DRIFT CURRENT AND DIFFUSION CURRENT

There are two types of current through a semiconducting material – one is drift current and the other is diffusion current.

The mechanism of drift current is similar to the flow of charge in a conductor. In case of conductor when a voltage is applied across the material, the electrons are drawn to the positive end. Similar is the case in semiconductor. However, the movement of the charge carriers may be erratic path due to collisions with other atoms, ions and carriers. So, the net result is a drift of carriers to the positive end.

In semiconducting material, when a heavy concentration of carrier is introduced to some region, the heavy concentrations of carriers distribute themselves evenly through the material by the process of diffusion. It should be remembered that there is no source of energy as required for drift current.

When an electric field is applied across the crystal, every charge carrier experiences a force due to the electric field and hence it will be accelerated in the direction of force. This results in drifting of the charge carriers in the direction of force will cause a net flow of electric current through the crystal. The magnitude of this current can be obtained by imagining an average drift velocity for every charge carrier in the direction of force. As the electrons and holes are of opposite charges, the force due to electric field on them will be opposite in direction. Hence the average drift velocity of the electrons will be in a direction opposite to the average drift velocity of the holes.

Let V_h = average drift velocity of holes

V_e = average drift velocity of the electrons.

$V_h \alpha E \Rightarrow V_h = \mu_h E$ and $V_e \alpha E \Rightarrow V_e = \mu_e E$, where μ_h, μ_e are the hole and electron mobility and positive quantity. Also we may say the mobility of the charge carriers are the average drift velocity per unit electric field applied.

Now the drift current density for hole and electrons are given by

$J_{h1} = p e V_h$ and $J_{e1} = - n e V_e$, where n,p are the electron and hole densities.

Negative sign indicates that the electrons having -ve charge move in direction opposite to the applied field.

Total drift current density $J_d = J_{h1} + J_{e1} = p e V_h - n e V_e$

$$= p e \mu_h E + n e \mu_e E$$

$$= (p \mu_h + n \mu_e) e E$$

For an intrinsic semiconductor $n_i = p_i$

So we can write $J_d = n_i e (\mu_h + \mu_e)E \Rightarrow J_{d1} = \sigma E$, where $\sigma = n_i e (\mu_h + \mu_e)$ refers to electrical conductivity of the material.

The electrons move with more ease compared to holes through the semiconductor I.e. the mobility of the electrons in a semi conducting material is considerably greater than that of holes. $V_e >> V_h$ and hence semiconductor current is largely due to free electrons. Only a small fraction of current is due to holes.

In semiconductor due to the non-uniformity of charge carriers (electrons/holes) which gives the diffusion current (is independent of the electric field) even when no electric field is applied. It depends on the concentration gradient.

Let us suppose that the concentration of holes(p) varies with the distance x

$$J_{h2} = - e \, D_p \frac{dp}{dx}$$, where D_p is diffusion constant or diffusion coefficient or diffusivity of holes.

The hole concentration is higher at lower value of x, so we assume the concentration gradient is negative along the +ve X- direction and the diffusion current due to hole is +ve along the +ve X-direction.

Similarly diffusion current density for electrons

$$J_{e2} = e \, D_n \frac{dn}{dx}$$

Here we take positive sign because electronic charge is negative and also the concentration gradient is negative which makes J_{e2} +ve and also it is +ve along the -ve X-axis

So the resultant diffusion current density for both holes and electrons is $J_D = e \, (D_n \frac{dn}{dx} - D_p \frac{dp}{dx})$

Total current density in semiconductor is the sum of drift current and diffusion current is given by

$$J = J_d + J_D$$

$$= e \, (p \, \mu_h + n \, \mu_e) \, E + e \, (D_n \frac{dn}{dx} - D_p \frac{dp}{dx})$$

PN JUNCTION

When a piece of semiconducting material is doped with pentavalent impurity in one side and with a trivalent impurity in the other side then the interface between the different regions is called pn-junction. A typical width of such pn junction is 10^{-4} cm.

The Fermi level in p type material is located close to the valence band whereas in n type material it lies close to the bottom of the conduction band.

When the contact between the two types of materials is made then to made Fermi level in a line, electrons in conduction band on n type side(supplied by n pentavalent impurity atoms) travel across the junction and leave positively ionised impurity atoms un neutralised. Consequently, there is a positively charged region adjacent to the junction in n type material. Electrons in conduction band of n side moves to the conduction band of p side so the Fermi level of n type lowers its level and in the p side it raises to align the Fermi level.

On the p side, the electrons which have traversed the boundary recombine with positive holes in the valence band. Near to the junction on p side, there is a layer of un neutralised negatively ionised trivalent impurity atoms which form a negatively charged region. These unneutralised impurity atoms are termed as immobile ions. These immobile ions are bound in the crystal lattice and no charges are available for conduction close to the junction. This region around the junction is called charge depletion region or space charge region. Due to this space charge, an internal potential barrier, V_B , exists between n and p regions. The band edges in the two samples shifts themselves to make the alignment of Fermi level possible and the energy band diagram remains no more of the shape shown in figure.1, but assume a shape shown in figure.2.
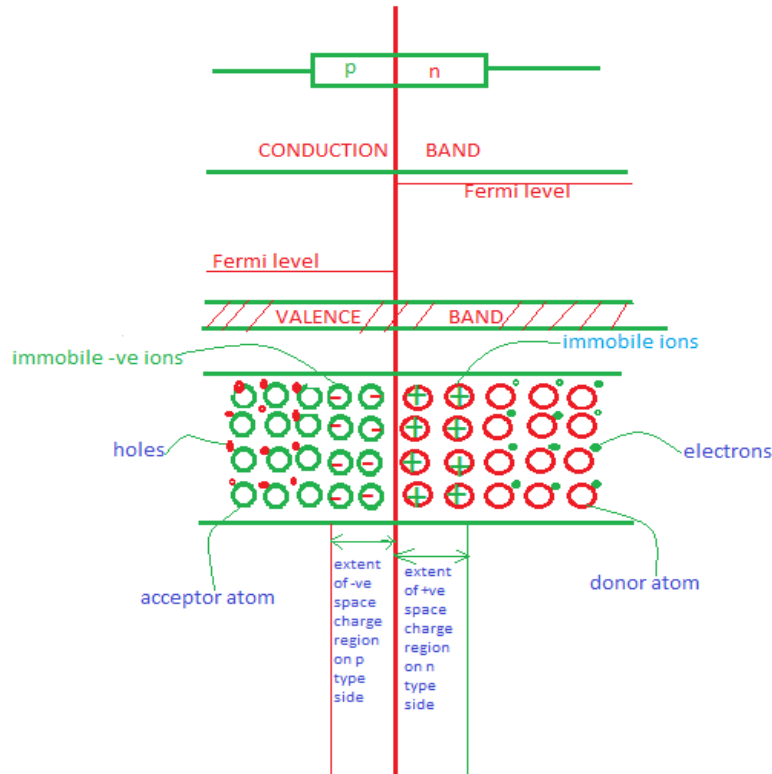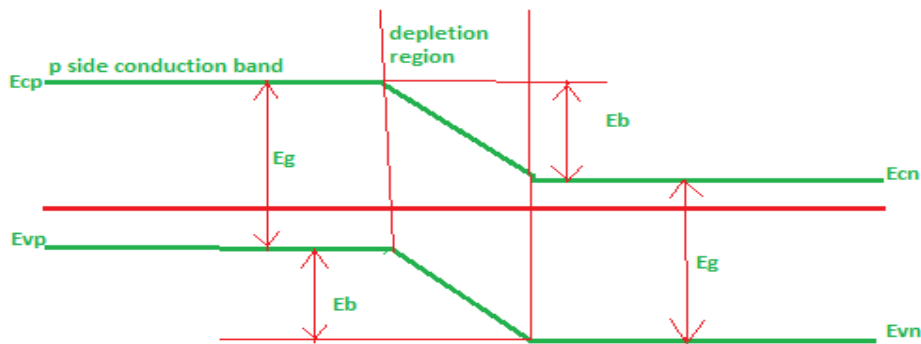
Figure.1

Figure.2

The conduction band of p type shifted upwards by eV_B , where V_B (= E_b/e) is the potential barrier across the junction arising due to already mentioned space charge.

Minority electrons in the conduction band of p side is at higher energy than the majority electrons in conduction band of n type crystal. The electrons crossing the junction from p region side will not encounter the potential barrier while the electrons crossing the junction from n region side will face this barrier.