UNIT 10 ELECTRONICS AND COMMUNICATION

Warm greetings:

Dear students

Welcome all. In this class we are going to discuss about

- Diodes
- P-N Junction diode:
- Characteristics of a junction diode
- Forward bias
- Reverse bias

DIODES:

P-N Junction formation :

i) Formation of depletion layer:

A single piece of semiconductor crystal is suitably doped such that its one side is *p*-type semiconductor and the other side is *n*-type semiconductor. The contact surface between the two sides is called *p-n* junction.

Whenever *p-n* junction is formed, some of the free electrons diffuse from the *n*-side to the *p*-side while the holes from the *p*-side to the *n*-side. The diffusion of charge carriers happens due to the fact that the *n*-side has higher electron concentration and the *p*-side has higher hole concentration.

The diffusion of the majority charge carriers across the junction gives rise to an electric current, called diffusion current.

When an electron leaves the *n*-side, a pentavalent atom in the *n*-side becomes a positive ion. The free electron migrating into *p*-side recombines with a hole present in a trivalent atom near the junction and the trivalent atom becomes a negative ion.

Since such ions are bonded to the neighbouring atoms in the crystal lattice, they are unable to move. As the diffusion process continues, a layer of positive ions and a layer of negative ions are created on either side of the junction accordingly.

The thin region near the junction which is free from charge carriers (free electrons and holes) is called depletion region (Figure 10.9).

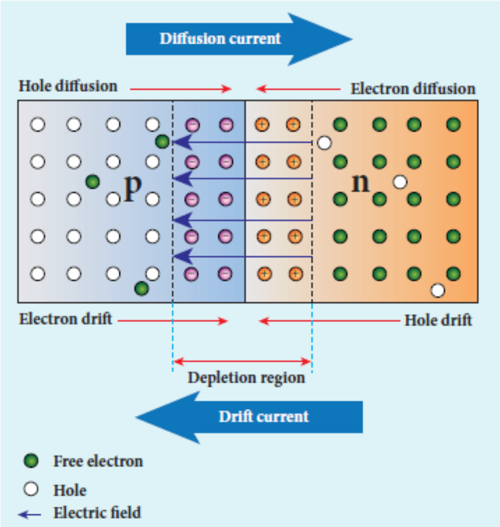


Figure 10.9 Formation of *p–n* junction

- An electric field is set up between the positively charged layer in the *n*-side and the negatively charged layer in the *p*-side in the depletion region as shown in the Figure 10.9.
- This electric field makes electrons in the *p*-side drift into the *n*-side and the holes in the *n*-side into the *p*-side.
- **The electric current produced due to the motion of the minority charge carriers by the electric field is known as drift current**.
- The diffusion current and drift current flow in opposite directions.
- Though drift current is less than diffusion current initially, equilibrium is reached between them at a particular time.
- With each electron (or hole) diffusing across the junction, the strength of the electric field increases thereby increasing the drift current till the two currents become equal.
- Hence at equilibrium, there is no net electric current across the junction. Thus, a *p-n* junction is formed.

ii) Junction potential or barrier potential:

- ❖ The movement of charge carriers across the junction takes place only to a certain point beyond which the depletion layer acts like a barrier to further diffusion of free charges across the junction.
- ❖ This is due to the fact that the immobile ions on both sides establish an electric potential difference across the junction.

- Therefore, an electron trying to diffuse into the interior of the depletion region encounters a wall of negative ions repelling it backwards.
- If the free electron has enough energy, it can break through the wall and enter into the *p*-region, where it can recombine with a hole and create another negative ion.

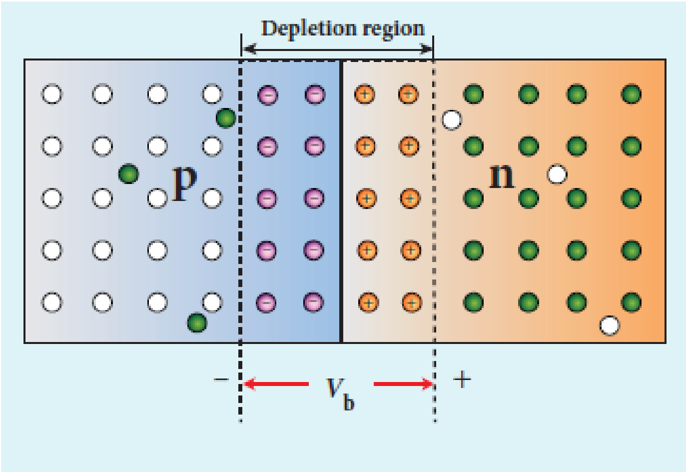
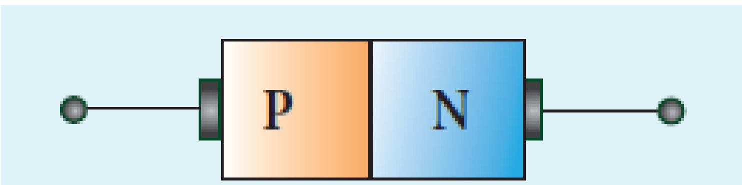


Figure 10.10 Barrier potential formed across the junction

- The strength of the electric potential difference across the depletion region keeps on increasing with the crossing of each electron until equilibrium is reached; at this point, the internal repulsion of the depletion layer stops further diffusion of free electrons across the junction.
- **Difference in potential across the depletion layer is called the barrier potential (V_b)** as shown in Figure 10.10. At 25 ^{0}C, this barrier potential is approximately 0.7 V for silicon and 0.3 V for germanium.

P-N Junction diode:

A *p-n* junction diode is formed when a *p*-type semiconductor is fused with an *n*-type semiconductor. It is a device with single *p-n* junction as shown in Figure 10.11(a) and its circuit symbol is shown in Figure 10.11(b).



(a)

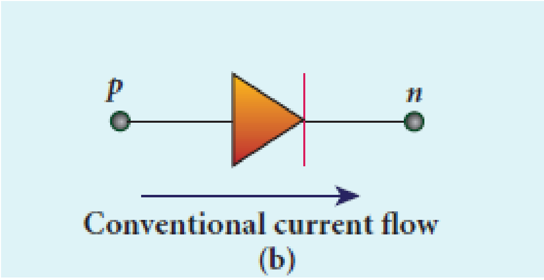


Figure 10.11 *p-n* junction diode
(a) Schematic representation
(b) Circuit symbol

Biasing a diode;

Biasing means providing external energy to charge carriers to overcome the barrier potential and make them move in a particular direction. The charge carriers can either move towards the junction or away from the junction. **The external voltage applied to the *p-n* junction is called bias voltage**. Depending on the polarity of the external source to the *p-n* junction, we have two types of biasing:

i) Forward bias
ii) Reverse bias

i) Forward bias:

- If the positive terminal of the external voltage source is connected to the *p*-side and the negative terminal to the *n*-side, it is called forward bias as shown in Figure 10.12.
- The application of a forward bias potential pushes electrons in the *n*-side and the holes in the *p*-side towards the junction.
- This initiates the recombination with the ions near the junction which in turn reduces the width of the depletion region and hence the barrier potential.
- The electron from the *n*-side is now accelerated towards the *p*-side as it experiences a reduced barrier potential at the junction
- In addition, the accelerated electrons experience a strong attraction by the positive potential applied to the *p*-side. This results in the movement of electrons in the *n*-side towards the *p*-side and similarly, holes in the *p*-side towards the *n*-side.
- When the applied voltage is increased, the width of the depletion region and hence the barrier potential are further reduced.
- This results in a large number of electrons passing through the junction resulting in an exponential rise in current through the junction.

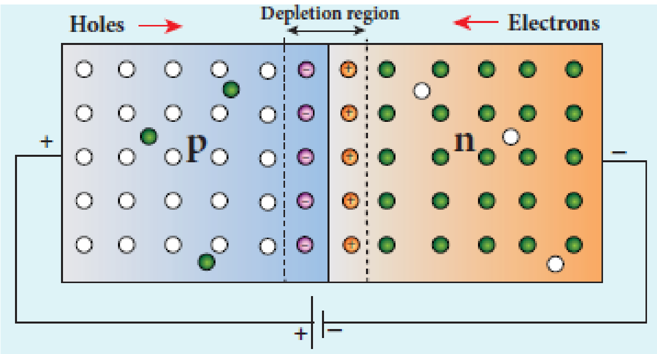


Figure 10.12 Schematic representation of a *p-n* junction diode under forward bias

ii) Reverse bias:

- If the positive terminal of the battery is connected to the *n*-side and the negative terminal to the *p*-side, the junction is said to be reverse biased as shown in Figure 10.13.

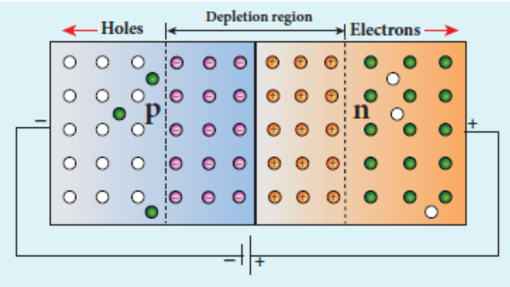


Figure 10.13 Schematic representation of a *p-n* junction diode under reverse bias

- As the positive terminal is connected to the *n*-type material, the electrons in the *n*-side are attracted towards the positive terminal and the holes in the *p*-side are attracted by the negative terminal.
- This increases the immobile ion concentration at the junction. The net effect is the widening of the depletion region leading to an increase in the barrier potential.
- Consequently, the majority charge carriers from both sides experience a great potential barrier to cross the junction.
- This reduces the diffusion current across the junction drastically.
- Yet, a small current flows across the junction due to the minority charge carriers in both regions.
- The reverse bias for majority charge carriers serves as the forward bias for minority charge carriers.

- The current that flows under a reverse bias is called the reverse saturation current**.** It is represented as I_S.
- The reverse saturation current is independent of the applied voltage and it depends only on the concentration of the thermally generated minority charge carriers.
- Even a small voltage is sufficient enough to drive the minority charge carriers across the junction.

Characteristics of a junction diode:

i) Forward characteristics:

⇒ It is the study of the variation in current through the diode with respect to the applied voltage across the diode when it is forward biased.

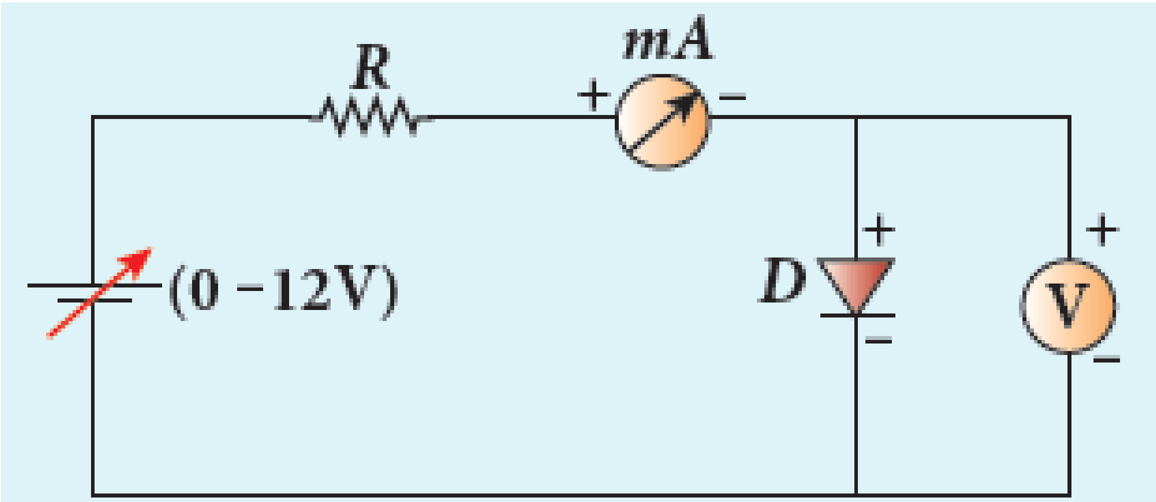
⇒ The *p-n* junction diode is forward biased as shown in Figure 10.14(a). An external resistance (*R*) is used to limit the flow of current through the diode.

⇒ The voltage across the diode is varied by varying the biasing voltage across the DC power supply. The forward bias voltage and the corresponding forward bias current are noted.

⇒ A graph is plotted by taking the forward bias voltage (V_F) along the x-axis and the current (I_F) through the diode along the y-axis.

⇒ This graph is called the **forward V-I characteristics** of the *p-n* junction diode and is shown in Figure 10.14(b).

⇒ Four inferences can be brought out from the graph:



(a)

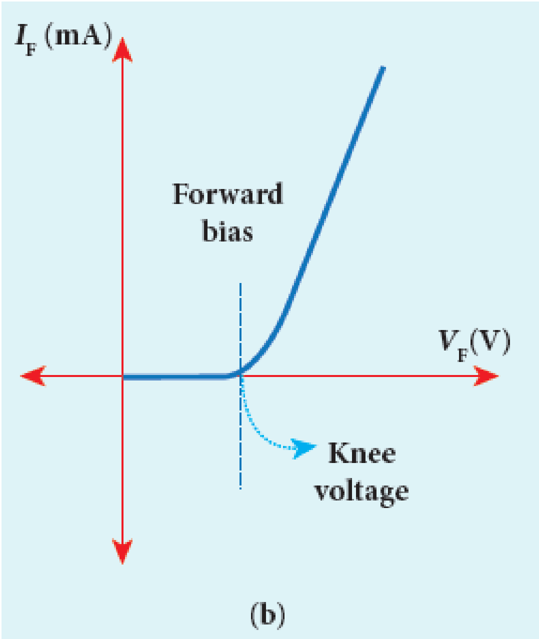


Figure 10.14 *p-n* junction diode
(a) Diode under forward bias
(b) Forward characteristics

(i) At room temperature, a potential difference equal to the barrier potential is required before a reasonable forward current starts flowing across the diode. This voltage is known as **threshold voltage or cut-in voltage or knee voltage** (V_{knee}). It is approximately 0.3 V for germanium and 0.7 V for silicon. The current flow is negligible when the applied voltage is less than the threshold voltage. Beyond the threshold voltage, increase in current is significant even for a small increase in voltage.

(ii) The graph clearly infers that the current flow is not linear and is exponential. Hence it does not obey Ohm's law.

(iii) The forward resistance (r_F) of the diode is the ratio of the small change in voltage (ΔV_F)to the small change in current(ΔI_F). That is,

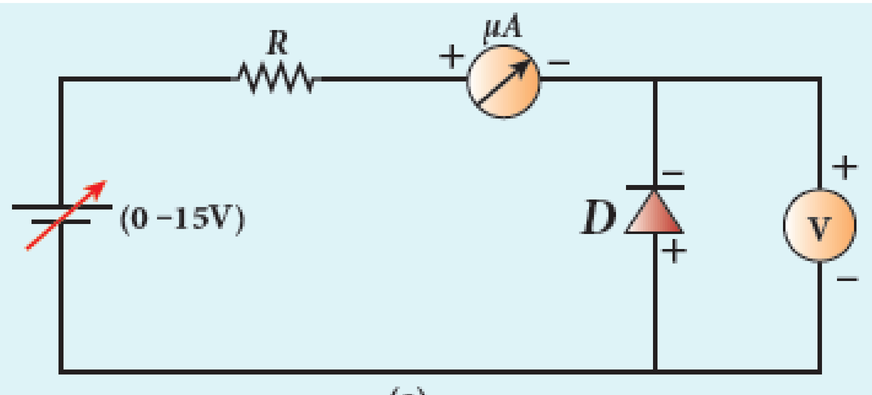
$$r_F = \frac{\Delta V_F}{\Delta I_F}.$$

(iv) Thus the diode behaves as a conductor when it is forward biased.

However, if the applied voltage is increased beyond a rated value, it will produce an extremely large current which may destroy the junction due to overheating. This is called as the breakdown of the diode and the voltage at which the diode breaks down is called the breakdown voltage. Thus, it is safe to operate a diode between the threshold voltage and the breakdown voltage.

ii) Reverse characteristics:

- The circuit to study the reverse characteristics is shown in Figure 10.15(a). In the reverse bias, the *p*-side of the diode is connected to the negative terminal and *n*-side to the positive terminal of the dc power supply.
- A graph drawn between the reverse bias voltage and the current across the junction is called the reverse characteristics of a *p*-*n* junction diode. It is shown in Figure 10.15(b).
- Under this bias, a very small current in μA flows across the junction. This is due to the flow of the minority charge carriers and is called the leakage current or reverse saturation current.
- This reverse current is independent of the voltage up to a certain voltage, known as breakdown voltage.



(a)

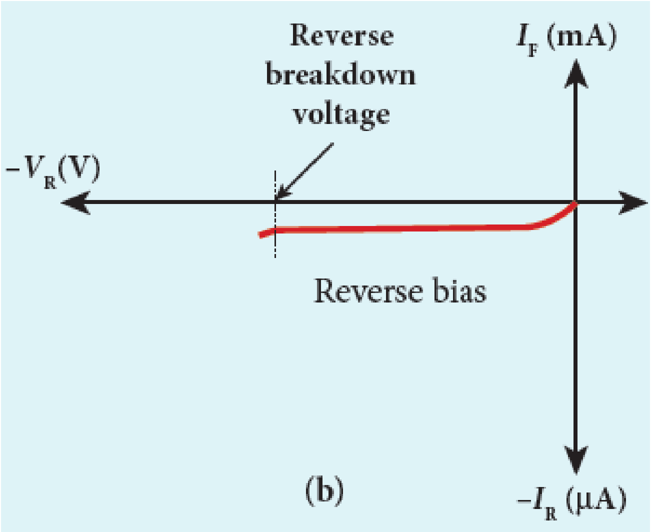


Figure 10.15 *p-n* junction diode
(a) Diode under reverse bias
(b) Reverse characteristics

The forward and reverse charactristics are given in one graph as shown in Figure 10.16.

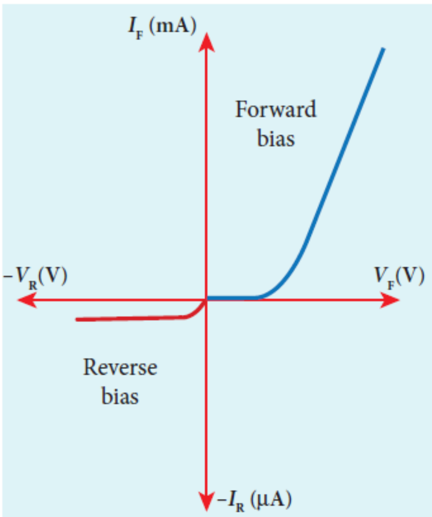


Figure 10.16 Forward and reverse charactristics of a diode

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