Comparison between N type and P type semiconductor

Sl.No.	N type semiconductor	P type semiconductor
1.	N type semiconductor is created by adding pentavalent impurity into pure Silicon or Germanium.	P type semiconductor is created by adding trivalent impurity into pure semiconductor (Si or Ge).
2.	Doping agent is arsenic, antimony etc.	Doping agent is gallium, indium etc.
3.	Here, majority carriers are electrons and minority carriers are holes.	Here, majority carriers are holes and minority carriers are electrons.

4.6 THEORY OF PN JUNCTION

- A junction is formed between a sample of 'P' type semiconductor and a sample of 'N' type semiconductor, both joined together. This device is called the PN junction.
- The formation of PN junction is also called as Diode, because it has two electrodes one for P region named as, Anode and the other for 'N' region named as, Cathode.

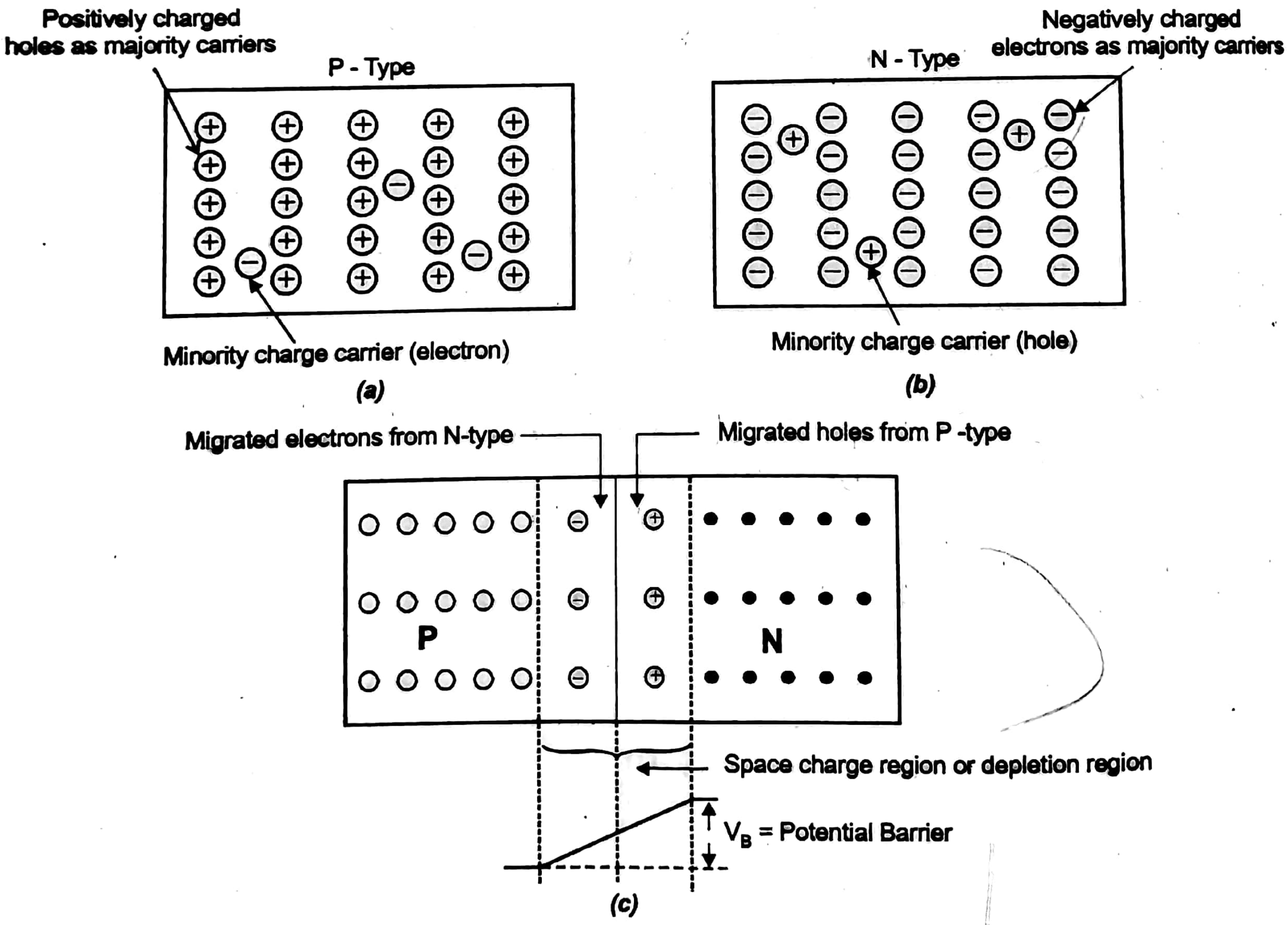

Figure 4.5 Operation of PN junction

- The N type semiconductor has high concentration of free electrons while 'P' type semiconductor has high concentration of holes as shown in figure 4.5 (a). At the junction there is a tendency for the free electrons to move towards the 'P' side and holes to the ' N' side and vice versa. This process is known as Diffusion. The diffusion is the process by which charge carrier move from high concentration area to low concentration area.
- When free electrons diffusing from 'N' side into 'P' side recombine with the holes and leaves negatively charged immobile ions near the junction of 'P' side. Similarly, holes diffusing from 'P' side into 'N' side recombine with electrons and leaves positively charged immobile ions near the junction of 'N' side.
- After certain extent, the immobile positive ions deposited across the 'N' region prevents further charge carrier diffusion from 'P' region into 'N' regions. Similarly, the immobile negative ions deposited across then 'N' regions into 'P' region is restricted. These immobile ions forms a region, known as depletion region. i.e., the region over which all the mobile or free charge carriers are depleted. The region is also known as Space charge region or Charge free region because, there is no free charge carriers are available for conduction.
- The existence of these immobile ions develops the potential difference across the junction, this potential acts as barrier for further conduction between the junction. Thus, this potential is named as barrier potential or cut in voltage of semiconductor diode. The value of barrier potential is 0.3 V for germanium diodes and 0.7 V for silicon diodes.

Junction Voltage or Barrier Voltage

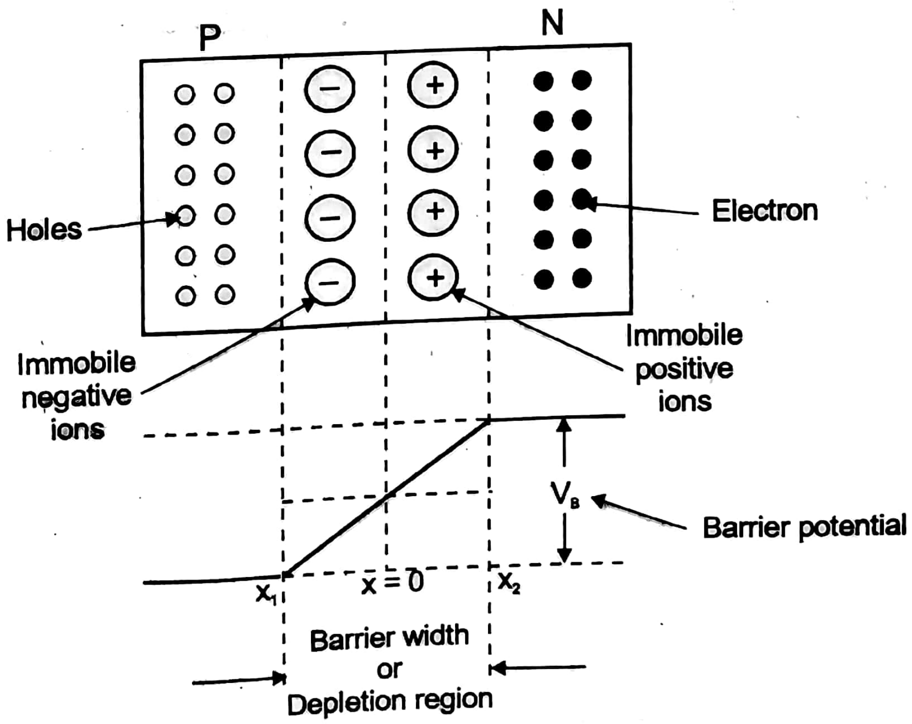

Figure 4.6 Formation of barrier voltage

When the depletion layer is formed there are negative immobile ions in P-type semiconductor and positive immobile ions in N-type semiconductor as shown in figure 4.6. Due to this charge separation, a voltage V_B is developed across the junction under equilibrium condition. This voltage is known as **"junction potential or barrier potential"**.

It is clear from the figure 4.6, that the potential barrier V_B set up in this manner gives rise to an electric field. This electric field prevents the respective majority carriers from crossing the barrier region. The potential barrier is in the order of 0.1 V to 0.3 V for Ge and 0.7 V to 1.1 V for Si.

The barrier potential of a PN junction depends upon three factors namely, density, charge and temperature. For a given PN junction, the first two factors are constant. Thus, making the value of V_B dependent only on temperature. It has been observed that both germanium and silicon diodes decrease their barrier potential by 2 mV/°C.

4.6.1 *Operation of a PN Junction*

In order to understand the working of the PN junction diode, we shall consider the effect of forward bias and reverse bias across the P-N junction.

i) Forward Bias

- In an unbiased PN junction, there is no flow of current. A PN junction connected to an external voltage source is called as **"biased PN junction"**. By this biasing, the width of depletion region is controlled which results in control of its resistance and current flow is possible.
- When an external voltage is applied to the P-N junction, in such a way that it cancels the potential barrier and permits the current flow, it is called as **biasing**.

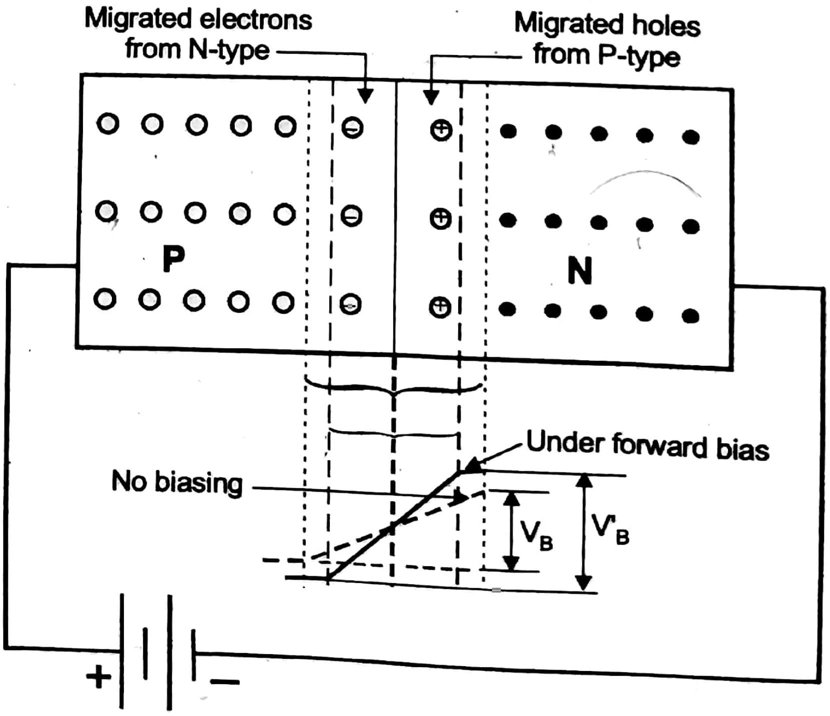

Figure 4.7 Forward biased PN junction

- The positive terminal of a battery connected with P-type semiconductor and the negative terminal connected with N-type semiconductor as shown in the figure 4.7, provides the **forward bias to PN junction.**
- The applied forward potential establishes an electric field opposite to the potential barrier. Therefore, the potential barrier is reduced. As the potential barrier is very small (0.3 V for Ge and 0.7 V for Si), a small forward voltage is sufficient to completely eliminate the barrier potential, thus the junction resistance becomes zero.
- In other words, the applied positive potential repels the holes in the 'P' region so that the holes move towards the junction and applied negative potential repels the electrons in the 'N' region towards the junction results in reduction of depletion region. When the applied potential is more than the internal barrier potential, then the depletion region completely disappear, thus the junction resistance becomes zero.
- Once the potential barrier is eliminated by a forward voltage, junction establishes the low resistance path for the entire circuit, thus a current flows in the circuit, it is called as **forward current.**

ii) Reverse Bias

- When an external voltage is applied to P-N junction in such a way that it increases the potential barrier then it is called as **"reverse bias"**. For reverse bias, the negative terminal is connected to P type semiconductor and positive terminal is connected to N type semiconductor as shown in figure 4.8.

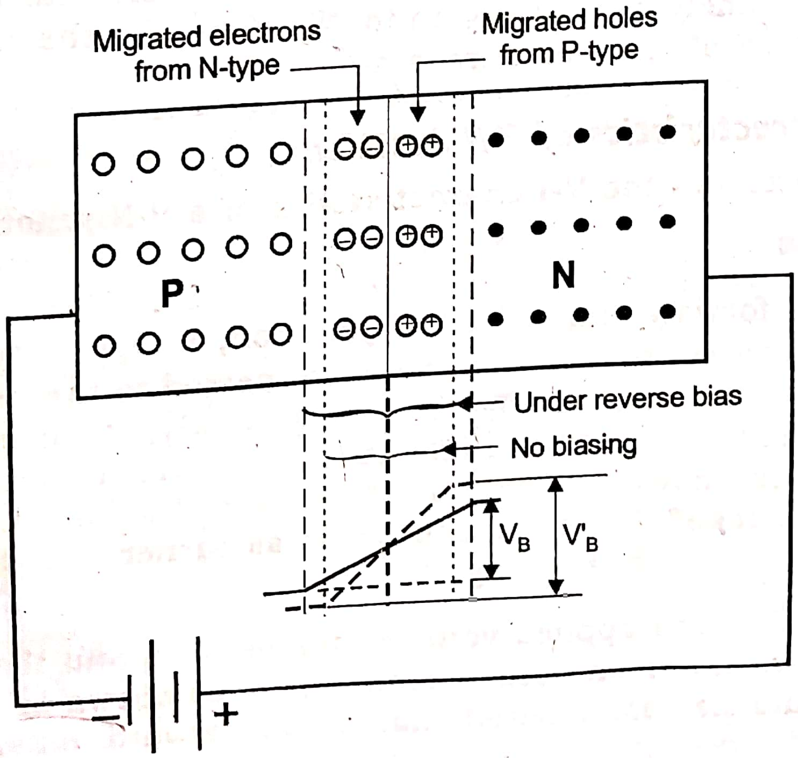

Figure 4.8 Reverse biased P-N junction

- When reverse bias voltage is applied to the junction, all the majority carriers of 'P' region are attached towards the negative terminal of the battery and the majority carriers of the N region are attached towards the positive terminal of the battery, hence the depletion region increases.
- The applied reverse voltage establishes an electric field which acts in the same direction of the potential barrier. Therefore, the resultant field at the junction is strengthened and the barrier width is increased. This increased potential barrier prevents the flow of charges carriers across the junction, results in a high resistance path is established.
- From the above discussion, we conclude that when a P-N junction is forward biased, it has a low resistance path and hence current flows in the circuit due to the majority carriers. On the other hand, when it is reverse biased, it has high resistance path and no current flows in the circuit. This process cannot be continued indefinitely because after certain extent, the junction break down occurs. As a result, a small amount of current flows through it due to minority carriers. This current is known as **"reverse saturation current"**.
- Thus, P-N junction diode is a unilateral device which offers a low resistance when forward biased and behaves like an insulator when reverse biased.

The holes traveling from 'P' region to 'N' region and electrons travelling from 'N' region to 'P' region constitute the conventional currents in the same direction namely from 'P' region to 'N' region. So, the resultant current is the summation of the two currents.

4.6.2 V-I Characteristics of P-N Junction

Figure 4.9 shows the V-I characteristics of a P-N junction diode.

i) Forward Bias

- For the forward bias of a P-N junction, P-type is connected to the positive terminal while N-type is connected to the negative terminal of the battery. On varying this voltage slowly, at some forward voltage the potential barrier is eliminated and current starts flowing. This voltage is known as **"thershold voltage (V_{Th}) or cut in voltage or knee voltage"**. It is practically same as barrier voltage V_B. For $V < V_{Th}$ the current flow is negligible.
- As the forward applied voltage increases beyond threshold voltage, the forward current rises exponentially as shown in the figure 4.17. It should be remembered that, if the forward voltage is increased beyond a certain safe value, it produces an extremely large current which may destroy the junction due to overheating.

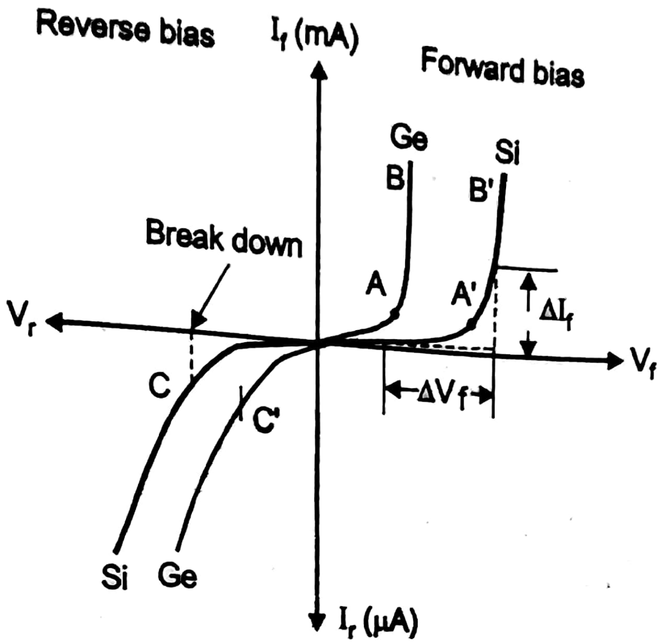

Figure 4.9 V-I characteristics of PN junction diode

- In portion OA or OA' (non linear operating region), even if there is large variation in applied voltage there will be small variation in the current flowing through the diode, because of the depletion region. At point 'A', $V_f = V_{Th} = V_B$ hence, the depletion region disappears result in linear increase of current in portion AB or AB'. This portion is known as **linear operating region** of diode.

  The forward resistance of the diode is obtained from the slope of the curve

$$R_f = \frac{\Delta V_f}{\Delta I_f}$$

ii) Reverse Bias

- For the reverse bias of P-N junction, P-type semiconductor is connected to the negative terminal and N-type semiconductor is connected to the positive terminal of the battery.
- Under this condition, a strong depletion region is formed across the junction. It offers very high resistance, thus very small current flows OC and OC' shown in figure 4.9.
- In this case the junction resistance becomes very high and practically no current flows through the circuit. If the reverse voltage is further increased, the kinetic energy of the electrons become so high that they knock out electrons from semiconductor atoms. At this stage, breakdown of junction occurs which results in sudden rise of reverse current. This current is known as **reverse saturation current**.

  The reverse resistance of the diode is obtained from the slope of the curve

$$R_r = \frac{\Delta V_r}{\Delta I_r}$$

4.6.3 *Diode Resistance*

An ideal diode has zero resistance in forward bias and infinite resistance in reverse bias. But in practice no diode can acts as ideal one.

The ratio of V/I of volt ampere characteristics of diodes gives the **static resistance**. It is the reciprocal of the slope of a line joining the operating point to origin.

AC or Dynamic Resistance

It is defined as reciprocal of the slope of V-I characteristics

$$r_f = \frac{\text{charge in voltage}}{\text{charge in current}} = \frac{\Delta V}{\Delta I}$$

4.6.4 *Applications of PN Diode*

1. As switches
2. As rectifiers
3. Power supplies
4. Clippers and clampers.
5. Digital systems
6. Communication systems