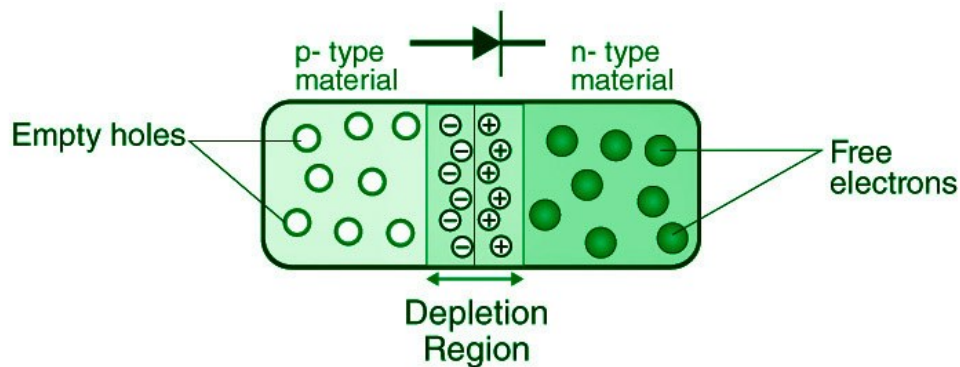


Formation of P-N Junction

When we utilise various semiconductor materials to form a p-n junction, there will be a grain boundary that will prevent electrons from moving from one side to the other by scattering electrons and holes, which is why we employ the doping procedure.

For example, consider a p-type silicon semiconductor sheet that is very thin. A portion of the p-type Si will be changed to n-type silicon if a tiny quantity of pentavalent impurity is added. This sheet will now have both a p-type and an n-type area, as well as a junction between the two. Diffusion and drift are the two sorts of processes that occur following the creation of a p-n junction. As we all know, the concentration of holes and electrons on the two sides of a junction differs, with holes from the p-side diffusing to the n-side and electrons from the n-side diffusing to the p-side. This causes a diffusion current to flow across the connection.



When an electron diffuses from the n-side to the p-side, it leaves an ionised donor on the n-side, which is stationary. On the n-side of the junction, a layer of positive charge develops as the process progresses. When a hole is moved from the p-side to the n-side, an ionised acceptor is left behind on the p-side, causing a layer of negative charges to develop on the p-side of the junction. The depletion area is defined as a region of positive and negative charge on each side of the junction. An electric field direction from a positive charge to a negative charge is generated due to this positive space charge area on each side of the junction. An electron on the p-side of the junction travels to the n-side of the junction due to the electric field. The drift is the name given to this motion. We can observe that the drift current runs in the opposite direction as the diffusion current.

Biasing conditions for the p-n Junction Diode

In a p-n junction diode, there are two operational regions:

1. p-type
2. n-type

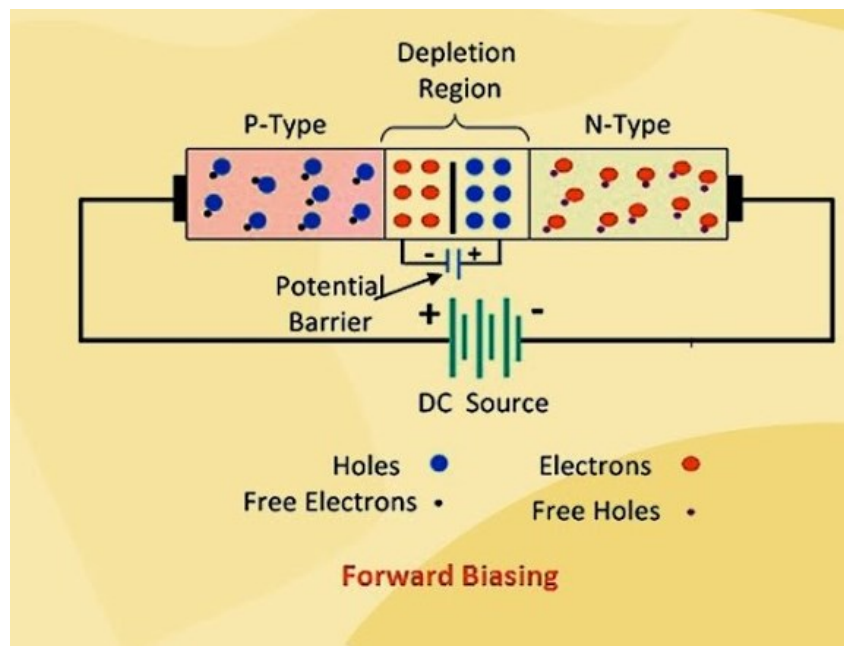
The voltage applied determines one of three biasing conditions for p-n junction diodes: There is no external voltage provided to the p-n junction diode while it is at **zero bias**.

Forward bias: The p-type is linked to the positive terminal of the voltage potential, while the n-type is connected to the negative terminal.

Reverse bias: The p-type is linked to the negative terminal of the voltage potential, while the n-type is connected to the positive terminal.

Forward and Reverse Bias of a PN Junction

Forward Biased PN Junction



A PN junction is said to be **forward-biased** when the p-type region of a junction is connected to the positive terminal of a voltage source and the n-type region is connected to the voltage source's negative terminal.

In this forward-biased condition, due to the attraction of the positive terminal of the source, electrons that participated in covalent bond creation in the p-type material will be attracted towards the terminal. As a result, the number of covalent bonds is broken, and electrons are shifted towards the positive terminal. This results in the electrons' concentration in the crystal closer to the terminal to increase, and these electrons recombine with holes here.

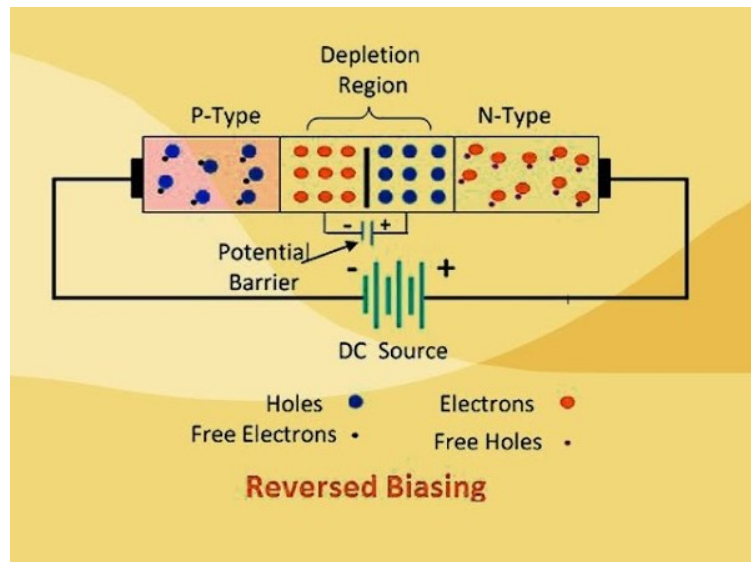
In this way, the number of holes increases in the portion of the p-type region away from the junction, and it is reduced in the portion of the p-type region nearer to the terminal as such holes are shifted from terminal to junction. Due to the higher concentration of holes adjacent to the negative impurity ions layer, the electrons of negative ions come out and recombine with those holes and create new holes in the layer. Consequently, the width of this negative ions

layer is reduced, and finally, this layer vanishes. Similarly, due to the negative terminal of the source, the free electrons in the n-type region will repel towards the junction where they will find the layer of positive impurity ions and start recombining with these ions and generate free electrons inside the layer. Consequently, the width of positive impurity ions is reduced, and finally, it vanishes.

In these ways, both layers of ions disappear, and there will be no more depletion layer. After the depletion layer disappeared, free electrons from the n-type region can easily drift to the p-type region and holes from the p-type region to the n-type region in the crystal.

Hence, ideally, there will be no obstruction of flowing current, and the PN junction behaves as the short circuit.

Reverse Biased PN Junction



When the positive terminal of a voltage source is connected to the n-type region and the negative terminal of the source is connected to the p-type region. The PN junction is said to be in reverse biased condition. When there is no voltage applied across the p n junction, the potential developed across the junction is 0.3 volts at 25°C for germanium on the junction and 0.7 volts at 25°C for silicon p n junction.

The polarity of this potential barrier is the same as the voltage source's polarity applied during the reverse biased condition. If the reverse biased voltage across the PN junction is increased the barrier potential developed across the PN junction is also increased. Hence, the PN junction is widened.

When positive terminal of the source is connected to the n-type region, the free electrons of that region are attracted towards the positive terminal of the source because of that more

positive impurity ions are created in the depletion layer which makes the layer of positive impurity ions thicker.

At the same time since the negative terminal of the source is connected to the p-type region of the junction, electrons are injected in this region. Due to the positive potential of the n-type region, the electrons are drifted towards the junction and combine with holes adjacent to the layer of positive impurity ions and create more positive impurity ions in the layer. Hence, the thickness of the layer increases.

In this way, the overall width of the depletion layer increases along with its barrier potential. This increment of the depletion layer's width will continue till the barrier potential reaches to applied reverse biased voltage.

Although this increment of barrier potential will continue up to applied reverse-biased voltage, if the applied reverse biased voltage is sufficiently high, then the depletion layer will disappear due to Zener breakdown and avalanche breakdowns.

It is also to be noted that after completion of reverse biased depletion layer there is no more drift of charge carriers (electrons and holes) through the junction as the potential barrier opposes the applied voltage which has the same value as the potential barrier.

Although tiny current flow from n-type region to p-type region due to minority carriers that are thermally generated electrons in p-type semiconductor and holes in an n-type semiconductor.

Forward Current in PN Junction

When the battery voltage is applied across the forward bias junction, a current will flow continuously through this junction.

$$\text{Forward biased current } i_D = I_s \left(e^{\frac{V_D}{nV_T}} - 1 \right)$$

I_s is Saturation Current (10^{-9} to 10^{-18} A)

V_T is Volt-equivalent temperature (= 26 mV at room temperature)

n is the Emission coefficient ($1 \leq n \leq 2$ for Si ICs)

Actually, this expression is approximated.

Reverse Current in PN Junction

When a p-n junction is connected across a battery in such a manner that its n-type region is connected to the positive polarity of the battery and the p-type region is connected to the negative polarity of the battery the p n junction is said to be in reverse biased condition. Ideally, there is no current flowing through the junction. But practically there will be a tiny reverse bias current i_D which is expressed as.

i_D drops to zero value or minimum value. i_D can be written as i_0 .

$$\text{Reverse biased current } i_0 \approx I_s e^{\frac{V_D}{nV_T}}$$

I_s is Saturation Current (10^{-9} to 10^{-18} A)

V_T is Volt-equivalent temperature (= 26 mV at room temperature)

n is the Emission coefficient ($1 \leq n \leq 2$ for Si ICs)

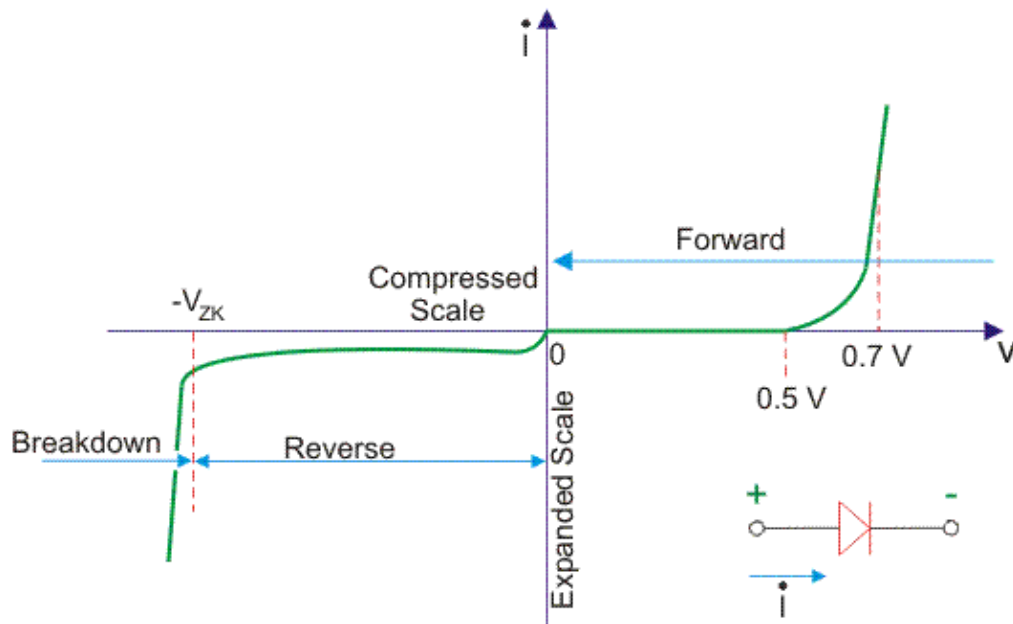
Actually, this expression is approximated.

General Specification of PN Junction

A p-n junction is specified in four manners.

1. Forward Voltage Drop (V_F): Is the forward biasing junction level voltage (0.3V for Germanium and 0.7V for Silicon Diode)
2. Average Forward Current (I_F): It is the forward-biased current due to the drift electron flow or the majority carriers. If the average forward current exceeds its value, the diode gets overheated and may be damaged.
3. Peak Reverse Voltage (V_R): The maximum reverse voltage across the diode at its reverse biased condition. Over this reverse voltage diode will go for breakdown due to its minority carriers.
4. Maximum Power Dissipation (P): It is the product of the forward current and the forward voltage.

V-I Characteristics of A PN Junction



In the forward bias, the operational region is in the first quadrant. The threshold voltage for Germanium is 0.3 V and for Silicon is 0.7 V. Beyond this threshold voltage, the graph goes upward in a non-linear manner. This graph is for the dynamic Resistance of the junction in the forward bias.

In the reverse bias the voltage increases in the reverse direction across the p-n junction, but no current due to the majority carriers, only a minimal leakage current flows. But at a certain reverse voltage p-n junction breaks in conduction.

It is only due to the minority carriers. This amount of voltage is sufficient for these minority carriers to break the depletion region. In this situation, a sharp current will flow through this junction. This breakdown of voltage is of two types.

- Avalanche Breakdown: it is not a sharp graph, rather inclined linear graph, i.e. after the break down a small increase in reverse voltage causes more sharp current gradually.
- Zener Breakdown: This breakdown is sharp and no need to increase reverse bias voltage to get more current, because current flows sharply.

PN JUNCTION BREAKDOWN CHARACTERISTICS