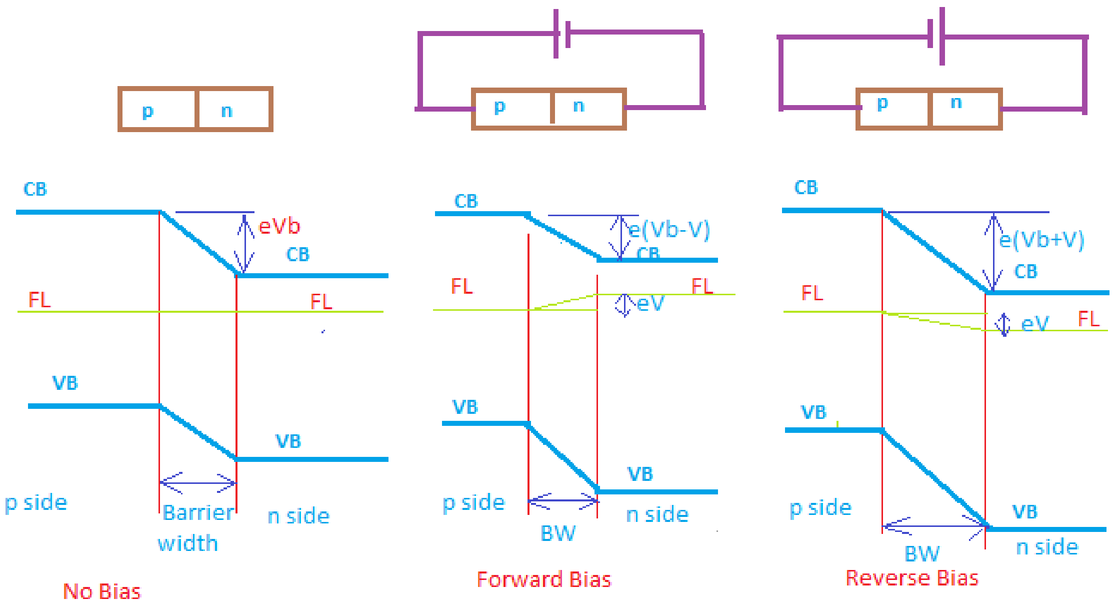
BIASING OF PN JUNCTION

When PN junction is in equilibrium, the number of carriers diffusing from p side to n side is equal to the number of carriers diffusing from n side to p side. Consequently, there is no current across the junction.

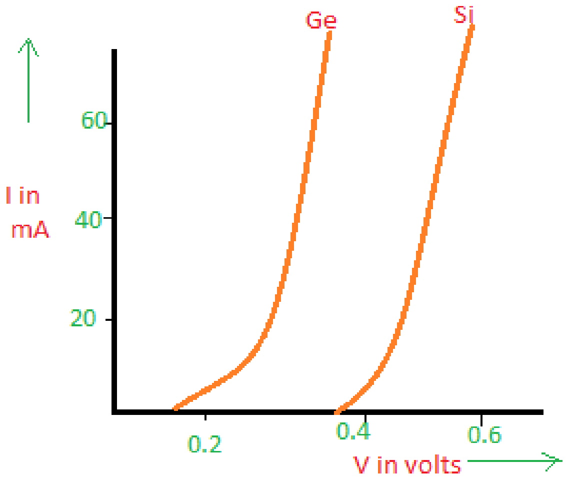


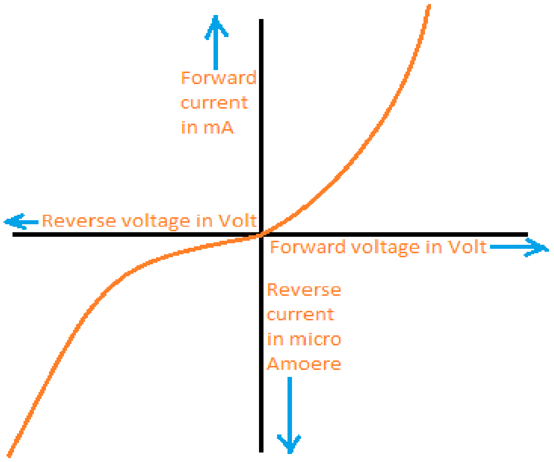
PN JUNCTION WITH FORWARD BIAS

In forward bias condition, due to external bias, equilibrium conditions are disturbed and therefore energy bands and Fermi level are altered. The negative terminal of the battery is connected to the n-type side, the energy of the electrons in n-type region increases by an amount eV, where V is the voltage applied by the battery. Consequently, the Fermi level raises by eV and the energy bands adjust their positions so as to suit the elevation of Fermi level. Due to the increase in energy on n-type side, potential barrier is reduced to $e(V_B - V)$. Space charge region width or barrier width or depletion width also reduced. The net result is that the electrons crossing the junction from n side will now face a low potential barrier and small widths of space charge region. Consequently, they can easily cross the junction. Since the electron in the n-type side are in majority, current across the junction increase considerably.

REVERSE BIAS

When n side is connected to the positive terminal of the battery, this lowers the Fermi level on n side by an amount eV raising the barrier height to $e(V_B + V)$ and increasing the depletion width too. The electrons that are in majority in n side will now face, in crossing the junction, a greater potential barrier and larger width of space charge region. Therefore, number of electrons crossing the space charge region from n side to p side decreases. Consequently, current is very much reduced in reverse biasing of PN junction. Thus, PN junction acts as a rectifier like vacuum diode.





BREAKDOWN OF PN JUNCTION

When a large reverse bias is applied, PN junction breaks down. This break down occurs due to two main reasons:

AVALANCHE BREAKDOWN

When the applied reverse bias in a PN junction increases, the field across the junction increases correspondingly. At some value of bias, the field becomes so large that the few minority carriers while traversing the junction acquires a large amount of energy from the field. These carriers are then able to disrupt covalent bonds and create new electron hole pairs while colliding with immobile ions. These newly generated carriers again pick up sufficient energy from the applied field. Now they collide with other immobile ions generating further electron-hole pairs. The process is cumulative. This mechanism of carrier generation is referred as avalanche multiplication. As we approach the breakdown voltage, the field becomes so large that the chain of collisions can give rise to an almost infinite current with very slight increase in voltage. This process is known as impact ionisation.

EFFECT OF TEMPERATURE ON THE AVALANCHE BREAKDOWN VOLTAGE

The magnitude of the avalanche breakdown voltage increases as the junction temperature increases. As the junction temperature increases, the amplitude of vibrations of crystal atoms increases. Therefore, the probability of collisions, with the crystal atoms increases. Consequently, there will be loss of energy of the electrons. Therefore, to make up the loss and to start the avalanche process the applied reverse voltage should be increased.

ZENER BREAKDOWN

Zener breakdown takes place in very thin junctions i.e. when both sides of junctions are very heavily dopedand consequently the depletion region is narrow. When the reverse voltage across a PN junction diode, in which both p and n regions have very large concentrations of acceptor impurity atoms and donor impurity atoms respectively, is increased, the reverse current increases very rapidly at a certain reverse voltage below 6 volts and the junction breaks down. This break down at such a low reverse voltage cannot be due to avalanche multiplication of electron -hole pairs. This breakdown is explained on the basis of Zener effect which does not involve collisions of minority carriers with the semiconductor atoms.

In a PN junction diode in which both P and N regions are heavily doped, the width of the depletion region is very small; it may be about 5×10^{-8} m. The electric field at the junction is given by

$E_0 = \frac{2(V_0-V)}{d}$ where $V_0$is the internal potential barrier, V is the applied voltage across the junction and d is the width of the depletion region.

For silicon diode $V_0 \approx 0.6$ V. If the reverse voltage V = - 5V, then

$E_0 = \frac{2(0.6+5)}{5\times 10-8} = 2.25 \times 10^{8}$ V/m

An electric field of such high magnitude exerts a large force on valence electrons of silicon atoms in the depletion region. Consequently, the covalent bonds are broken, and a large number of electron-hole pairs is produced. These carriers are then accelerated away from the junction by the applied voltage. Hence the reverse current increases rapidly. This process by which covalent bonds in the depletion region are directly broken by a strong electric field is called Zener break down, and the reverse voltage at which the breakdown takes place is called the Zener breakdown voltage. It is found that Zener breakdown of an insulator occurs when the electric field is approximately 2×10^{7} V/m. In diodes with large concentration of acceptor and donor impurity atoms the electric field at the junction reaches this value when the reverse voltage is below about 6V.

EFFECT OF TEMPERATURE ON THE ZENER BREAKDOWN VOLTAGE

The magnitude of Zener breakdown voltage decreases as the junction temperature increases. When the junction temperature increases the valence electrons gain energy. Therefore, a smaller reverse voltage is sufficient to produce required electric field to break covalent bonds in the depletion region.

CUT IN VOLTAGE

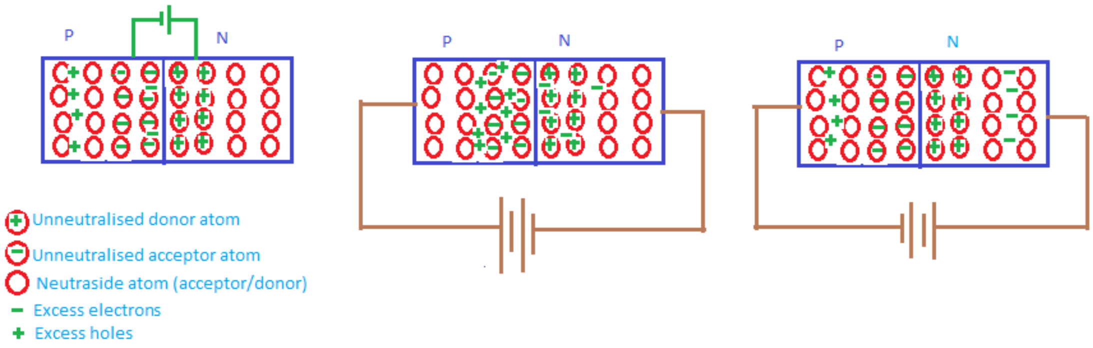
The plot of forward bias characteristics of Ge and Si diode at room temperature (25^{0} C) shows that there exists a break point, threshold, offset or cut in voltage below which the current is negligibly small (less than 1% of maximum rated value). Beyond this voltage, current rises very rapidly. Cut in voltage for Ge diode is 0.2 V and 0.6 V for Si diode.

Both the diodes are of comparable ratings. The difference between cut in voltage is partly attributed to the reverse current saturation which is in the range of µA for Ge diode whereas in mA for a Si diode, at room temperature.

CURTRENT ACROSS THE PN JUNCTION(QUALITATIVE)

When a p-type material is intimately joined to n type, PN junction is formed. Simply by putting the two junctions in contact, PN junction cannot be produced because the lattice remains discontinuous at the junction.

Near the junction due to diffusion, free electrons of the n section will combine with the holes of the p section leaving unnaturalised positive donor atoms and negative acceptor atoms in the n and p sections respectively. This produces an electric field across the junction as if a fictitious battery, connected with its positive terminal to n and negative terminal to p section. This will prevent the electrons and holes from crossing the junction against the electrostatic forces developed. Due to thermal agitation, only few electrons and holes can cross the junction as ordinarily their energy will be insufficient to overcome this repelling force.



FORWARD BIAS

In order to obtain current through the junction, it is necessary to neutralise these repelling forces across the junction. This is done by applying forward bias across the crystal. The free electrons in n section will be repelled by the negative force set up by the power source and will move towards the junction. At the same time, the holes in the p section will be repelled by the positive force set up by the power source also moves towards the junction. In this way, there is a flow of number of electrons from n region to p region and a good number of holes from p side to n side through the junction. As the applied voltage increased further, the electrons and holes having lower energy will be will be able to cross the barrier and current will increase further.

For each hole in the p section that combines with an electron from n section, an electron from an electron pair bond leaves the crystal and enters the positive terminal of the battery. Due to this action, a new hole is created which is again forced by power source to move towards the junction. For each electron in n section, that combines with a hole from p section, an electron enters the crystal from the negative terminal of the battery. The constant movement of electrons towards the positive terminal and holes towards the -ve terminal produces a high forward current I_f . The minority carriers in the two sections (electrons in the p section and holes in the n section) which are newly created produce a small reverse current I_r. The net current (I_f - I_r) increases as the applied power of source increased but the maximum value is always limited in order to avoid the damage of crystal junction

REVERSE BIAS

If the crystal is reverse biased then the battery increases the restraining force and the current through junction is exceedingly small. The cause of this small current is the conduction by the minority electrons and holes obtained due to light and thermal agitation. The electrons in n section and holes in p section are attracted away from the junction under the action of applied power source and thus causing minute current in opposite direction. The maximum reverse voltage that can be applied to the semi-conductor should not produce excessive reverse current.

REVERSE SATURATION CURRENT

Under reverse bias condition, the widening of the depletion region establishes too great a barrier for the majority carriers to overcome, effectively reducing the majority carrier flow to zero. However, the number of minority carriers that find themselves entering the depletion region will not change. The current that exists under this condition is called is reverse saturation current. This is not more than a few microamperes excepts for high power devices. Here the term saturation is used because the reverse minority current reaches its maximum value quickly and does not change significantly with increase in reverse bias potential.