-junction

The P-N junction cannot be made simply by joining two pieces. Special fabrication techniques are required to form a P-N junction. A semiconductor P-N junction is formed when a wafer of the semiconductor material such as silicon is doped so that one region is N-type and the other region is P-type.

The P-N junction is an important device because, all other semiconductor devices contain at least one P-N junction.

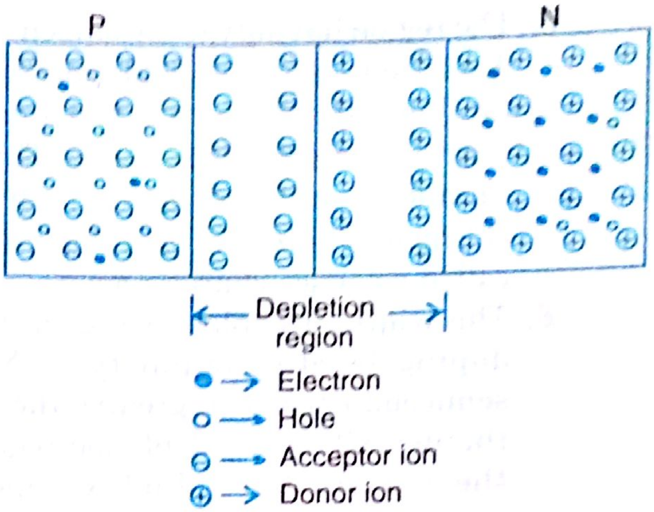


Fig. 4.2. Formation of depletion region in a P-N junction

4.2. THE DEPLETION REGION FORMATION

(U.P.Tech. Tutorial Question Bank) (U.P. Tech. First Semester (C.O.), 2002-03, 2005-06, 2006-07) (05 marks)

Figure 4.2 shows a P-N junction with depletion region formed at the junction. The P-region contains holes as majority carriers, electrons as minority carriers and negative charged immobile ions called acceptor ions. The N-region contains electrons as majority carriers, holes as minority carriers and positive charged immobile ions called donor ions. The sample as a whole is the neutral so the P-region and N-region separately. In figure 4.2 no voltage is applied to the P-N junction. As soon as the PN-junction is formed, the following actions take place:

DO YOU KNOW?

The depletion region is also known as space charge region. In the unbiased P-N junction, the depletion region gets formed very quickly after the formation of the junction.

1. Holes from the P-region diffuse into the N-region. In the N-region, they combine with the electrons.
2. Electrons from the N-region diffuse into the P-region. In the P-region, they combine with the free holes.
3. The P-region has more number of holes and N-region has more number of electrons, therefore, there is a difference of concentrations in two regions. Due to this difference, the diffusion of holes and electrons takes place. A concentration gradient is produced due to the difference in concentration. Besides this, the electrons and holes move at random in all directions because of thermal energy. Some charge carriers cross the junction.
4. The process of diffusion continues only for a short period of time. After a few recombination of holes and electrons, a restraining force is set up automatically in the neighbourhood of the junction. This restraining force is called barrier. As a result of this force, further diffusion of holes and electrons from one region to other is checked. The formation of this barrier may be given in following steps:

   (*i*) As the PN-junction is formed, some of holes in the P-region and some of the electrons in the N-region diffuse in each other and recombine.

   (*ii*) Each recombination eliminates a hole and a free electron.

   (*iii*) In the above process, the negative acceptor ions in the P-region and positive donor ions in the N-region are left uncovered or uncompensated in the neighbourhood of the junction.

   (*iv*) Further holes trying to diffuse into N-region are repelled by the uncovered positive charge of the donor ions. Similarly, further electrons trying to diffuse into the P-region are repelled by the uncovered negative charge of the acceptor ions. As a result of this, the further diffusion of holes and electrons across the junction is stopped.

5. The region having the uncompensated accepted and donor ions is called depletion region. The reason for this is that there is a depletion (dirth) of mobile charge carriers in this region. This region contains immobile or fixed ions which are electrically charged. Therefore, this depletion region is also called as space-charge region.
6. The width of depletion region depends upon the doping level of impurity in N-type or P-type semiconductor. The greater the doping level, the thinner will be the depletion region. This is due to the reason that a highly doped P-N junction contains a large number of electrons and holes.

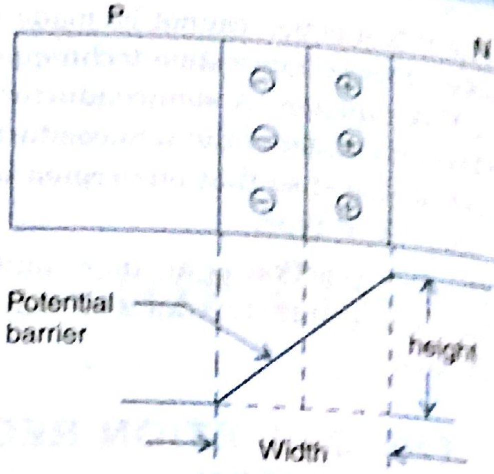


Fig. 4.3. Potential barrier

4.3. BARRIER POTENTIAL OR JUNCTION POTENTIAL (V_j)

(U.P. Tech, Sem. Exam. 2005-06) (05 marks)

Due to the presence of immobile positive and negative ions on opposite sides of the junction, an electric field is created across the junction. This electric field is known as the *barrier potential* or *junction potential* or *cut in voltage*. It has fixed polarities as shown in figure 4.3. The polarities of barrier potential are decided by the type of immobile ions present on the two sides of the junction. Thus the negative terminal of the barrier potential is on the *P* side and positive side is on the N-side as shown in figure 4.3. This is called as barrier potential because it acts as a barrier to oppose the flow of electrons and holes across the junction. The barrier potential represents the height of the barrier that is to be overcome for commencement of flow of electrons and holes. Barrier potential is measured in volts. The barrier potential for silicon is about 0.7 volt whereas its value for the Germanium is 0.3 volt at 25°C as shown in Table 4.1.

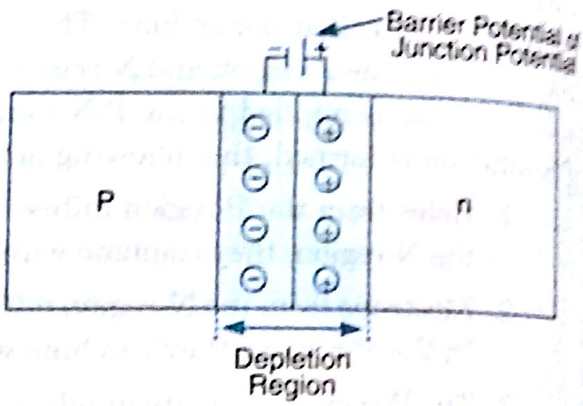


Fig. 4.4. Barrier potential

Table 4.1: Barrier Potential for Different Materials

S.No.	Material	Barrier potential
1.	Silicon	0.7 volt
2.	Germanium	0.3 volt

(i) Importance of barrier potential

Barrier potential acts as a barrier (wall) which does not allow the electrons and holes to cross the junction. So, if we want them to cross the junction, then an external voltage of appropriate polarity has to be applied in order to overcome the opposition of the barrier potential. Then, the flow of electrons and holes across the junction can restart again.

(ii) Factors deciding the barrier potential value

Following are the factors which decide the value of the barrier potential:

(i) Semiconductor material used (Silicon or Germanium).
(ii) The intrinsic concentration of Si or Ge before doping.
(iii) The level of doping on *P* and *N* sides
(iv) Temperaure.

The complete unbiased P-N junction, immobile ions and the variation of barrier potential along the length is shown in figure 4.5.

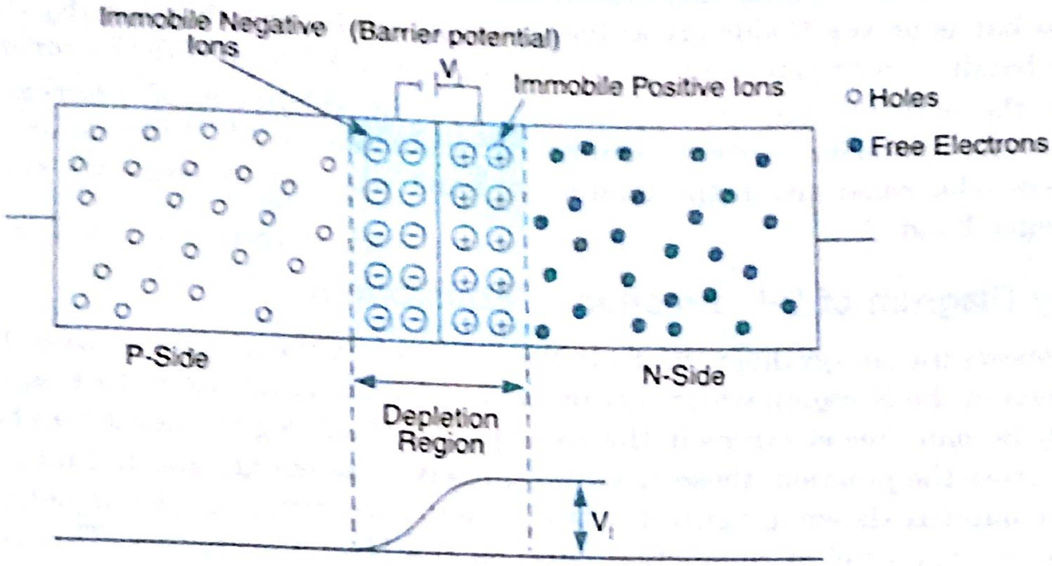
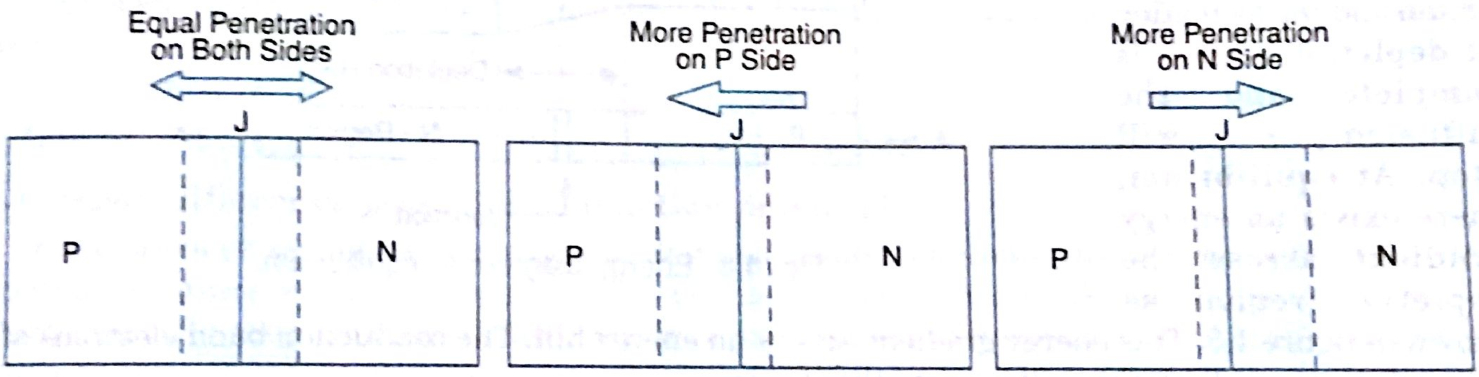


Fig. 4.5. Open circuited P-N junction and variation of junction potential

(*iii*) Penetration of depletion region

The penetration of the depletion region into *P* or *N* side depends on the doping levels of those sides. If both these sides are equally doped then the depletion region penetrates equally on both the sides as shown in figure 4.6 (*a*). But, if *P*-region is lightly doped as compared to the N-region then the penetration depletion region is more on the *P*-side as shown in figure 4.6 (*b*). Similarly, if *N*-side is lightly doped as compared to *P*-side then the depletion region extends more into the *N*-side as shown in figure 4.6 (*c*).



(a) Both sides equally doped (b) P side is lightly doped (c) N side is lightly doped

Fig. 4.6.

Thus, the depletion region always penetrates more on the side which is lightly doped as to the other.

4.6. CURRENTS IN A P-N JUNCTION WITH NO EXTERNAL BATTERY

When a PN-junction is formed, a depletion region is established across the junction. Because of this a barrier potential exists across the junction which stops the further diffusion of holes and electrons across the junction. Few majority carriers have sufficiently high kinetic energy to balance the barrier potential and cross the junction. Hence due to majority carriers small current flows which is called majority carrier current.

There is another current which flows across the junction. This current is due to the minority carriers. Since, there are some minority carriers in the P-region and in the N-region, they are accelerated across the junction by the barrier potential. This current due to minority carriers is called minority carrier current.

> **DO YOU KNOW?**
>
> When the P-N junction is formed, the depletion region gets created and the movement of electrons and holes stops. Thus, the current flowing through an unbiased P-N junction is zero.

But the majority carrier current flows in a direction opposite to the direction of minority carrier current. Hence flow of minority carriers across the junction is balanced by the flow of some majority carriers. Therefore, there is no net flow of current across the junction when no external battery is applied.

4.7. BIASING OF A P-N JUNCTION

(U.P. Tech. First Sem. Exam. 2005-06) (05 marks)

When we apply a battery across the PN-junction, this process is called biasing of a PN-junction. By applying external voltage source across the PN-junction, the width of the depletion region can be controlled. By controlling the width of depletion region, P-N junction finds a large number of applications in the field of electronics.

The P-N junction can be biased in two ways:

1. Forward-Bias
2. Reverse-Bias

4.7.1. Forward-Biasing of P-N junction

(U.P. Tech. Sem. Exam. 2005-06), 2006-07) (05 marks)

In forward-biasing of a P-N junction, positive terminal of the battery is connected to the P-side and the negative terminal to the N-side as shown in the figure 4.11. In this case, holes are repelled from the positive terminal of the battery and forced towards the junction. Similarly electrons are repelled from the negative terminal of the battery and forced towards the junction. Because of this increased energy, some holes and electrons enter the depletion region. This reduces the potential barrier. Therefore, width of depletion region also reduces. As a result of this, more majority carriers diffuse across the junction. Hence, this causes a large current to flow across the junction.

For each recombination of free electron and hole, an electron from the negative terminal of the battery enters the N-type region. This then moves towards the junction. Similarly, in the P-type region near the positive terminal of the battery, an electron breaks a bond in the crystal

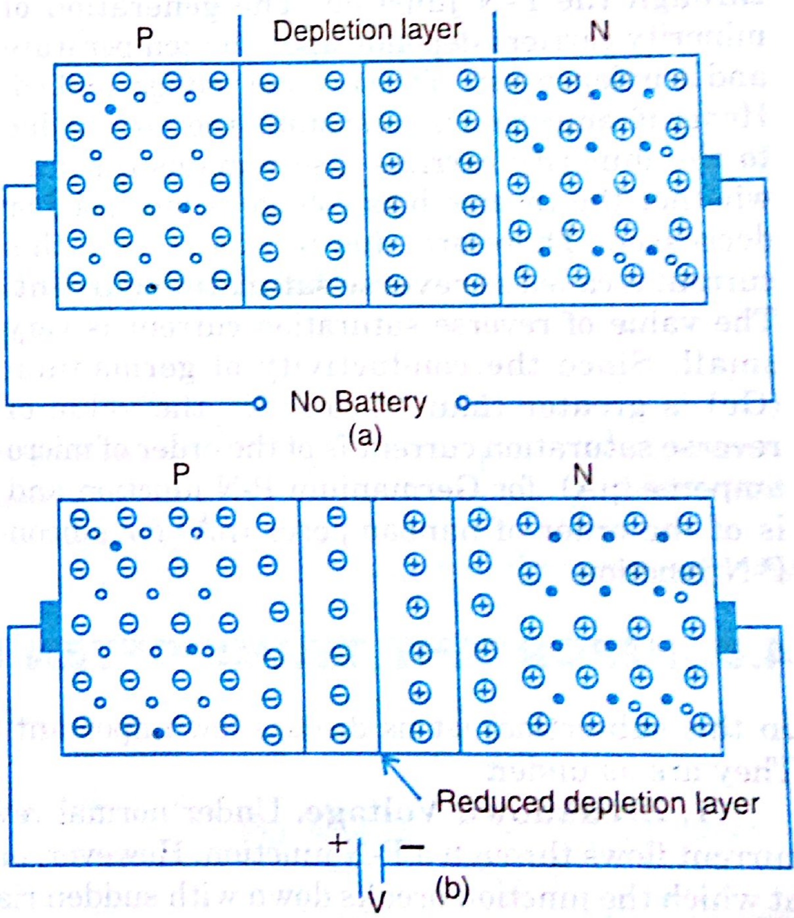


Fig. 4.11. Forward biasing of P-N junction

structure and enters the positive terminal of the battery. For each electron which breaks its bond, a hole is created. This hole moves towards the junction. Therefore, the current through the external circuit is due to the movement of electrons only. On the other hand, the current in the P-type region is due to the movement of holes and the current in the N-type region is due to the movement of electrons. Hence, there is a large current in the external circuit as long as the external battery is present in the circuit.

4.7.2. Reverse Biasing of P-N Junction

(U.P. Tech. Sem. Exam. 2005-06, 2006-07, 2007-08) (05 marks)

In reverse biasing of a PN-junction, a battery is connected across the P-N junction in such a way that its positive terminal is connected to the N-region and negative terminal is connected to the P-region.

In reverse bias the holes in the P-region are attracted towards the negative terminal of the battery whereas the electrons are attracted towards the positive terminal of the battery. In this way majority charge carriers are drawn away from the PN-junction. Due to this, the depletion region becomes wider. This increases the barrier potential.

Due to the increased barrier potential, the majority charge carriers are not able to cross the junction. Hence, in reverse bias, there is no current due to the majority charge carriers.

But there are few thermally generated minority carriers in both the regions. The increased barrier potential enhances the flow of minority carriers across the junction. As a minority carrier is generated, it is drifted towards the P-N junction due to the barrier potenial. Therefore, a very small amount of current flows through the P-N junction. The generation of minority carriers depends upon the temperature and is independent of the reverse voltage applied. Hence if temperature is constant, the current due to the minority carriers also remains constant whether the reverse bias voltage is increased or decreased. Therefore, due to this reason, this current is called as **reverse saturation current**. The value of reverse saturation current is very small. Since the conductivity of germanium (Ge) is greater than silicon (Si), the value of reverse saturation current is of the order of micro amperes (μA) for Germanium P-N junction and is of the order of nanoamperes (nA) for silicon P-N junction.

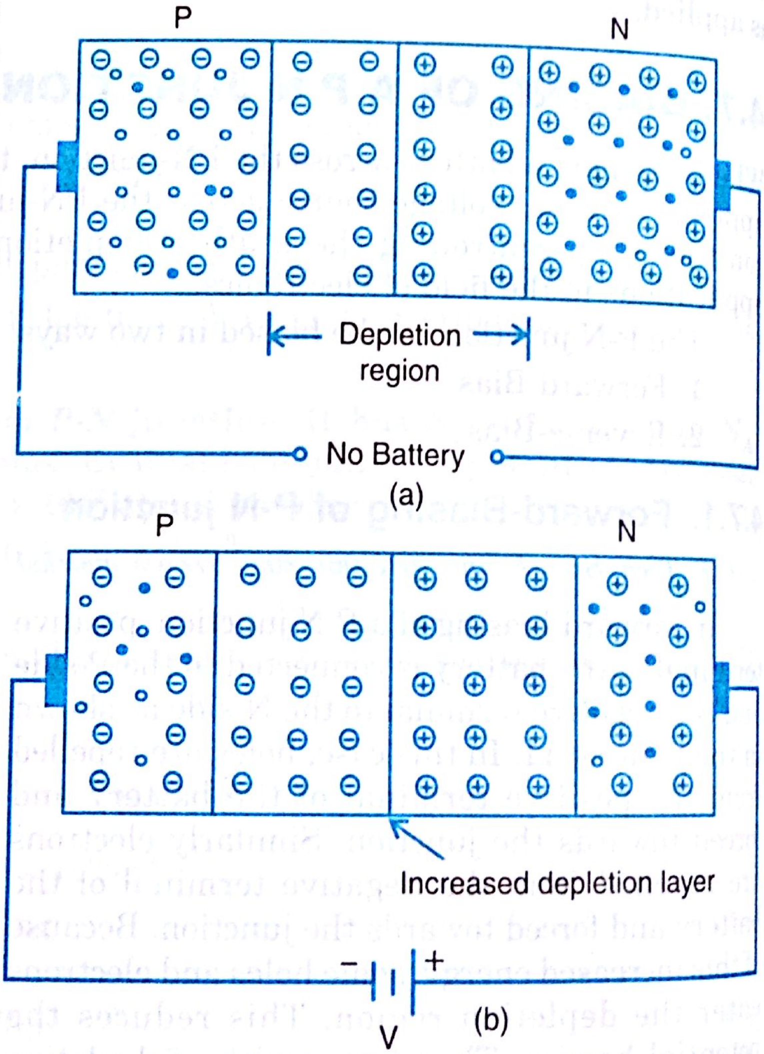


Fig. 4.12. Reverse biasing of PN-junction