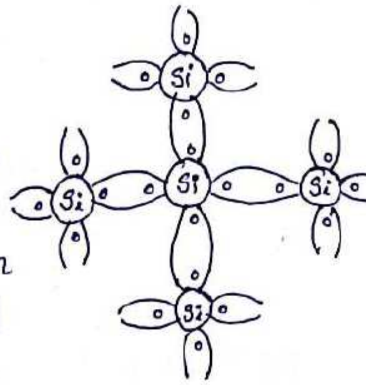
Module - 2 (Semi Conductors)

Intrinsic Semi Conductor are one having no impurity but may have defects. The important Intrinsic Semi Conductors are Silicon and Germanium.

If we Consider pure silicon Lattice, there are four nearest neighbours to each silicon atom and there are two electron bonds between each of the neighbours and the atom. In Intrinsic Semi Conductor a forbidden gap exist between a Filled Valence band and the Conduction band, but the width of the forbidden gap expressed in energy is much smaller than that of an Insulator.



In order to Conduct, the electrons from top of the full Valence band have to move into the Conduction band by crossing the forbidden gap. The field that needs to be applied to do this work will be extremely large.

For example - Si - E_g - 1.1eV (neighbouring ion core distance $\simeq 1\mathring{A} = 10^{-10}m$)

Therefore field gradient of $1V/10^{-10}m = 10^{10}V/m$ is necessary to move an electron from the top of valence band to bottom of Conduction band. Such high field gradient is not realizable in practice.

The other possibility by which this transition can be brought about is by thermal excitation. At room temperature, the thermal energy that is available can excite a limited number of electrons across the energy gap. This limited number account for Semi Conduction.

The promotion of some electrons across the gap leaves Some Vacant sites in Valence band Called holes. An Intrinsic SemiConductor Contains equal number of electrons in Conduction band and equal number of holes in valence band. ie. ($n_e = n_p$)

Under extremely applied field, the electrons which are excited into the Conduction band by thermal means, can accelerate using the vacant sites available in the Conduction band. At the same time, the holes in Valence band also move but in direction opposite to that of electrons. Thus electrical Conducting is written as $\sigma_i = n_e e \mu_e + n_p e \mu_p$

Fermi Energy in Intrinsic Semi Conductor

The number of free electrons per unit Volume in intrinsic SemiConductor

$$n = 2\left[\frac{2\pi m_e^* kT}{h^2}\right]^{3/2} \exp\left(\frac{E_F - E_c}{kT}\right)$$

The number of free holes per unit volume in intrinsic SemiConductor

$$P = 2\left[\frac{2\pi m_p^* kT}{h^2}\right]^{3/2} \exp\left(\frac{E_V - E_F}{kT}\right)$$

In Intrinsic Semi Conductor $(n = p)$

$$\therefore 2\left[\frac{2\pi m_e^* kT}{h^2}\right]^{3/2} \exp\left(\frac{E_F - E_c}{kT}\right) = 2\left[\frac{2\pi m_p^* kT}{h^2}\right] \exp\left(\frac{E_V - E_F}{kT}\right)$$

$$(m_e^*)^{3/2} \exp\left(\frac{E_F - E_c}{kT}\right) = (m_p^*)^{3/2} \exp\left(\frac{E_V - E_F}{kT}\right)$$

$$e^{2E_F/kT} = \left[\frac{m_p^*}{m_e^*}\right]^{3/2} \exp\left(\frac{E_V + E_c}{kT}\right)$$

Taking log on both sides

$$\frac{2E_F}{kT} = \frac{3}{2}\log_e\left(\frac{m_p^*}{m_e^*}\right) + \log_e\left[\exp\left(\frac{E_V + E_c}{kT}\right)\right]$$

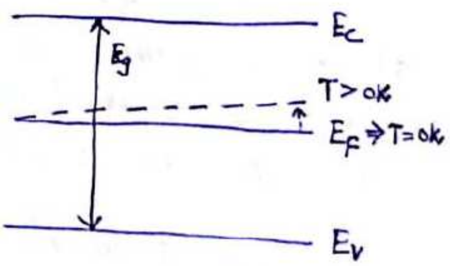
$$\frac{2E_F}{kT} = \frac{3}{2}\log_e\left(\frac{m_p^*}{m_e^*}\right) + \left(\frac{E_V + E_c}{kT}\right) \Rightarrow \boxed{E_F = \frac{3kT}{4}\log_e\left(\frac{m_p^*}{m_e^*}\right) + \frac{E_V + E_c}{2}}$$

If $m_p^* = m_e^*$ then $\boxed{E_F = \frac{E_V + E_c}{2}}$

Variation of fermi level based on temperature

When $T = 0K \Rightarrow E_F = \left(\frac{E_V + E_c}{2}\right)$

Fermi level is located half way between valence and Conduction band as its position is independent of temperature

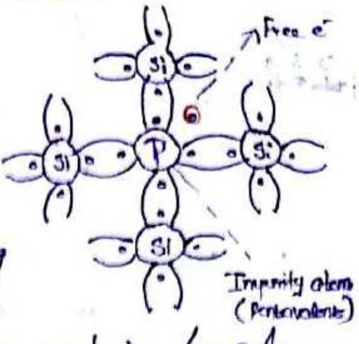


When $T > 0K \Rightarrow E_F = \frac{3kT}{4}\log_e\left(\frac{m_p^*}{m_e^*}\right) + \left(\frac{E_V + E_c}{2}\right)$

Fermi level rises slightly $(\because m_p^* > m_e^*)$ upward with increase in temperature

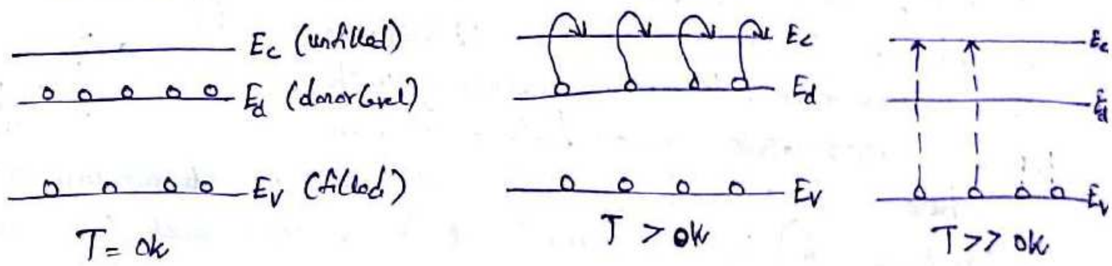
N-type Semiconductor — when pentavalent impurity is added to pure semiconductor, N-type semiconductors are formed.

Consider a silicon crystal which is doped with pentavalent impurity such as P, As (or) Sb. In case of phosphorous added as impurity to pure Si crystal, four of five electrons in outermost orbital of phosphorous atom take part in bonding with four silicon neighbours. The fifth electron cannot take part in the discrete covalent bonding and is loosely bound to parent atom (e^- orbit is ~ 80 Å). Such large orbit evidently means that fifth electron is almost free and is at the energy level close to conduction band.



When T = 0K, valence band is filled and phosphorous atoms will be unionised. The energy levels of donor electrons are very close to bottom of conduction band.

At T > 0K, donor electrons are excited to conduction band and becomes majority charge carriers. If thermal energy is sufficiently high, in addition to ionization of donor impurity atoms, breaking of covalent bonds may also occur thereby giving rises to generation of electron - hole pairs



Fermi Energy in N-type semiconductor is given by

$$E_F = \left[\frac{E_d + E_c}{2}\right] + \frac{kT}{2} \ln\left(\frac{N_d}{N_x}\right) \quad \text{where } N_x = 2\left[\frac{2\pi m_e^* kT}{h^2}\right]^{3/2}$$

When T = 0K

$$E_F = \left[\frac{E_d + E_c}{2}\right]$$

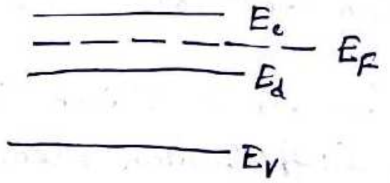
When T > 0K

$$E_F = \left[\frac{E_d + E_c}{2}\right] + \frac{kT}{2} \ln\left[\frac{N_d}{N_x}\right]^{-1}$$

$$E_F = \left[\frac{E_d + E_c}{2}\right] - \frac{kT}{2} \ln\left(\frac{N_x}{N_d}\right)$$

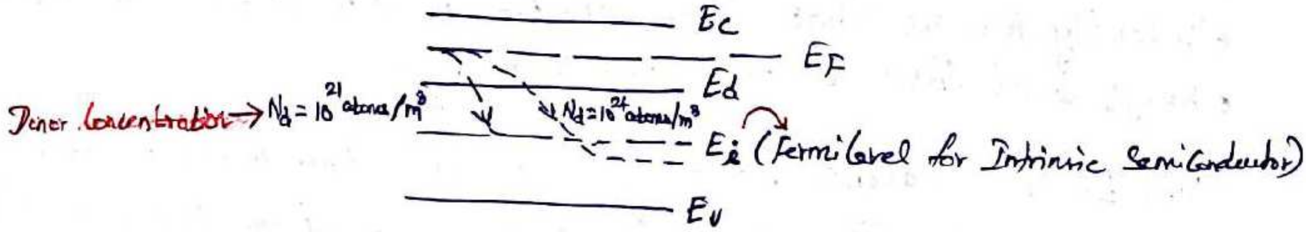
Variation of fermi level with Concentration (donor) & temperature

At $T = 0k$ $\quad E_F = \left[\frac{E_d + E_c}{2}\right]$ ----→



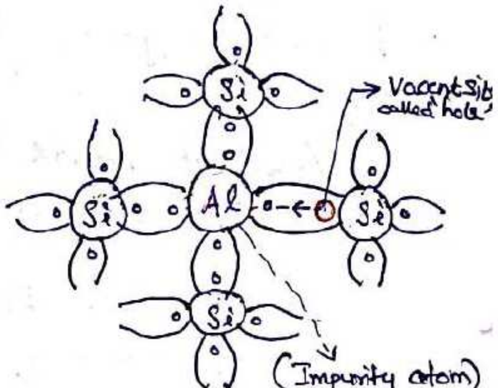
At $T > 0k$ $\quad E_F = \left[\frac{E_d + E_c}{2}\right] - \frac{kT}{2}\ln\left(\frac{N_x}{N_d}\right)$

(ie) when T increases, E_F decreases — Initialy donor atoms are ionized and further increase in temperature leads to generation of electron-hole pair due to breaking of covalent bonds and material tends to behave in intrinsic manner.



P-type SemiConductor — When trivalent impurity is added to pure Semi Conductor, P-type SemiConductors are formed

Conside silicon crystal which is doped with trivalent impurity such as Al, B. In case of Al added as impurity to pure Si-crystal, three electrons bonds with three neighbouring silicon atoms and Al accepts one electron from fourth Silicon atom and Creats Vacant site called hole on silicon.



This hole is considered to resolve around the aluminium atom (Orbit ~ 80Å) is free and is at the energy level close to top of valence band.

When $T = 0k$, valence band is filled and Al atom is ready to accept electron. Hence accepter level is close to top of valence band

At $T > 0k$, acceptor level takes electrons from valence band and thus giving to holes in valence band for Conduction. If temperature $T >> 0k$ electron-hole pairs are generated due to breaking of covalent bond

Fermi Energy in P-type Semiconductor is given by

$$E_F = \left(\frac{E_v + E_a}{2}\right) - \frac{kT}{2}\ln\left(\frac{N_a}{N_y}\right) \quad \text{where } N_y = 2\left[\frac{2\pi m_p^* kT}{h^2}\right]^{3/2}$$

When $T = 0k$

$$E_F = \left[\frac{E_v + E_a}{2}\right]$$

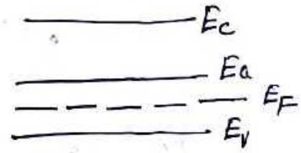
When $T > 0k$

$$E_F = \left(\frac{E_v + E_a}{2}\right) - \frac{kT}{2}\ln\left(\frac{N_a}{N_y}\right)^{-1}$$

$$E_F = \left(\frac{E_v + E_a}{2}\right) + \frac{kT}{2}\ln\left(\frac{N_a}{N_y}\right)$$

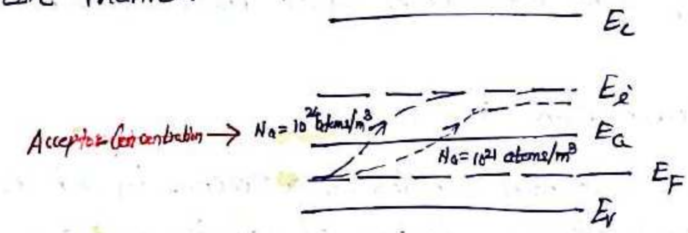
Variation of fermi level with concentration (acceptor) & temperature

At $T = 0k$ $\quad E_F = \left(\frac{E_v + E_a}{2}\right) \longrightarrow$



At $T > 0k$ $\quad E_F = \left(\frac{E_v + E_a}{2}\right) + \frac{kT}{2}\ln\left(\frac{N_a}{N_y}\right)$

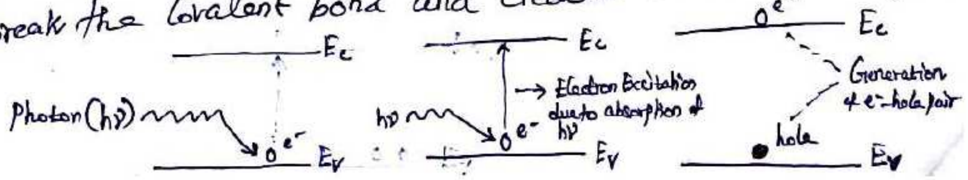
(ie) when T increases, E_F increases — Initially acceptor atoms are ionized and further increase in temperature leads to generation of electron-hole pair due to breaking of covalent bonds and material tends to behave in intrinsic manner



Explanation for Carrier Generation

Generation is a process where free electron & holes are generated in pair for semiconductor by absorbing light energy or raising temperature

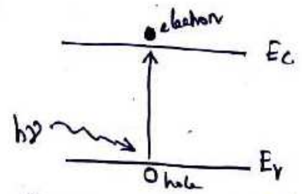
Consider the process of optical absorption in semiconductor. If light of energy ($h\nu$) is allowed to fall on the semiconductor. If the photon energy ($h\nu$) $\geq E_g$ (band gap of semiconductor) then photon energy is absorbed in the semiconductor because it has enough energy to break the covalent bond and creates electron - hole pair.



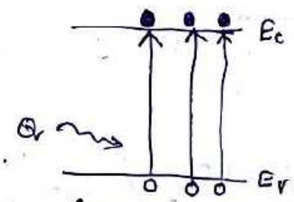
(i) Generation due to light absorption - Occurs if photon energy is large enough to raise an electron from valence band into empty conduction band state, thereby generating one electron-hole pair. For this phonon energy $E \geq E_g$ & $E - E_g$ is added to electron & the hole in the form of kinetic energy

(ii) Generation due to High energy beam - Occurs if high energy beam whose available energy (E) is much larger than (E_g) so that multiple electron-hole pairs can be formed. This kind of generation mechanism are used in nuclear particle counter based on semiconductors

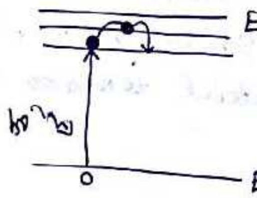
(iii) Generation due to Impact Ionization - Caused by an electron/hole with an energy, which is much larger/smaller than the conduction/valence band edge



Generation - Due to light absorption



Generation - Due to high energy beam

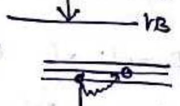


Generation - due to Impact ~~Impact~~ ionization

Explanation for Recombination Process

Recombination of electron & holes is a process by which both carriers annihilates each other - electron occupy through one or multiple steps - the empty state associated with hole. Both carriers eventually disappear in this process. This leads to one possible classification of the recombination processes.

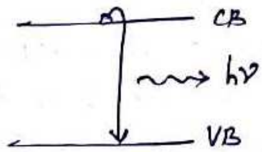
1) Radiative Recombination



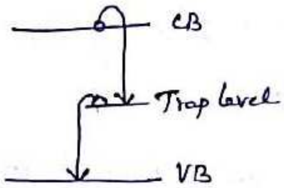
2) Non Radiative Recombination

Let us see different types of Recombination mechanisms

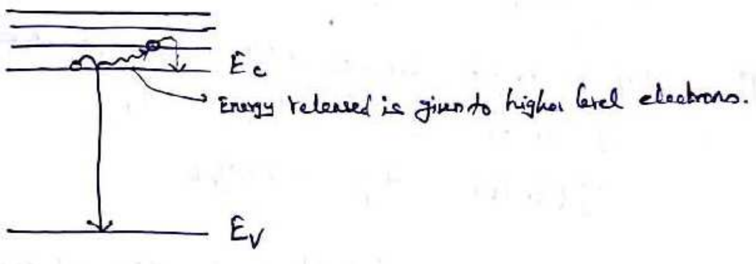
1) Band to band Recombinations - Occurs when electron moves from its conduction band state into empty valance state associated with hole. This type of Recombination is mostly radiative



2) Trap-assisted Recombination - Here electron falls into a trap or energy level within the band gap caused by the presence of impurity atoms or structural defects. During Recombination the electrons falls to trap from conduction band & then to valance band. This Recombination is also called Shockley-Read-Hall Recombination



3) Auger Recombination — Involves band to band transition but resultant energy is released either to next level electrons in conduction band or lower level in valance band. This recombination mostly results with phonon emission to stimulate other electrons (or) holes in conduction /valance bands.



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Carrier transport - Drift & Diffusion Current

Current flow in a semiconductor can be either due to an applied electric field (drift current) (or) due to difference in the carrier concentration (diffusion current)

Drift Current — When electric field is applied across a bar of semiconductor, electron & hole acquire a drift velocity (V_d) proportional to the magnitude of the electric field. While electron move in a direction opposite to that of applied field, holes move in the direction of the field. This directional movement of charge carriers constitutes a current, which is usualy refered as "Drift Current"

Consider 'J' be the current density in semiconductor having 'n' electrons per unit volume travelling at a velocity 'V_d' is given by

$$J = neV_d$$

But $V_d \propto E \Rightarrow V_d = \mu E$ where μ is mobility of charge carrier

$$\therefore J = ne\mu E$$

If the matrial is semiconductor, the current flow could be due to electron & hole moment, correspondingly the current densities due to electron drift & hole drift are

$$\boxed{J_n(\text{drift}) = ne\mu_n E}$$

$$\boxed{J_p(\text{drift}) = pe\mu_p E}$$

Thus total drift current is the sum of the two components

$$J(\text{drift}) = J_n(\text{drift}) + J_p(\text{drift})$$

$$J(\text{drift}) = ne\mu_n E + pe\mu_p E$$

Diffusion Current — If there is non-uniform concentration of charge carriers in semiconductor, in addition to drift current, there exists another important current component due to this concentration gradient. When there is a concentration gradient, the carrier tends to diffuse from region of higher concentration to region of lower concentration thereby constituting a current flow called diffusion current.

Let us consider Δn be the electron concentration with distance 'x' in semiconductor.

$$\text{The rate of electron flow} = \frac{\partial}{\partial x}(\Delta n)$$

Then rate flow of electron across unit area $= D_n \dfrac{\partial(\Delta n)}{\partial x}$ (D_n - Diffusion Coefficient)

Then current density due to electron diffusion $\boxed{J_n = eD_n \frac{\partial}{\partial x}(\Delta n)}$

Similarly current density due to hole diffusion $\boxed{J_p = -eD_p \frac{\partial}{\partial x}(\Delta p)}$

−ve sign signifies that direction of hole current is opposite to the direction of the increasing concentration gradient.

Current density Equations

When Electric field and concentration gradient is present across the semiconductor sample, both drift and diffusion current flow and the total current density for electron and hole is given by

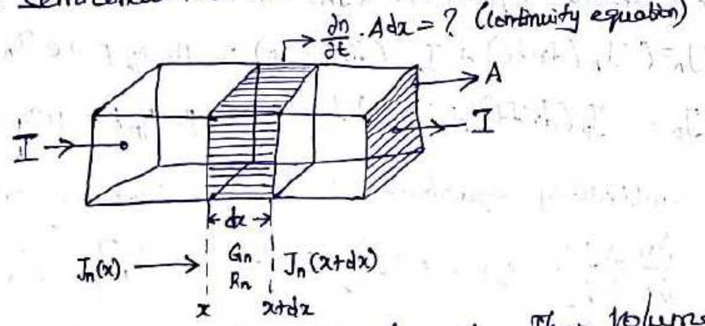
$$J_n = J_n(\text{drift}) + J_n(\text{diffusion}) = ne\mu_e E + eD_n \frac{\partial}{\partial x}(\Delta n)$$

$$J_p = J_p(\text{drift}) + J_p(\text{diffusion}) = pe\mu_p E - eD_p \frac{\partial}{\partial x}(\Delta p)$$

Continuity Equation

The overall effect when drift, diffusion, generation as well as recombination of carriers in a semiconductor is expressed by the continuity equation.

Consider a bar semiconductor with cross sectional area (A) as shown



(dx) be the infinitesimal thickness of element. Then volume of infinitesimal element is (A·dx).

The essence of continuity equation is that the overall rate of increase in number of electrons $\left(\frac{\partial n}{\partial t}\right)$ at the given volume (A·dx) is given by algebraic sum of four components:

1) Rate of flow of electrons into the infinitesimal element at (x)
2) Rate of flow of electron out of it at (x+dx)
3) Rate at which electrons generated in the element (G_n)
4) Rate of recombination in the element (R_n)

Then $\frac{\partial n}{\partial t} \cdot A \cdot dx = J_n(x+dx)\frac{A}{q} - J_n(x)\frac{A}{q} + (G_n - R_n)$

We know $J = I/A$

$J \cdot A = I$

Electron flux (or) Rate of electron flow $= \frac{J \cdot A}{q} = \frac{dn}{dt}$ $\left[\because \frac{dn}{dt} = I\right]$

in volume $(A \cdot dx)$

Here

Rate of electron flow at $(x) = \frac{J_n(x)}{q} \cdot A\,dx \longrightarrow$ (into the element)

Rate of electron flow at $(x+dx) = \frac{J_n(x+dx)}{q} \cdot A\,dx \rightarrow$ (out of the element)

Increase in electron flow at given volume $A \cdot dx$

then $$\frac{\partial n}{\partial t} A \cdot dx = \left[\frac{J_n(x+dx)}{q} - \frac{J_n(x)}{q} + G_n - R_n\right] A \cdot dx$$

Since dx is extremely small, we can express

$$J_n(x+dx) = J_n(x) + \frac{\partial J_n}{\partial x} \cdot dx$$

Then $$\frac{\partial n}{\partial t} = + \frac{\partial J_n}{\partial x}\left(\frac{1}{q}\right) + G_n - R_n \quad \text{(for electrons)}$$

Also $$\frac{\partial p}{\partial t} = - \frac{\partial J_p}{\partial x}\left(\frac{1}{q}\right) + G_p - R_p \quad \text{(for holes)}$$

In the above equation J_n & J_p depends on

$$J_n = J_n(\text{drift}) + J_n(\text{diffusion}) = n e \mu_e E + e D_n \frac{d}{dx}(\Delta n)$$

$$J_p = J_p(\text{drift}) + J_p(\text{diffusion}) = p e \mu_p E - p D_p \frac{\partial}{\partial x}(\Delta P)$$

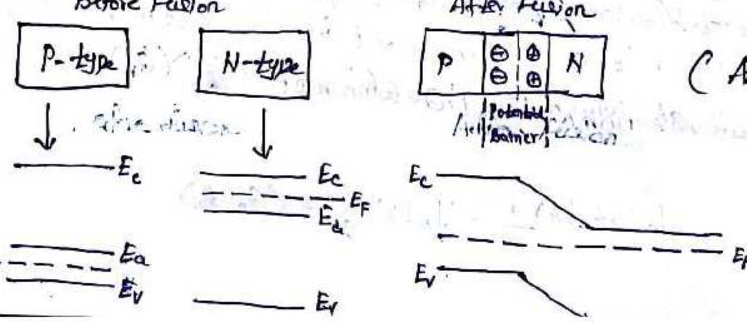
So continuity equation for charge carriers becomes

$$\frac{\partial n}{\partial t} = \frac{1}{q} \frac{\partial}{\partial x}\left[n e \mu_e E + e D_n \frac{\partial}{\partial x}(\Delta n)\right] + G_n - R_n \quad \text{for electrons}$$

$$\frac{\partial p}{\partial t} = -\frac{1}{q} \frac{\partial}{\partial x}\left[p e \mu_p E - p D_p \frac{\partial}{\partial x}(\Delta P)\right] + G_p - R_p \quad \text{for holes}$$

PN-Junction

P-n Junction is one of the basic building blocks of integrated circuits. Such a Junction can be formed by selective diffusion (or) Ion implantation of n-type (or) P-type (dopant) to P-type (or) N-type semiconductor.



(At thermal equilibrium)

When p-region and an n-region are brought in close contact, a pn-Junction forms due to diffusion of charge carriers. While holes diffuse from p-region to n-region, electrons diffuse from n-region to the p-region. under thermal equilibrium, a built in electric field directed from positive to negative charge which gives rise to drift current and no net transport of carriers ~~due to~~ diffusion is observed across the potential barrier. (also called depletion region)

At thermal equilibrium, drift & diffusion component of current must cancel each other, J_p & J_n is zero. Therefore fermi level must be constant throughout & electron, hole concentrations on both sides remain same.

Fermi level on p-region & N-region is given by

$$E_F = E_{ip} - kT \ln\left(\frac{N_a}{n_i}\right) \text{ for p-region}$$

$$E_F = E_{in} - kT \ln\left(\frac{N_d}{n_i}\right) \text{ for N-region}$$

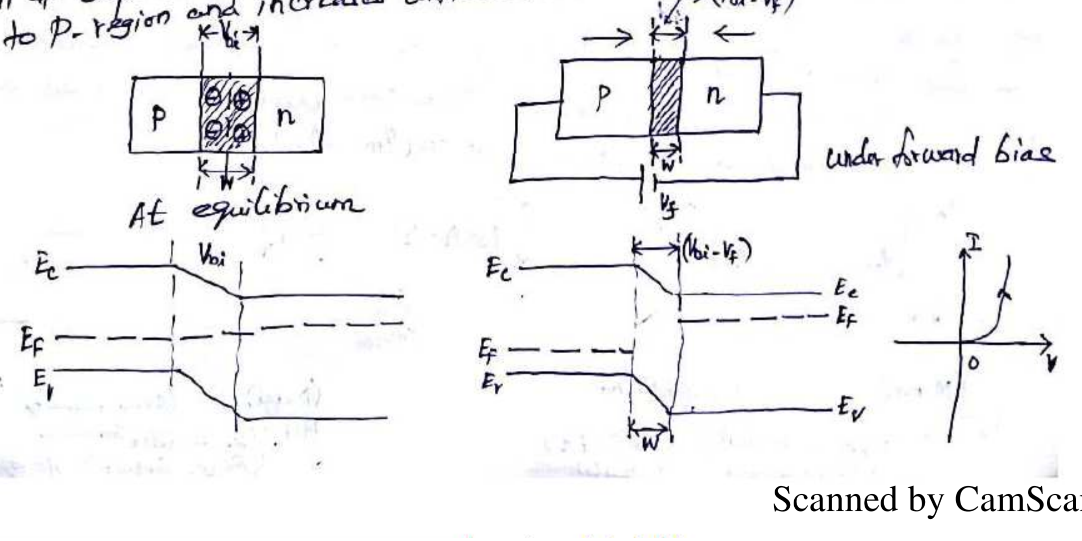
(E_F) p-region $= (E_F)$ N-region then $E_{ip} - E_{in} = kT \ln\left(\frac{N_a N_d}{n_i^2}\right)$

If $E_{ip} - E_{in} = V_{bi} \rightarrow$ Therefore built in potential $V_{bi} = kT \ln\left(\frac{N_a N_d}{n_i^2}\right)$

pn-Junction under forward biasing

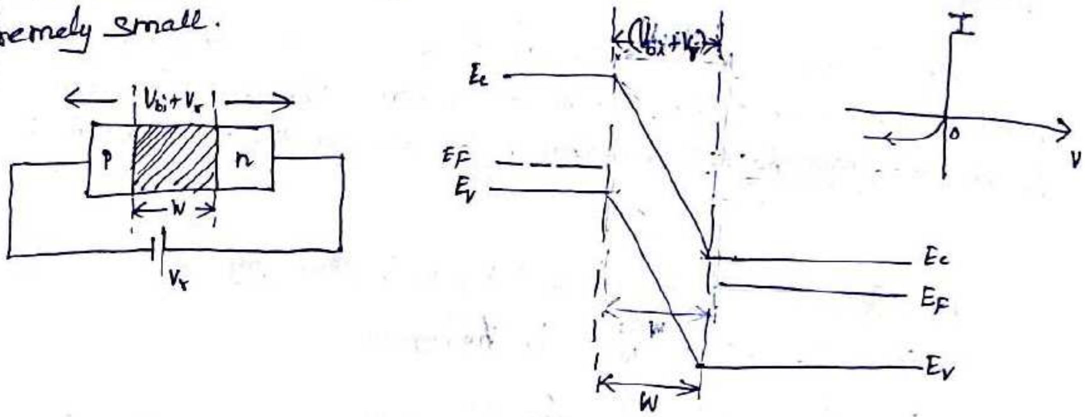
When pn-Junction is applied with external voltage, the electron and hole concentration deviates from their equilibrium values. Also potential difference across depletion region deviates from its equilibrium value (V_{bi}) by an amount of applied bias.

When pn-Junction is forward biased by (V_f), that is, +ve terminal of battery is connected to p-region and -ve terminal to N-region, the potential difference across depletion region decreases by ($V_{bi} - V_f$). Thus width of depletion region width decreases. Thus more electron from n-region moves to p-region and increases diffusion current.



pn - Junction under reverse biasing

When a pn - Junction is reverse biased by(V_r), that is, the terminal of battery is connected to n-region and -ve terminal to p-region, the potential difference across depletion layer increases by ($V_{bi}+V_r$). Thus width of depletion layer increases and hence no electron from n-region and no holes from p-region diffuse across the Junction. Now current is due to diffusion of minority charge carriers in p & N region which is extremely small.



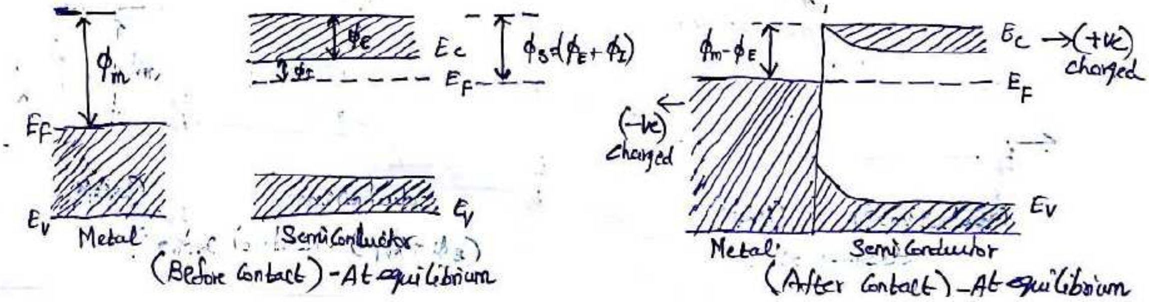
Metal- semiconductor Junction

The metal - semiconductor Junction is the oldest practical semiconductor device. This can be either be rectifying (or) Non-rectifying. The rectifying semiconductor Junction is also known as schottky diode, while the non-rectifying Junction is called an ohmic contact.

1) Rectifying Junction (or) Schottky Junction - [Non ohmic]

whenever a work function of n-type semiconductor is smaller than that of the metal (or) workfunction of p-type semiconductor is greater than that of metal, it forms Rectifying (or) schottky Junctions.

Let ϕ_m and ϕ_s be the workfunction of metal & n-type semiconductor respectively, when $\phi_m > \phi_s$. when the metal-semiconductor contact is made, the conduction electrons begin to flow from semiconductor into the metal until fermi energies on both sides of Junction are equal. Therefore metal becomes -ve charged and n-type semiconductor (depleted) becomes +ve charged. As a result, Potential barrier is formed at the metal-semiconductor junction equal to $(\phi_m - \phi_E) = eV$



When potential is applied to system after contact such that

N-type is connected to +ve charge & metal to -ve charge, the heigh of barrier on semiconductor side increases by (V_s+V) and metal remains uncharged. Therefore junction is said to reverse biased & current flows from metal to semiconductor

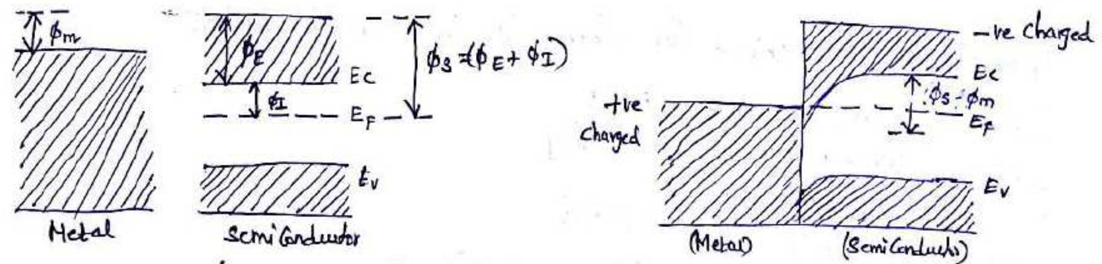
Conrasly if the voltage is reversed so as to make semiconductor with -ve charge and metal to +ve charge, the height of barrier on semiconductor side decreases by (V_s-V) and metal remains uncharged. Therefore junction is said to forward biased & current flows from n-type to metal.

For forward bias - net current increases exponentially with applied voltage and for reverse bias - net current is constant. The metal - semiconductor contact acts like rectifier and hence called rectifying contact.

2) Non Rectifying Junction - [Ohmic]

whenever the workfunction of metal is less than n-type semi-conductor $(\phi_m < \phi_s)$ it forms non rectifying (or) ohmic junction.

Let ϕ_m & ϕ_s are workfunctions of metal & semiconductor considered when metal - semiconductor contact is made, the conducting electrons begin to flow from metal to semiconductor until fermi energies on both sides of junction are equal. Therefore metal becomes +ve charged and n-type semiconductor becomes -ve charged. As a result ... potential barrier is created between metal - semiconductor equal to $(\phi_s - \phi_m) = eV$



Before Contact - (At equilibrium)

After Contact - (At equilibrium)

when potential is applied to system such that metal to -ve charge and semiconductor to +ve charge, the electron flows from semiconductor to metal without encountering an appreciable barrier. When semiconductor is applied with -ve charge and metal with +ve charge, the electron flows from metal to semiconductor without any change in barrier. Thus in both cases current is directly proportional to applied voltage in accordance to ohms law. Such contacts are called Ohmic Contact

SemiConducting materials for optoelectronic applications

Major SemiConducting materials used for optoelectronic applications are III-V and II-VI Group

Among the two groups of semiConductors - III-V is more suitable as they are direct bandgap materials which is necessary condition needed for optoelectronic devices to convert electrical to light energy Conversion.

III-V materials - Column III & V in periodic table
III Column - Al, Ga, In
V Column - N, P, As, Sb

Important applications for some III-V SemiConducting materials
AlGaAs - light emitter & modulator
GaInAsP - optoelectronic device
AlGaInP - Red Emitter LED
GaAsP - Visible LED
AlGaAsSb - Light emitter & Detectors

The Suitable choice of above materials depends on their size of quantum dimensions (1D, 2D or 3D) for optoelectronic applications

II-VI SemiConducting materials - Column II & VI in periodic table
They are having wide range of optoelectronic properties ranging from far IR to UV region. Easily tuned to different (Eg) by incorporating magnetic ions. They have stronger polarity due to Ionic bonding Character.

Important applications for Some II-VI SemiConductors
ZnSe - Blue - Green LEDs
ZnS - UV emitters, Display
ZnO - UV emitters
CdS - Visible light LEDs
CdSe - Colour LEDs (short wave)

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Photo Current in pn - Junction diode

In a photodiode, the incident optical signal generates Electron -hole pairs that gives rise to a photo current across pn-Junction

When pn-Junction is illuminated with light of photon energy $(E) \geq (E_g)$, photons are absorbed in semiconductor & electron-hole pairs are generated both in n-region and p-region of the Junction. For the electron -hole pair to contribute towards current in external circuit, the generated electron and holes must be seperated before they recombine. This is achieved if electron-hole pairs are generated in the depletion layer, where the electric field sweeps away the electron & holes in opposite directions.

The photogenerated minority carriers, which are generated within one diffusion length from the depletion layer edge, can also diffuse to the depletion region without recombining. They are then swept across the junction due to the electric field present in the depletion region. Due to the direction of electric field being from the n-region to p-region the holes flow towards the p-region and electrons to the n-region. Since the direction of this photogenerated current I_L is opposite to that in a forward-biased diode, the total current in illuminated p-n Junction diode is

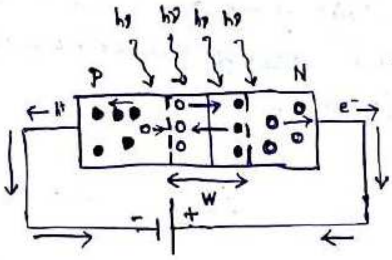
$$I = I_{nL} + I_{pL} + I_d$$

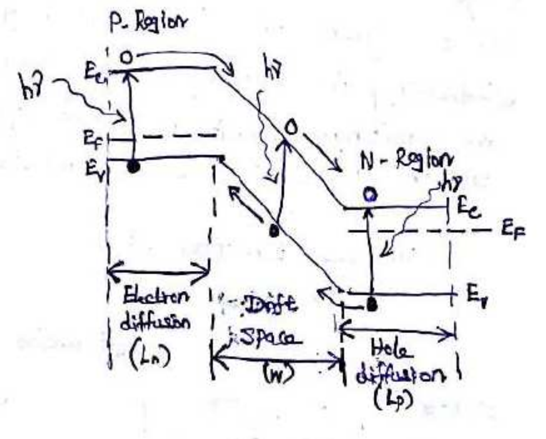
If G is generation rate, A is diode area then photo current

$$(I) = eG(L_p + L_n + W)A$$

Where L_p & L_n are distance of the depletion region edge where electron, holes are generated

W - width of depletion Region





Light emitting Diodes (LED)

LED are pn-Junctions that can emit spontaneous radiation in Ultraviolet, visible (or) IR regions. These device converts electrical energy to optical energy under forward bias mode.

Principle

Under forward bias, the majority carriers from n & p regions cross the junction and becomes minority carriers in the other regions

(ie) Electrons from N-region crosses Junction & becomes minority carrier in P-region

Also holes from P-region crosses Junction & becomes minority carrier in N-region

The above process is called "minority carrier injection". If biasing voltage is further increased, the excess minority carriers diffuse away from Junction and recombine with majority carriers as shown in diagram. Thus a radiative recombination events leads to photon emission with energy equal to ($h\nu$) and is equal to E_g

(ie) $h\nu = E_g$

$$\frac{hc}{\lambda} = E_g \Rightarrow \boxed{\frac{hc}{E_g} = \lambda} \rightarrow \text{photon wavelength}$$

Types of LED's

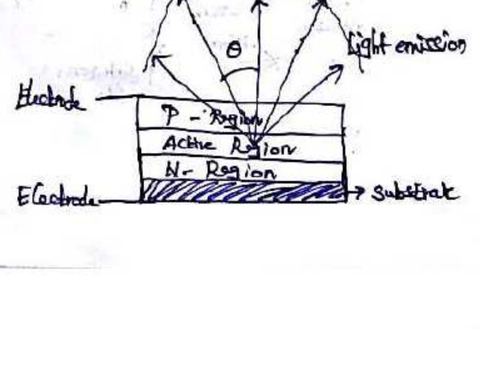
LED must be constructed such that light emitted by radiative recombination events can escape the structure

Designed as either Surface / Edge emitters

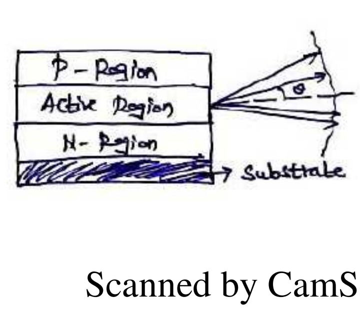
1) Surface Emitters - designed to reflect light from bottom edge to top surface to enhance output Intensity.

2) Edge emitters - Here light emission is relatively direct from the active region (or) depletion region. Edge emitters have higher efficiency in coupling to an optical fibre whereas surface emitters are emitting light in wide angle and is highly incoherent and so used in signaling device and as indicators.

Surface Emitter LED



Edge emitter LED



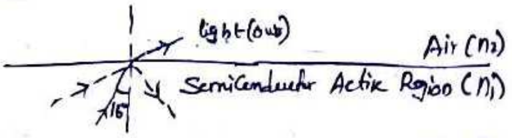
External quantum efficiency in LED

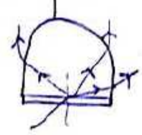
Internal quantum efficiency is 100%. But external quantum efficiency decreases. The main reason is that most of emitting light radiation strikes the material Interface at greater than Critical angle and hence trapped with the device.

(ie) Critical angle at semiconductor – air boundary is given by $\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$

For example if $n_1 = 3.5$ (Material) & $n_2 = 1.0$ (air)

$$\theta_c = \sin^{-1}\left(\frac{1}{3.5}\right) = 16^\circ \text{ then}$$





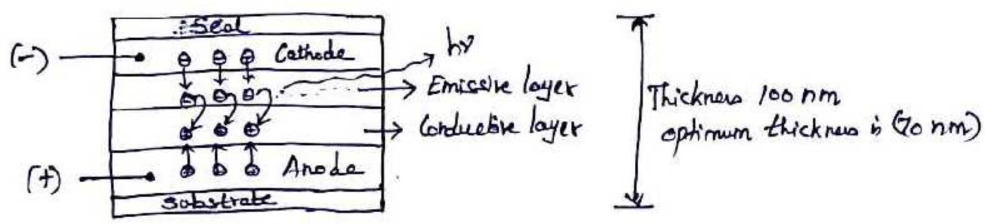
In the above diagram all the rays striking surface above 16° suffers total internal reflection and reflected back inside. Hence to improve external efficiency losses caused by bulk absorption and to improve surface transmission – Hemispherical domes made of plastics are fused at surface

Choice of materials for device fabrication – GaP, GaAs, GaAsP etc.

Organic Light Emitting Diode (OLED)

A type of LED where emissive electroluminescent layer is a film of organic Compound which emit light in response to an electric current.

Structure of OLED – A simple OLED is made of six different layers. On the top and bottom there are layers of protective glass or plastic. The top layer is called seal and bottom layer is substrate. In between – a negative terminal (cathode) and positive terminal (anode) and finally between cathode and anode – two layers made of organic molecules called emissive layer (produces light) and the conductive layer



1) Substrate – clean glass / plastic
2) Anode – Positive charged (Indium Tin oxide) - injects holes
3) Organic layer – (Emissive + Conductive layers) – polyaniline + polyfluorene
4) Cathode – Negative charged & injects electrons

Conjugated polymers are having characteristics of LED and having (E_g) same like semiconductors, by doping with p-type / N-type materials used for light emission

Types of OLED

1) Passive Matrix OLED - The organic layer is between strips of cathode and anode that run perpendicular

Advantages - easy fabrication, useful for small screen display

2) Active matrix OLED - organiclayer is between larger layer of Cathode and anode

Advantages - Less power requirments, Suitable for large Screen

Advantages of using OLED - much thinner Compared to LCD, less in weight, flexible, Consumes less power, suitable for display in cellphones and MP3 Players. Response time is 200 times faster than LCD, bigger viewing angle, less expensive

Disadvantages - OLED display do not last as long, Organic molecules are sensitive to water

Applications - Animated bill boards, Display in cellphone, MP3 players, Tablet Computers with folding display, wrist watches, head sets, TV, Camera etc.,