PN-JUNCTION DIODE

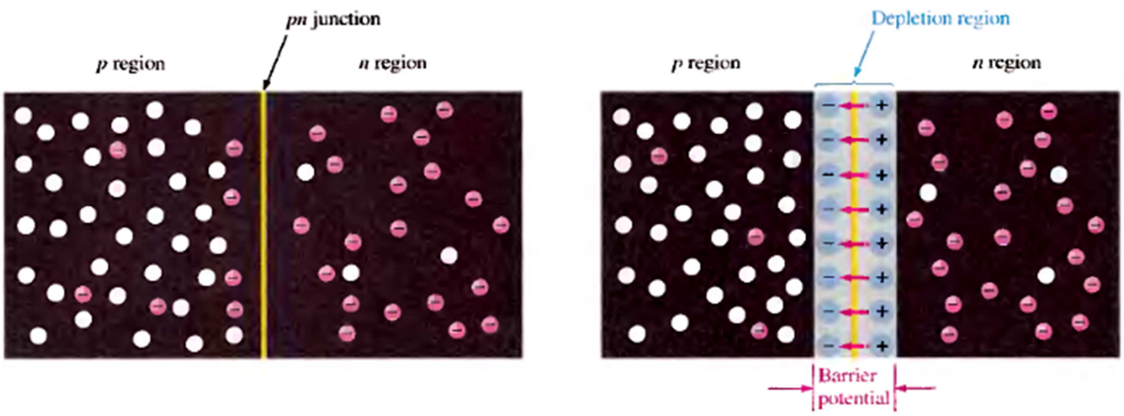
PN-Junction Diode

If a piece of intrinsic silicon is doped so that a part is n-type and the other part is p-type, then the boundary between the p-type and n-type is called PN-junction diode.

The p region has many holes (majority carriers) from the impurity atoms and only a few thermally generated free electrons (minority carriers). The n region has many free electrons (majority carriers) from the impurity atoms and only a few thermally generated holes (minority carriers).

Formation of the Depletion Region

When a p-type semiconductor is brought close an n-type to form a PN-junction, then the free electrons near the junction in the n region begin to diffuse across the junction into the p-type region where they combine with holes near the junction, as shown in figure below:



When the PN-junction is formed, the n region loses free electrons as they diffuse across the junction. This creates a layer of positive charges (pentavalent ions) near the junction. As the electrons move across the junction, the p region loses holes as the electrons and holes combine. This creates a layer of negative charges (trivalent ions) near the junction. These two layers of positive and negative charges form the depletion region.

The term depletion refers to the fact that the region near the PN-junction is depleted of charge carriers (electrons and holes) due to diffusion across the junction. After the initial surge of free electrons across the PN-junction, the depletion region has expanded to a point where equilibrium is established and there is no further diffusion of electrons across the junction. In other words, the depletion region acts as a barrier to the further movement of electrons across the junction.

Barrier Potential

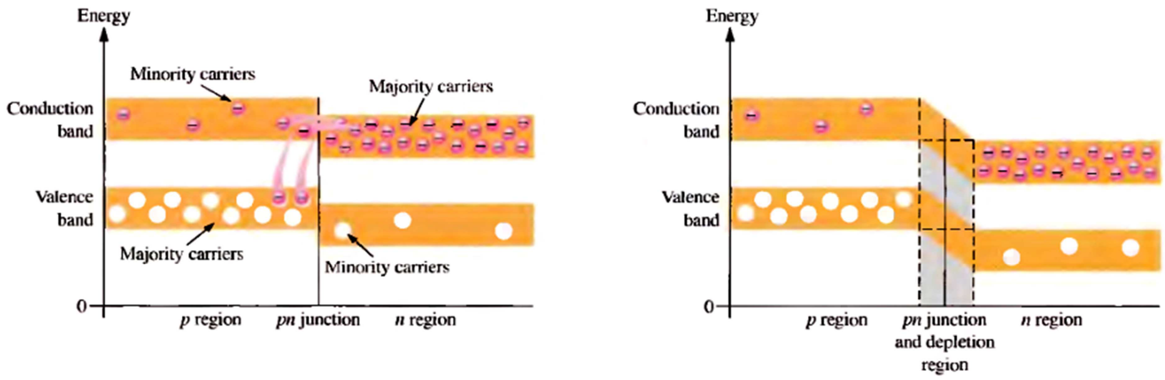
In the depletion region there are many positive charges and many negative charges on opposite sides of the PN-junction. The forces between the opposite charges form a "field of forces" called an electric field. This electric field is a barrier to the free electrons in the n region, and energy must be expended to move an electron through the electric field. That is, external energy must be applied to get the electrons to move across the barrier of the electric field in the depletion region.

The potential difference of the electric field across the depletion region is the amount of voltage required to move electrons through the electric field. This potential difference is called the barrier potential and is expressed in volts. The typical barrier potential is approximately 0.7 V for silicon and 0.3 V for germanium at 25°C.

Energy Diagrams of the PN-Junction and Depletion Region

The valence and conduction bands in an n-type material are at slightly lower energy levels than the valence and conduction bands in a p-type material. This is due to differences in the atomic characteristics of the pentavalent and the trivalent impurity atoms. The valence and conduction bands in the n region are at lower energy levels than those in the p region, but there is a significant amount of overlapping.

The free electrons in the n region that occupy the upper part of the conduction band in terms of their energy can easily diffuse across the junction and temporarily become free electrons in the lower part of the p-region conduction band. After crossing the junction, the electrons quickly lose energy and fall into the holes in the p-region valence band as indicated in figure below:



(a) At the instant of junction formation (b) At equilibrium

As the diffusion continues, the depletion region begins to form and the energy level of the n-region conduction band decreases. The decrease in the energy level of the conduction band in the n region is due to the loss of the higher-energy electrons that have diffused across the junction to the p region. Soon, there are no electrons left in the n-region conduction band with enough energy to get across the junction to the p-region conduction band. At this point, the junction is at equilibrium; and the depletion region is complete because diffusion has ceased. There is an energy gradiant across the depletion region which acts as an "energy hill" that an n-region electron must climb to get to the p region.

Notice that as the energy level of the n-region conduction band has shifted downward, the energy level of the valence band has also shifted downward. It still takes the same amount of energy for a valence electron to become a free electron. In other words, the energy gap between the valence band and the conduction band remains the same.

Biasing

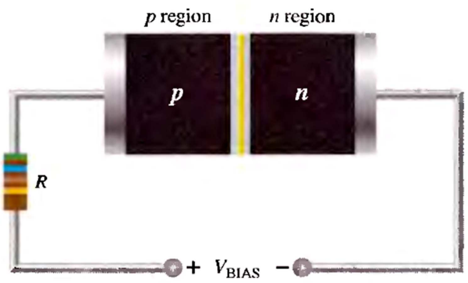
Application of an external voltage to the PN-junction is called biasing. There are two types of biasing:

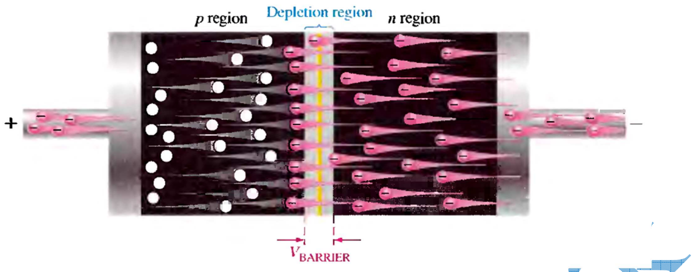
Forward Biasing

Reverse Biasing

Forward Biasing

A junction diode is said to be forward biased if its P-type region is connected to the positive terminal and N-type region is connected to the negative terminal of the battery.



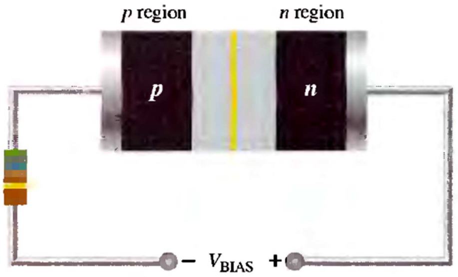


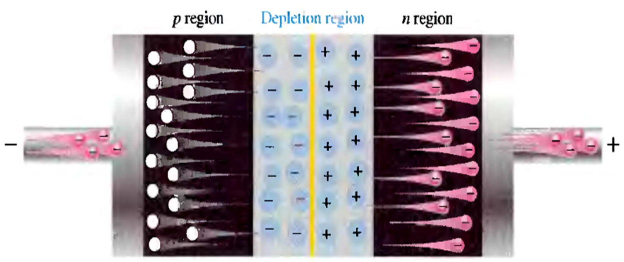
The emf of the battery should be greater than the barrier potential of the junction. Under such conditions, the electrons from N-type region and the holes from P-type region are pushed towards the junction and neutralize the positive and negative ions in depletion region. So the width of depletion region is decreased during forward biasing.

When the depletion region is decreased, then the electrons from N-type moves towards P-type and holes from P-type move towards N-type. This results in flow of current across the junction. Hence the junction diode is conductive when it is forward biased.

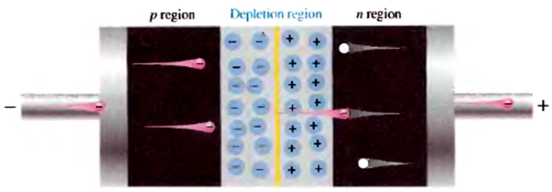
Reverse Biasing

A junction diode is said to be reversed biased, if its P-type region in connected with the negative terminal and N-type region with positive terminal of the battery.





In reverse biasing, the negative terminal attracts the holes and the positive terminal attracts the electrons away from the junction, so that the depletion region is widened and the barrier potential increases with increase in applied voltage. With increase of barrier potential there is no possibility of majority charge carriers to flow across the junction. Hence a junction diode does not conduct when it is reversed biased.



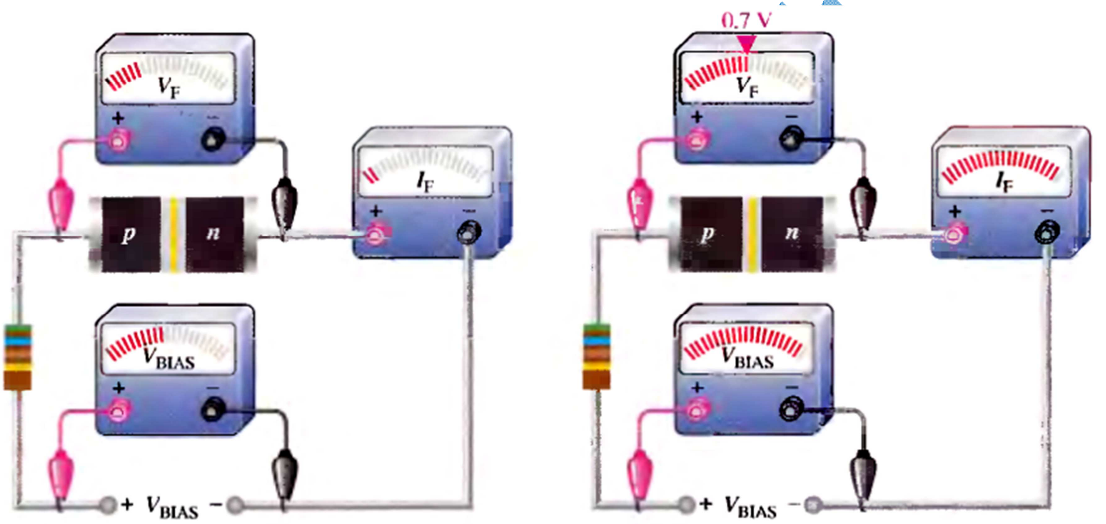
However a very small current (of the order of a few micro-amperes) flow in the circuit due to minority charge carriers, which is called a reverse current.

Characteristics of a PN-Junction

A graph between current and voltage applied across the PN-junction is called characteristics of PN-junction.

V-I Characteristic for Forward Bias

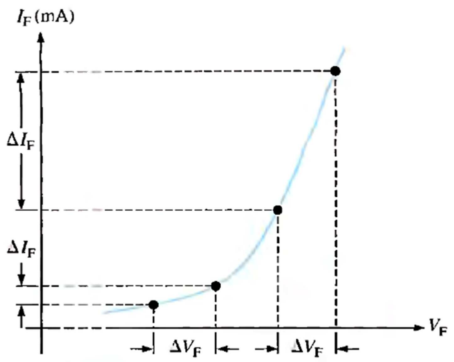
When a forward-bias voltage is applied across a diode, there is current. This current is called the forward current and is designated I_F as the forward-bias voltage is increased positively from 0 V. The resistor is used to limit the forward current to a value that will not overheat the diode and cause damage.



(a) Small forward-bias voltage ($V_F < 0.7$ V), very small forward current.

(b) Forward voltage reaches and remains at approximately 0.7 V. Forward current continues to increase as the bias voltage is increased.

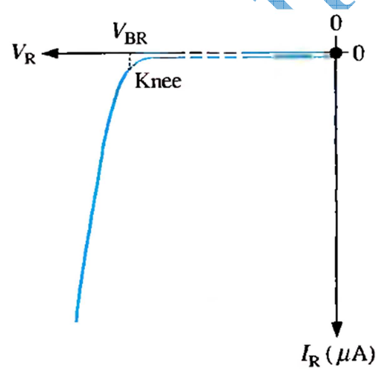
With 0 V across the diode, there is no forward current. As the forward-bias voltage is gradually increased, the forward current and the voltage across the diode gradually increase. When the forward-bias voltage is increased to a value where the voltage across the diode reaches approximately 0.7 V (barrier potential), the forward current begins to increase rapidly.



It can be seen from the curve that the forward current I_F is very small until the forward voltage V_F the barrier potential, of about 0.7 volts for silicon. As the forward voltage exceeds the value of barrier potential, called knee voltage, the current starts to increase rapidly. Beyond the knee of the forward characteristic, I_F increases almost linearly with increase in V_F.

V-I Characteristic for Reverse Bias

When a reverse-bias voltage is applied across a diode, there is only an extremely small reverse current (I_R) through the PN-junction. With 0 V across the diode. there is no reverse current. As you gradually increase the reverse-bias voltage, there is a very small reverse current and the voltage across the diode increases. When the applied bias voltage is increased to a value where the reverse voltage across the diode (V_R) reaches the breakdown value (V_{BR}), the reverse current begins to increase rapidly.



As you continue to increase the bias voltage, the current continues to increase very rapidly, but the voltage across the diode increases very little above V_{BR}. Breakdown, with exceptions, is not a normal mode of operation for most PN-junction devices.

At breakdown voltage the covalent bonds of the crystal start breaking and charge carriers produced which result in heavy flow of reverse current through diode.

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