DEPARTMENT OF PHYSICS
INDO – AMERICAN COLLEGE CHEYYAR

III B.SC PHYSICS – ODD SEMESTER
BASIC ELECTRONICS – BPH53

SYLLABUS:

UNIT – I: SEMICONDUCTOR THEORY DEVICES AND CHARACTERISTICS

Classification of solids in terms of forbidden energy gap Fermi level – Fermi-Dirac function – Carrier concentration intrinsic and extrinsic semi conductors – effect of temperature on Fermi level – PN junction diode – Zener diode – Tunnel diode – photo diode – PIN – APD – Photo transistor – JFET construction and working – types of JFET – biasing – V-I characteristics in common source mode – JFET as amplifier.

CHAPTER 1

SEMICONDUCTOR THEORY DEVICES AND CHARACTERISTICS

Introduction:

The study of the behavior of an electron under different condition of externally applied field is meant as "**ELECTRONICS**". The invention of solid state devices replaced vacuum tubes, which are small, more efficient, cheap, having more speed in action etc.

1.1 Energy bands in solids:

The electron in an orbit possesses definite energy normally the various levels in an atom are filled from the lowest energy level. The orbits completely filled with electrons are known as core electrons. The electrons in the outermost level are called **valence electrons.**

Valence band:

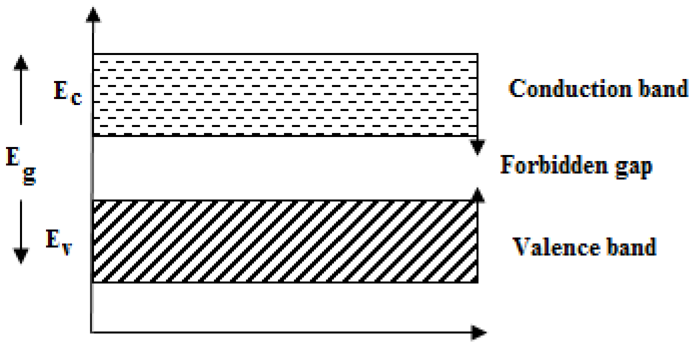
The valence band may be completely or partially filled. In the case of inert gases, the valence band is full whereas for other materials, it is only partially filled.

Conduction band:

The range of energies corresponding to the higher unoccupied level is known as **conduction band.** All electrons in the conduction band are free electrons.

Forbidden energy gap:

The region in between the conduction and valence band is known as forbidden gap. No electrons of a solid can stay in a forbidden gap.



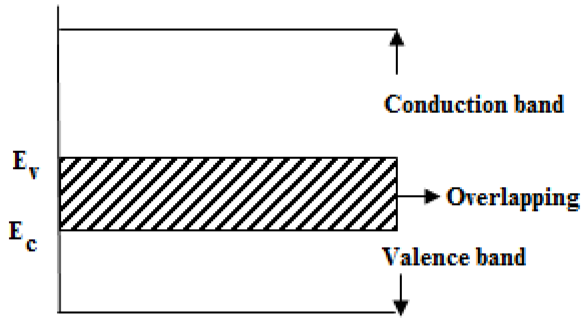
1.11 Classification of solids in terms of forbidden energy gap:

On the basis of energy band theory, solids are classified into three groups,

1. Metals
2. Insulators
3. Semiconductors

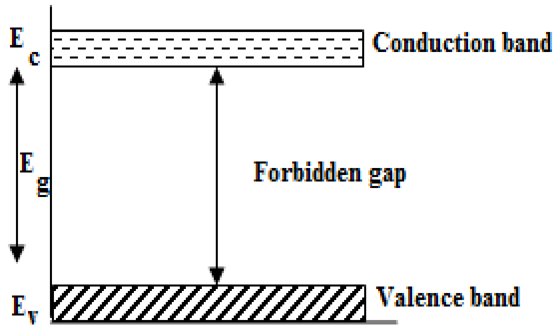
1. **Metals: (conductors)**

In metals the upper portion of the valence band and the lower portion of the conduction band get overlapped and so there is no forbidden energy gap. Hence no energy is required to shift the electrons from valence to conduction band.



2. **Insulators:**

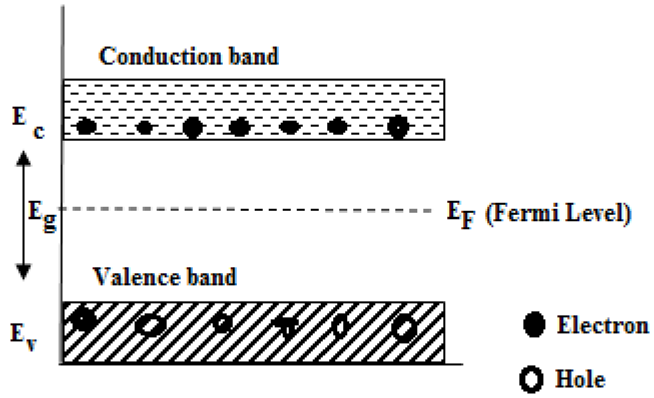
In insulators, the forbidden gap is very large. Since the forbidden energy gap is very large, large amount of energy is to be supplied to shift the electrons from the valence to the conduction band. So no electrons are available in the conduction band for conduction. Hence such types of material are known as insulators.



3. **Semiconductors:**

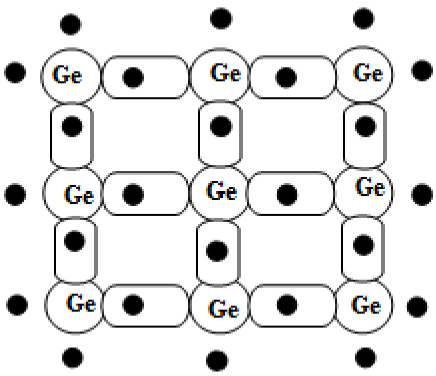
In semiconductors, the energy gap is very small so that, even at ordinary temperature, electrons can jump into the conduction band. As a result, some states in the conduction band are occupied and equal number of states in the valence band is unoccupied. The vacancies produced in the valence band are called as **holes**. Such materials are known as semiconductors.

If the temperature of the semiconductor is increased, more of electrons jump from valence to conduction band and this increases the electrical conduction. Thus at 0˙K, semiconductors behaves as insulator, but at or above room temperature, it behaves as conductor.



1.12 Bonds in semiconductors:

All the semi conducting materials are crystalline in nature and they lie in the IVth group in the periodic table. For eg. Germanium has 32 electrons. The electrons are arranged as 2, 8, 18, and 4 in accordance with Pauli's exclusion principle. Thus **Ge** has four outermost electrons which are called as **valence electrons**. The four outermost electrons will form four bonds with the outermost electrons of four neighboring **Ge** atom by sharing of electrons. Such bonds are known as covalent bonds.



1.2 Fermi level:

Fermi level is the maximum energy level up to which the electrons can be filled at 0K.

- It acts as a reference level which separates the vacant and filled states at 0K.
- It gives the information about the filled electrons states and empty states.

1.21 Types of semiconductors:

Semiconductors are divided into two types,

Intrinsic (or) pure semiconductor

Extrinsic (or) impure semiconductors

Intrinsic (or) pure semiconductor:

A semiconductor in an extremely pure form is known as **intrinsic semiconductor.** In this type, even at room temperature, electron-hole pairs are created. When electric field is applied, the current conduction takes place by two processes namely, by free electrons and holes. The free electrons are created by breaking up of some covalent bonds by thermal energy. At the same time holes are created in the covalent bonds. Therefore, the total electrons are equal to the holes and the total current inside the semiconductor is the sum of currents due to holes and electrons. At absolute zero, the intrinsic semiconductor behaves as a perfect insulator.

Extrinsic (or) impure semiconductor:

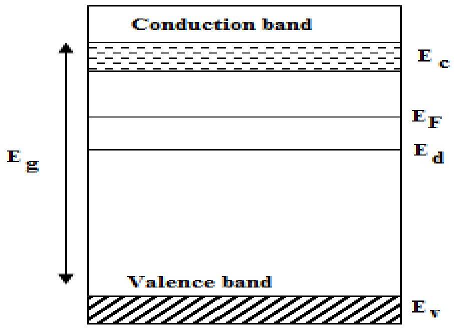
The charge carriers are produced due to impurity atoms are called **extrinsic semiconductor.** They are obtained by doping an intrinsic semiconductor with impurity atoms.

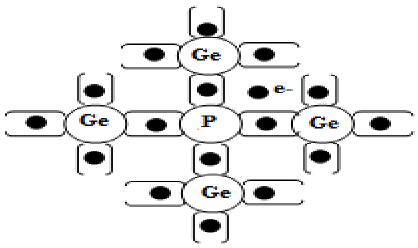
They are classified into two,

1. n – type semiconductors
2. p – type semiconductor

n – Type semiconductor:

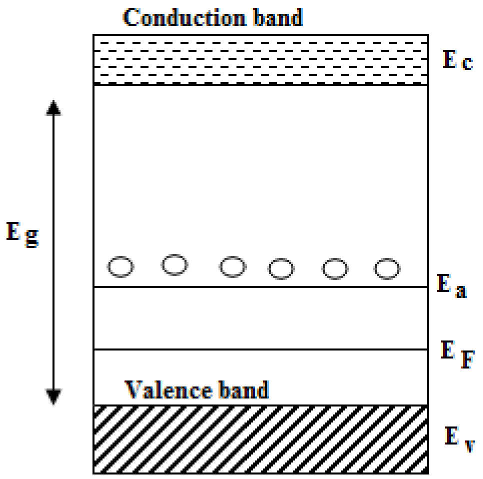
n – Type semiconductor is obtained by doping an intrinsic semiconductor with **pentavalent** impurity atoms like phosphorous, arsenic, antimony etc. The 4 valence electrons of the impurity atom bond with 4 valence electrons and the remaining one electron is left free. Therefore the no. of free electrons increases. As the electrons are in excess, they are the majority carriers in n – type and holes are the minority carriers. Since electrons are donated the energy level of these donated electrons is called **donor energy level(E_d). E_d** is very close to conduction band and hence even at room temperature the electrons are easily excited to conduction band. The current conduction is mainly due to **electrons.**

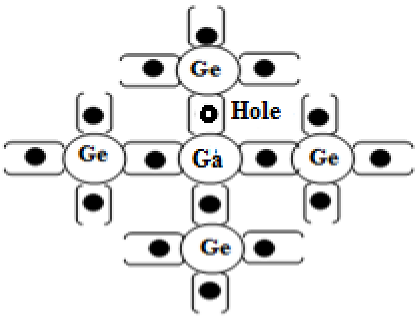




P – Type semiconductor:

P – Type semiconductor is obtained by doping an intrinsic semiconductor with **trivalent** impurity atoms like boron, gallium, indium etc. The three valence electrons of the impurity atom pairs with three valence electrons of semiconductor atom and one position of the impurity atom remains vacant, this is called **hole.** Therefore the number of holes is increased with the impurity atom. Since holes are produced in excess, they are the majority charge carrier and electrons are the minority carriers. Since the impurity can accept the electrons this energy level is called **acceptor energy level (E_a).** Here the current conduction is mainly due to holes.





1.3 Fermi – Dirac distribution function:

Fermi function F(E) represents the probability of an electron occupying a given energy states. The Fermi – Dirac statistics deals with the particles (electrons) having integral spin, named as fermions.

$$F(E) = \frac{1}{1 + e^{(E - E_F)/KBT}} \qquad (1)$$

E_F is the Fermi energy.

K_B is the Boltzmann constant.

Effect of temperature on Fermi function:

At 0 Kelvin, the electrons can be filled only up to a maximum energy level called Fermi energy E_F, above E_F all the energy levels will empty.

1. When $E < E_F$, equ (1) becomes,

$$F(E) = \frac{1}{1 + e^{-\infty}} = \frac{1}{1} = 1$$

100% chance for the electrons to be filled within Fermi energy level.

2. When E > $E_{F,}$ equ (1) becomes,

$$F(E) = \frac{1}{1+e^{\infty}} = \frac{1}{\infty} = 0$$

Zero% chance for the electrons not to be filled within the Fermi level.

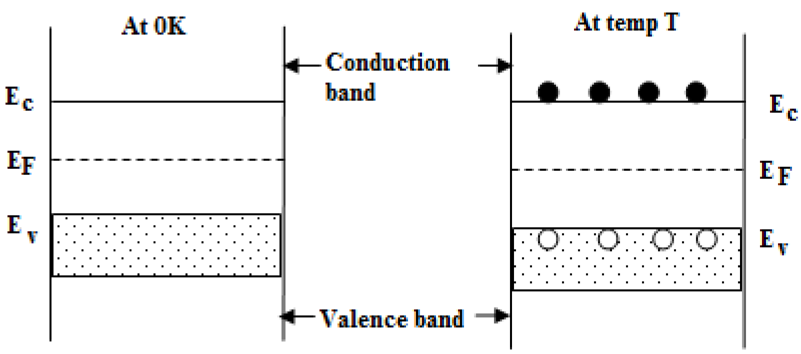
3. When E = E_F equ (1) becomes,

$$F(E) = \frac{1}{1+1} = \frac{1}{2} = 0.5$$

50% chance for an electron to be filed and not to be filled within the Fermi energy level.

1.4 Carrier concentration in intrinsic semiconductors:

At 0K the intrinsic semiconductor behaves as an insulator. But as the temperature increases some electrons move from valence band to the conduction band. Therefore both electrons & holes in the conduction and valence band contribute to electrical conductivity. Therefore the carrier concentration (or) density of electrons (n_e) and holes (n_h) has to be calculated. Assume that electrons in the conduction band is a free electron of mass m_e and the hole in the valence band as a free particle of mass m_h. The electrons in the conduction band have energies lying from E_c to ∞ and holes in the valence band have energies from - ∞ to E_v.



Density of electrons in conduction band:

Density of electron in conduction band

$$n_e = \int_{E_c}^{\infty} Z(E)F(E)dE \quad (1)$$

From Fermi – Dirac statistics,

$$Z(E)dE = 2\frac{\pi}{4}\left[\frac{8m_e}{h^2}\right]^{\frac{3}{2}} E^{\frac{1}{2}} dE \quad (2)$$

Considering minimum energy of conduction band as E_c and the maximum energy can go up to ∞, we can write equ(2) as,

$$Z(E)dE = \frac{\pi}{2}\left[\frac{8m_e}{h^2}\right]^{\frac{3}{2}} (E - E_c)^{\frac{1}{2}} dE \quad (3)$$

We know, Fermi function of finding an electron in a given energy state is,

$$F(E) = \frac{1}{1+e^{(E-E_F)/KBT}} \quad (4)$$

Substituting equ (4) & (3) in (1), within the limits E_c to ∞ as,

$$n_e = \frac{\pi}{2}\left[\frac{8m_e}{h^2}\right]^{\frac{3}{2}} \int_{E_c}^{\infty} \frac{(E-E_c)^{\frac{1}{2}}}{1+e^{(E-E_F)/KBT}} dE \quad (5)$$

Since to move an electron from valence to conduction band the energy required is greater than $4K_BT$. ie) $E - E_F >> K_BT$ (or) $(E - E_F) / K_BT) >> 1$ (or)

$e^{(E - E_F)/K_BT} >> 1$.

Therefore $1+e^{(E-E_F)/KBT} \approx e^{(E-E_F)/KBT}$

Therefore equ (5) becomes,

$$n_e = \frac{\pi}{2}\left[\frac{8m_e}{h^2}\right]^{\frac{3}{2}} \int_{E_c}^{\infty} \frac{(E-E_c)^{\frac{1}{2}}}{e^{(E-E_F)/KBT}} dE$$

Or

$$n_e = \frac{\pi}{2}\left[\frac{8m_e}{h^2}\right]^{\frac{3}{2}} \int_{E_c}^{\infty} (E-E_c)^{\frac{1}{2}} e^{(E_F-E)/KBT} dE \quad (6)$$

Let us assume $E - E_c = xK_BT$ (or) $E = E_c + x K_BT$

Differentiating the above, we get,

$dE = K_BT.dx$

Limits, when $E = E_c$, $x = 0$, when $E = \infty$, $x = \infty$ therefore limits are 0 to ∞ and hence equ (6) can be written as,

$$n_e = \frac{\pi}{2}\left[\frac{8m_e}{h^2}\right]^{\frac{3}{2}} \int_{0}^{\infty} (xKBT)^{\frac{1}{2}} e^{(E_F-xKBT-E_c)/KBT} KBTdx$$

$$= \frac{\pi}{2}\left[\frac{8m_e}{h^2}\right]^{\frac{3}{2}} \int_{0}^{\infty} x^{\frac{1}{2}} (KBT)^{\frac{1}{2}} e^{(E_F-E_c)/KBT} e^{-x} KBTdx$$

$$= \frac{\pi}{2}\left[\frac{8m_e KBT}{h^2}\right]^{\frac{3}{2}} \int_{0}^{\infty} x^{\frac{1}{2}} e^{(E_F-E_c)/KBT} e^{-x} dx$$

$$= \frac{\pi}{2}\left[\frac{8m_e KBT}{h^2}\right]^{\frac{3}{2}} e^{(E_F - E_c)/KBT} \int_0^\infty x^{\frac{1}{2}} e^{-x} dx$$

$$= \frac{1}{4}\left[\frac{8m_e \pi KBT}{h^2}\right]^{\frac{3}{2}} e^{(E_F - E_c)/KBT}$$

$$= \frac{\pi}{2}\left[\frac{8m_e KBT}{h^2}\right]^{\frac{3}{2}} e^{(E_F - E_c)/KBT} \frac{\sqrt{\pi}}{2}$$

Therefore density of electrons in conduction band is,

$$n_e = \frac{4\sqrt{4}}{4}\left[\frac{2m_e \pi KBT}{h^2}\right]^{\frac{3}{2}} e^{(E_F - E_c)/KBT}$$

$$\boxed{n_e = 2\left[\frac{2m_e \pi KBT}{h^2}\right]^{\frac{3}{2}} e^{(E_F - E_c)/KBT}} \qquad (7)$$

Density of holes in valence band:

Let the minimum energy in valence band be E_v and the minimum energy is - ∞. Therefore density of holes in valence band n_h is given by

$$n_h = \int_{-\infty}^{E_v} Z(E)(1 - F(E)dE \qquad (8)$$

We know that,

$$Z(E)dE = \frac{\pi}{2}\left[\frac{8m_h}{h^2}\right]^{\frac{3}{2}} (E_v - E)^{\frac{1}{2}} dE \qquad (9)$$

$$1 - F(E) = 1 - \frac{1}{1 + e^{(E - E_F)/KBT}}$$

$$= \frac{e^{(E - E_F)/KBT}}{1 + e^{(E - E_F)/KBT}}$$

E – E_F << K_BT (or) $= \frac{E - E_F}{KBT} << 1$ therefore $e^{(E - E_F)/KBT} << 1$

(Or) $1 + e^{(E - E_F)/KBT} \approx 1$

Therefore $1-F(E)=e^{(E-E_F)/KBT}$ (10)

Substituting equ (10) and (9) in (8), we get,

$$n_h = \frac{\pi}{2}\left[\frac{8m_h}{h^2}\right]^{\frac{3}{2}} \int_{-\infty}^{E_V} (E_v - E)^{\frac{1}{2}} e^{(E-E_F)/KBT} dE \tag{11}$$

Assume $E_v - E = xK_BT$, $E = E_v - xK_BT$

Differentiating $dE = -K_BT\,dx$, limits when $E = -\infty$, $E_v - (-\infty) = 0$ therefore $x = \infty$ when $E = E_v$, $x = 0$ therefore limits ∞ to 0.

Therefore equ (11) becomes,

$$n_h = \frac{\pi}{2}\left[\frac{8m_h}{h^2}\right]^{\frac{3}{2}} \int_{\infty}^{0} (xKBT)^{\frac{1}{2}} e^{(E_V - xKBT - E_F)/KBT} - KBTdx$$

To exclude – ve sign, the limits can be interchanged. Therefore

$$n_h = \frac{\pi}{2}\left[\frac{8m_h}{h^2}\right]^{\frac{3}{2}} \int_{0}^{\infty} (x)^{\frac{1}{2}} (KBT)^{\frac{1}{2}} e^{(E_V - E_F)/KBT} e^{-x} KBTdx$$

$$n_h = \frac{\pi}{2}\left[\frac{8m_h KBT}{h^2}\right]^{\frac{3}{2}} \int_{0}^{\infty} (x)^{\frac{1}{2}} e^{(E_V - E_F)/KBT} e^{-x} dx$$

$$n_h = \frac{\pi}{2}\left[\frac{8m_h KBT}{h^2}\right]^{\frac{3}{2}} e^{(E_V - E_F)/KBT} \int_{0}^{\infty} (x)^{\frac{1}{2}} e^{-x} dx$$

$$n_h = \frac{\pi}{2}\left[\frac{8m_h KBT}{h^2}\right]^{\frac{3}{2}} e^{(E_V - E_F)/KBT} \frac{\sqrt{\pi}}{2}$$

$$n_h = \frac{1}{4}\left[\frac{8\pi m_h KBT}{h^2}\right]^{\frac{3}{2}} e^{(E_V - E_F)/KBT}$$

Therefore density of holes in valence band,

$$n_h = \frac{(4)^{\frac{3}{2}}}{4}\left[\frac{2\pi m_h KBT}{h^2}\right]^{\frac{3}{2}} e^{(E_V - E_F)/KBT}$$

$$n_h = \frac{4\sqrt{4}}{4}\left[\frac{2\pi m_h KBT}{h^2}\right]^{\frac{3}{2}} e^{(E_V - E_F)/KBT}$$

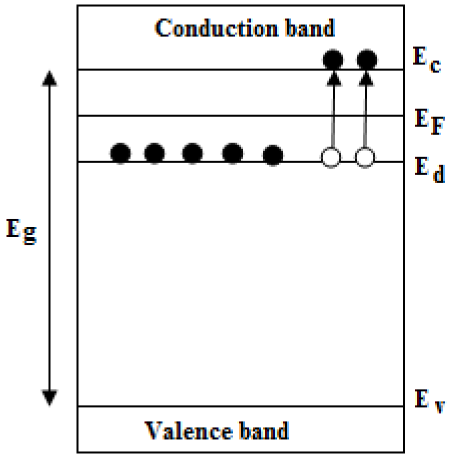
$$\boxed{n_h = 2\left[\frac{2\pi m_h KBT}{h^2}\right]^{\frac{3}{2}} e^{(E_V - E_F)/KBT}} \tag{12}$$

1.41 Carrier concentration in N – type extrinsic semiconductor:

At 0K, E_F will lie exactly between E_c and E_d, but even at low temperature some electrons may go from E_d to E_c.

Let us assume that $E_c - E_F > K_BT$. Then the density of electrons in conduction band can be written as,

$$n_e = 2\left[\frac{2m_e\pi KBT}{h^2}\right]^{\frac{3}{2}} e^{(E_F - E_c)/KBT} \qquad (1)$$



Let N_d be the number of donar energy level per cm^3 density of state $Z(E_d)$ dE, which has energy E_d below the conduction band. If some electrons are deviated from donar energy level to conduction band.eg) if two electrons go to conduction band two holes will be created in E_d. Thus, in general we can write the density of holes in donar energy level as,

$$N(E_d)dE = Z(E_d)dE(1 - F(E_d)$$

i.e.) $$n_h = N_d(1 - F(E_d)) \qquad (2)$$

We know,

$$F(E_d) = \frac{1}{1 + e^{(E_d - E_F)/KBT}}$$

Therefore,

$$1 - F(E_d) = 1 - \frac{1}{1 + e^{(E_d - E_F)/KBT}}$$

$$1 - F(E_d) = 1 - \frac{e^{(E_d - E_F)/KBT}}{1 + e^{(E_d - E_F)/KBT}} \quad (3)$$

Since $E_F - E_d >> K_BT$ (or) $E_d - E_F << K_BT$ (or)

$\frac{(E_d - E_F)}{KBT} << 1$ (Or) $e^{(E_d - E_F)}/K_BT << 1$, Therefore $1 + e^{(E_d - E_F)}/K_BT \approx 1$

Equ (3) becomes,

$$1 - F(E_d) = e^{(E_d - E_F)/KBT} \quad (4)$$

Substituting (4) in (2),

$$n_h = N_d e^{(E_d - E_F)/KBT} \quad (5)$$

At equilibrium condition,

No. of electrons per unit volume in conduction band = No. of holes per unit volume in donar energy level.

Therefore equating equ (1) and (5), we get

$$2\left[\frac{2m_e \pi KBT}{h^2}\right]^{\frac{3}{2}} e^{(E_F - E_c)/KBT} = N_d e^{(E_d - E_F)/KBT}$$

$$\frac{e^{(E_d - E_c)/KBT}}{e^{(E_F - E_c)/KBT}} = \frac{N_d}{2\left[\frac{2m_e \pi KBT}{h^2}\right]^{\frac{3}{2}}}$$

$$\frac{e^{(E_F - E_c - E_d + E_F)}}{KBT} = \frac{N_d}{2\left[\frac{2m_e \pi KBT}{h^2}\right]^{\frac{3}{2}}}$$

$$\frac{e^{(2E_F - (E_c + E_d))}}{KBT} = \left[\frac{N_d}{2\left[\frac{2m_e \pi KBT}{h^2}\right]^{\frac{3}{2}}}\right] \quad (6)$$

Taking log on both sides of equ (6),

$$\frac{2E_F-(E_c+E_d)}{KBT}=\log\left[\frac{N_d}{2\left[\frac{2m_e\pi KBT}{h^2}\right]^{\frac{3}{2}}}\right]$$

$$2E_F=(E_c+E_d)+KBT\log\left[\frac{N_d}{2\left[\frac{2m_e\pi KBT}{h^2}\right]^{\frac{3}{2}}}\right]$$

Therefore,

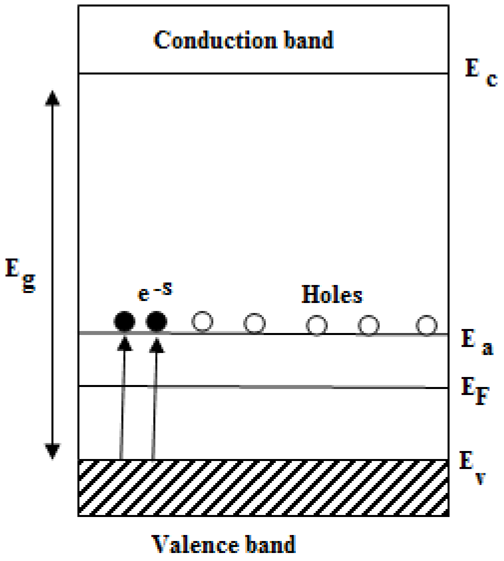
$$E_F=\frac{E_c+E_d}{2}+\frac{KBT}{2}\log\left[\frac{N_d}{2\left[\frac{2m_e\pi KBT}{h^2}\right]^{\frac{3}{2}}}\right] \quad (7)$$

At 0K, T = 0 then,

$$\boxed{E_F=\frac{E_c+E_d}{2}} \quad (8)$$

Equ (8) shows that at 0K, E_F lies exactly in between E_C and E_d.

Carrier concentration in P – type extrinsic semiconductor:



For P – type at absolute zero E_F will be exactly between E_a and E_v. At low temperature some electron from valence band fills the holes in the acceptor energy level. We know the density of holes in the valence band,

$$n_h = 2\left[\frac{2m_h \pi KBT}{h^2}\right]^{\frac{3}{2}} e^{(E_v - E_F)/KBT} \tag{1}$$

Let N_a be the number of acceptor energy levels per cm^3 which has energy E_a above valence band eg. If two electrons are accepted to fill the hole in the acceptor levels, then two holes will be created in the valence band. Therefore in general the electron density in the acceptor level can be written as,

$$N(E_a)\, dE = Z(E_a)\, dE.\, (1 - F(E_a)$$

$$n_e = N_a\, (1 - F(E_a) \tag{2}$$

Here,

$$F(E_a) = \frac{1}{1 + e^{(E_a - E_F)/KBT}} \tag{3}$$

Since $E_a - E_F >> K_BT$

$$\frac{E_a - E_F}{KBT} >> 1 \qquad \text{(Or)} \qquad e^{(E_a - E_F)/KBT} >> 1$$

(Or) $$1 + e^{(E_a - E_F)/KBT} \approx e^{(E_a - E_F)/KBT}$$

Therefore,

$$F(E_a) = \frac{1}{e^{(E_a - E_F)/KBT}} \tag{4}$$

Substituting (4) in (2), we get,

$$n_e = \frac{N_a}{e^{(E_a - E_F)/KBT}} \tag{5}$$

At equilibrium,

No. of holes per unit volume in valence band = No. of electrons per unit volume in acceptor level.

Therefore equating equ (1) & (5), we have,

$$2\left[\frac{2m_h\pi KBT}{h^2}\right]^{\frac{3}{2}} e^{\frac{(E_V-E_F)}{KBT}} = \frac{N_a}{e^{\frac{(E_a-E_F)}{KBT}}}$$

$$\frac{e^{\frac{(E_V-E_F)}{KBT}}}{e^{\frac{(E_a-E_F)}{KBT}}} = \frac{N_a}{2\left[\frac{2m_h\pi KBT}{h^2}\right]^{\frac{3}{2}}}$$

$$\frac{e^{(E_V-E_F+E_a-E_F)}}{KBT} = \frac{N_a}{2\left[\frac{2m_h\pi KBT}{h^2}\right]^{\frac{3}{2}}}$$

$$\frac{e^{(E_V+E_a-2E_F)}}{KBT} = \frac{N_a}{2\left[\frac{2m_h\pi KBT}{h^2}\right]^{\frac{3}{2}}} \qquad (6)$$

Taking log on both sides of equ (6)

$$\frac{E_V+E_a-2E_F}{KBT} = \log\left[\frac{N_a}{2\left[\frac{2m_h\pi KBT}{h^2}\right]^{\frac{3}{2}}}\right]$$

$$E_V+E_a-2E_F = KBT\log\left[\frac{N_a}{2\left[\frac{2m_h\pi KBT}{h^2}\right]^{\frac{3}{2}}}\right]$$

$$E_V + E_a - KBT \log\left[\frac{N_a}{2\left[\frac{2m_h \pi KBT}{h^2}\right]^{\frac{3}{2}}}\right] = 2E_F$$

Therefore,

$$E_F = \frac{E_V + E_a - KBT}{2} \log\left[\frac{N_a}{2\left[\frac{2m_h \pi KBT}{h^2}\right]^{\frac{3}{2}}}\right] \quad (7)$$

At 0K, T = 0 equu (7) becomes, $\boxed{E_F = \frac{E_V + E_a}{2}}$ (8)

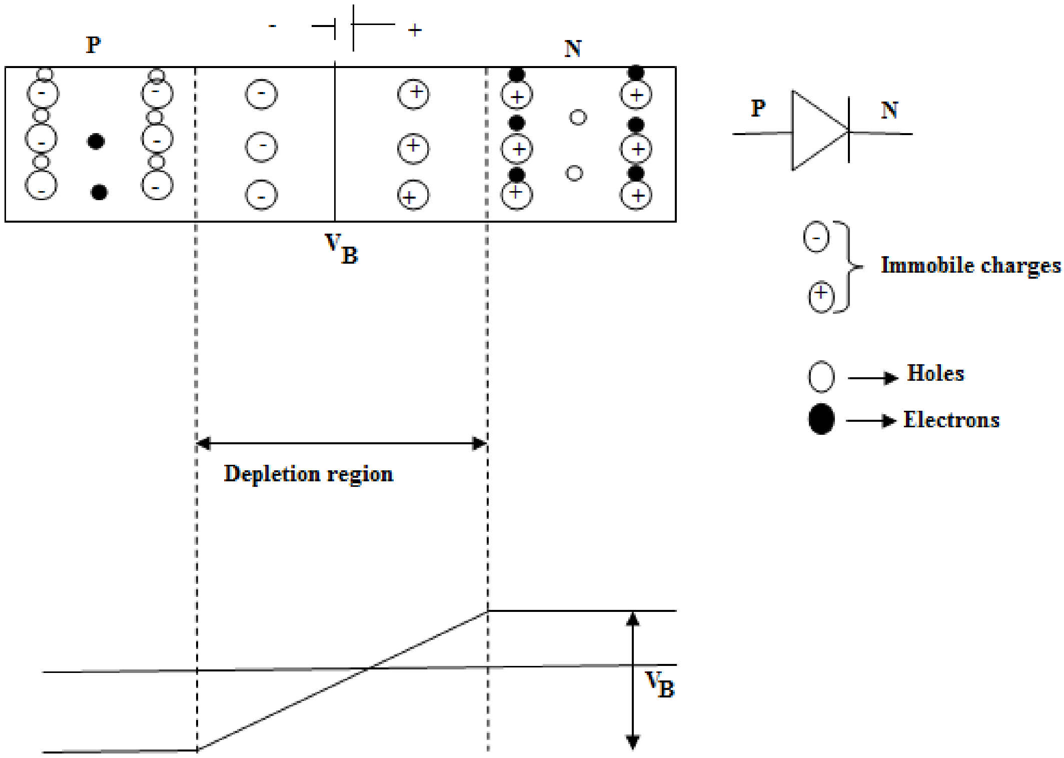
Equ (8) denotes that the Fermi energy level lies exactly between valence band and acceptor level.

1.5 PN junction diode:

When P – type semiconductor is suitably joined to N – type semiconductor, the contact surface is called P – N junction and this arrangement is known as **P - N junction diode.**

At the junction, there is a tendency for the electrons in the N – type to diffuse into the P – type and the holes from P – type to N – type. This process is called **diffusion.** While crossing the junction, the electrons and holes recombines with each other, leaving the immobile ions in the nearby atom of the junction unneutralised, these immobile +ve and –ve ions, setup a potential across the junction called **potential barrier (V_B).**

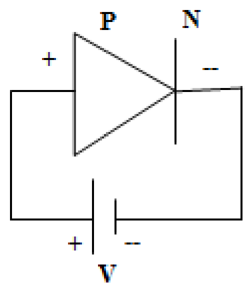
Due to this, no further diffusion of electrons and holes takes place, across the region. At the vicinity of the junction, since the mobile charge carriers are depleted, this region is called **depletion region or space charge region.**



1.5.1 Forward bias:

Applying an external voltage to the junction is known as **biasing**. When the +ve terminal of the external battery is connected to the P side and the –ve side to the N side, the junction is said to be **forward biased.**

The holes in the P side move towards, the junction while the electrons in the N side move towards the junction this reduces the width of the barrier. If the applied voltage V is greater than the potential barrier V_B, then the majority carriers namely holes in P side and electrons in N side, crosses the barrier and some of them get neutralized. The remaining charges after crossing reach the other side to increase the forward current.

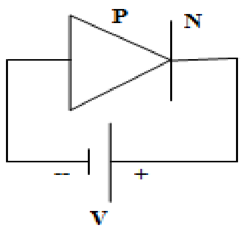


1.5.2Reverse bias:

When the +ve terminal of the external battery V is connected to the N side and negative terminal to the P side of the junction diode, then it is said to be in the **reverse bias.**

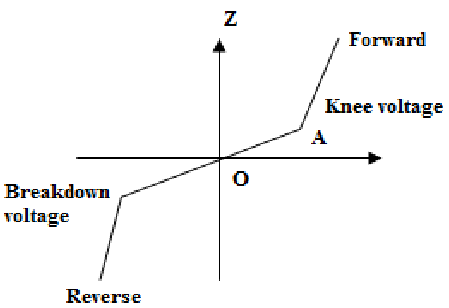
Under reverse bias, the holes in the P type are attached by the –ve terminal of the external battery. Hence the width of the barrier is increased. So no majority carriers can cross the barrier to constitute current. When the applied voltage is greater than the barrier voltage these minority carriers, cross the barrier. During crossing some may get recombined. The remaining minority carriers after crossing reach the other side and constitute current. But this is very small.

As the applied reverse voltage increases, the minority current also increases, but with small value. At a particular reverse voltage (p) the junction break down, there is random motion of carriers and hence current increases abruptly. Such a reverse voltage, at which junction breaks down is called **Avalanche break down voltage,** this effect is known as Avalanche effect.



1.5.3 Breakdown voltage:

It is a minimum reverse voltage at which PN junction breaks down with sudden rise in reverse current.



1.5.4 Knee voltage:

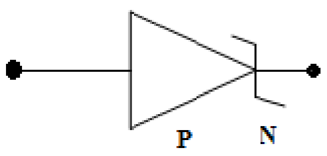
It is the forward voltage at which the current through the junction starts to increase rapidly.

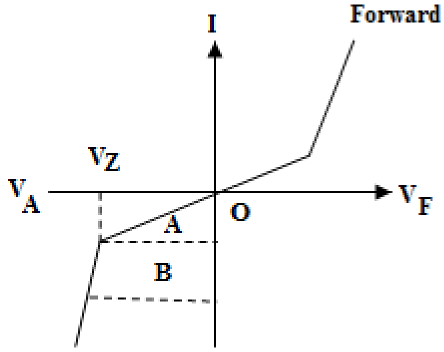
1.6. SPECIAL DIODES:

1.6.1 Zener diode:

A properly doped crystal diode which has a sharp breakdown voltage is known as **Zener diode.** This diode was first designed by the American scientist **C.ZENER.** Therefore the breakdown voltage is sometimes called, Zener voltage and the current as Zener current.

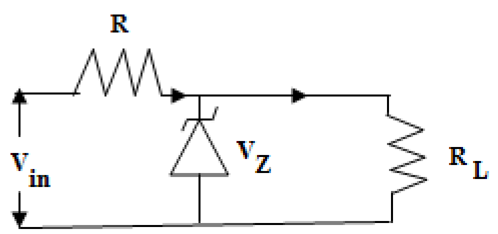
When the reverse voltage reaches breakdown voltage in normal PN junction diode, the current through the junction will be high. Such an operation is destructive and diode gets damaged, whereas diodes can designed to operate in the breakdown region is known as Zener diode which is heavily doped than ordinary diode.





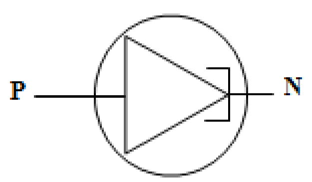
From the V-I characteristics of the Zener diode, it is found that the operation of Zener diode is same as that of ordinary PN diode under forward biased condition. Whereas under reverse biased condition, voltage occurs. The breakdown voltage depends upon the doping. If the diode is heavily doped, depletion layer will be thin and breakdown occurs at lower reverse voltage

1.6.2 Zener diode as voltage stabilizer:



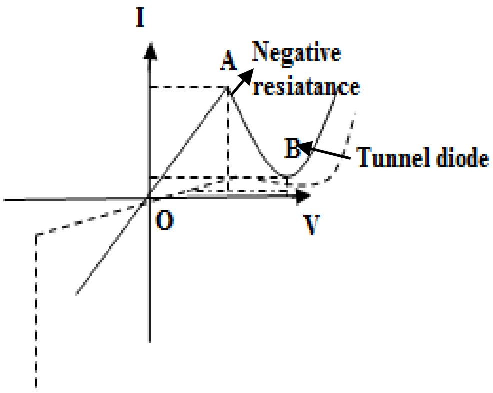
Under the reverse bias condition, the voltage across the diode remains almost constant although the current through the diode increases. Thus the voltage across the Zener diode serves as a reference voltage. Hence the diode can be used as a voltage regulator. Though the Zener breakdown occurs for lower breakdown voltage and avalanche breakdown occurs for higher breakdown, such diodes are normally called as Zener diodes.

1.6.3 Tunnel diode:



The **tunnel or Esaki** diode is a thin junction diode which exhibits negative resistance under low forward bias conditions. The width of the junction barrier varies inversely as the square root of the impurity concentration. This thickness is only about $1/50^{th}$ of the wavelength of visible light. For such thin potential energy barriers, the electrons will penetrate through the junction rather than overwrite them. This quantum mechanical behavior is referred to as tunneling and hence, these high impurity density PN junction devices are called tunnel diodes.

The V-I characteristics of a tunnel diode is shown in the above figure, it is seen that at first forward current rises sharply as applied voltage is increased, where it would have risen slowly for an ordinary PN junction diode



Also reverse current is much larger than other diodes due to the thinness of the junction. At the point A on the curve, the peak voltage, as the forward bias is increased beyond this point, the forward current drops and continues to drop until point B reached. This is the valley voltage. At B, the current start to increase once again as bias is increased. Beyond this point, it resembles as ordinary diode.

When a small forward bias is applied to the junction, the energy level of the P side is lower as compared with N side. Hence tunneling from N side to P side takes place. Tunneling other direction is not possible.

When the forward bias is raised beyond this point, tunneling will decrease. As the bias is raised, forward current drops. This corresponds to –ve resistance region of the diode. As forward bias is raised, tunneling stops and it behaves as a normal PN junction diode.

Applications:

- It is used as an ultra -high speed switch of order of ns or ps.
- As logic memory storage device.
- As microwave oscillator.
- In relaxation oscillator circuits
- As an amplifier.

Advantages:

- Low noise
- Easy operation
- High speed
- Low power consumption

Disadvantages:

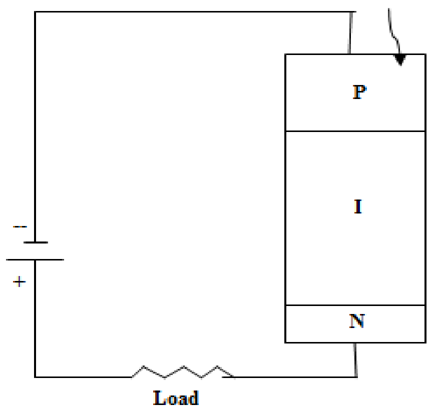
- Voltage range over which it can be operated is 1 V less.
- Being a two terminal device, there is no isolation between the input and output circuit.

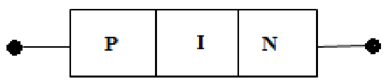
1.6.4 PIN photodiode:

It is compressed of three regions. In addition to the usual N and P regions, an intrinsic layer is sandwiched between them. Two advantages compared to an ordinary PN diode.

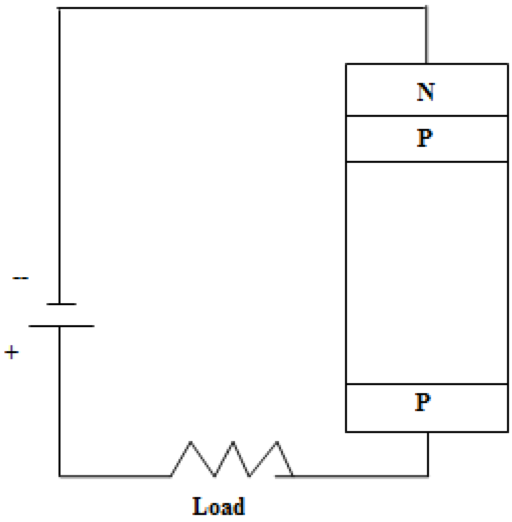
- Decrease in capacitance between P & N is inversely proportional to the separation between these regions and allows faster response time for the diode.
- Possibility of greater electric field between P & N junctions.

It is used for the detection of light at the receiving end in optical communication. It is a three region reverse biased junction diode. The depletion region extends almost to the entire intrinsic layer where most of the absorption of light photons takes place. The width of the intrinsic layer is large compared to the width of the other two layers. This ensures large absorption of light photons in the depletion region. Light photons incident on the PIN photodiode are absorbed which leads to the generation of electron-hole pairs, the reverse current flowing in the external circuit increases linearly with the level of illumination.





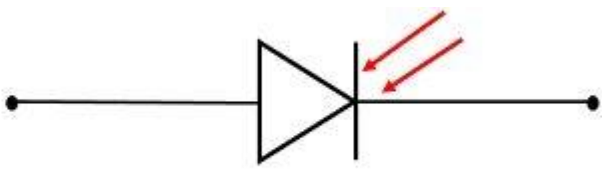
1.6.5 Avalanche photo diode:



APD is used in optical communication for detection of light at the receiving end. It converts the input light signal into electrical signal. The structure of an APD is shown in figure. It consists of reverse biased PN junction is formed by immobile positively charged donor atoms in the N type semiconductor material and immobile negatively charged acceptor atoms in the P type material. The electric field in this depletion region is very high where APD requires a high reverse bias voltage of 100 – 400V. Electron – hole pairs thus generated separate and drift under the influence of the electric field in the depletion region they are finally collected in the detector terminals. This leads to a flow of current in the external circuit which is proportional to the intensity of light incident on APD. Due to the internal gain mechanism in an APD, a large electrical response is obtained even for a weak input light signal.

1.6.7 Photo diode:

A special type of PN junction device that generates current when exposed to light is known as Photodiode. It is also known as photo detector or photo sensor. It operates in reverse biased mode and converts light energy into electrical energy**.**



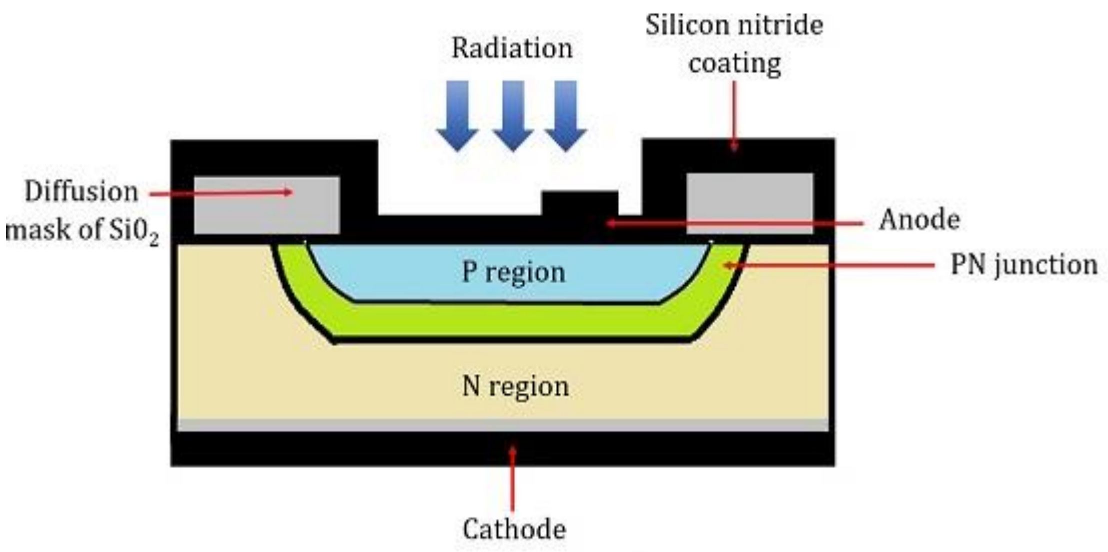
Symbolic representation of Photodiode

Principle of Photodiode

It works on the principle of **Photoelectric effect**. The operating principle of the photodiode is such that when the junction of this two-terminal semiconductor device is illuminated then the electric current starts flowing through it. Only minority current flows through the device when the certain reverse potential is applied to it.

Construction of Photodiode

The figure below shows the constructional detail of a photodiode:



The PN junction of the device placed inside a glass material. This is done to order to allow the light energy to pass through it. As only the junction is exposed to radiation, thus, the other portion of the glass material is painted black or is metalized. The overall unit is of very small dimension nearly about **2.5 mm**. It is noteworthy that the current flowing through the device is in **micro-ampere** and is measured through an ammeter.

Operational Modes of Photodiode:

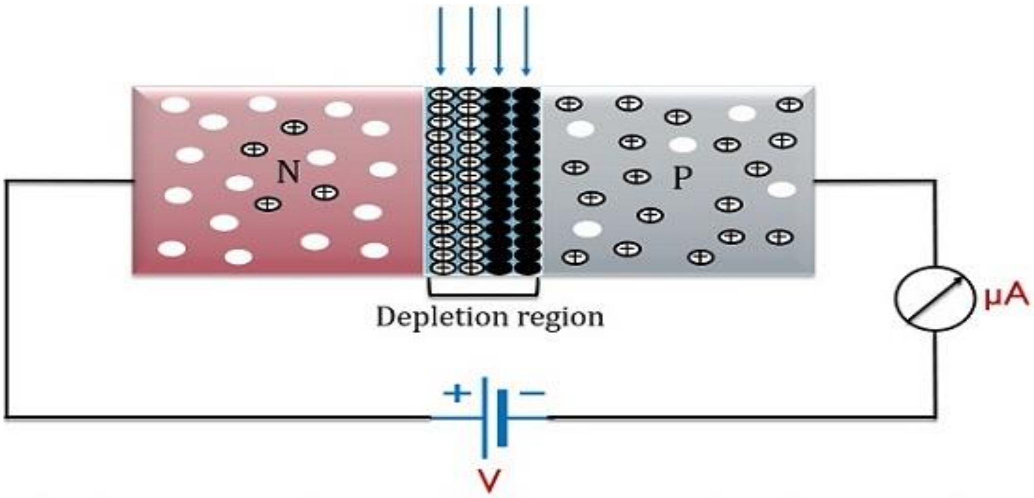
Photovoltaic mode: It is also known as zero-bias mode because no external reverse potential is provided to the device. However, the flow of minority carrier will take place when the device is exposed to light.

Photoconductive mode: When a certain reverse potential is applied to the device then it behaves as a photoconductive device. Here, an increase in depletion width is seen with the corresponding change in reverse voltage.

Working of Photodiode

In the photodiode, a very small reverse current flows through the device that is termed as **dark current**. It is called so because this current is totally the result of the flow of minority carriers and is thus flows when the device is not exposed to radiation.

The electrons present in the p side and holes present in n side are the minority carriers. When a certain reverse-biased voltage is applied then minority carrier, holes from n-side experiences repulsive force from the positive potential of the battery.



Similarly, the electrons present in the p side experience repulsion from the negative potential of the battery. Due to this movement electron and hole recombine at the junction resultantly generating depletion region at the junction.

Due to this movement, a very small reverse current flows through the device known as dark current. The combination of electron and hole at the junction generates neutral atom at the depletion. Due to which any further flow of current is restricted.

Now, the junction of the device is illuminated with light. As the light falls on the surface of the junction, then the temperature of the junction gets increased. This causes the electron and hole to get separated from each other.

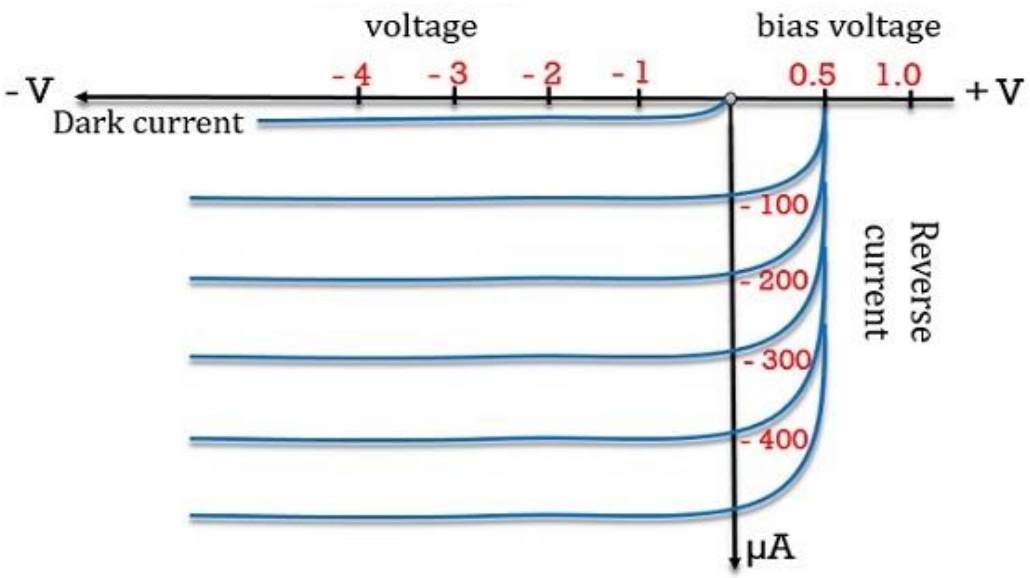
At the two gets separated then electrons from n side gets attracted towards the positive potential of the battery. Similarly, holes present in the p side get attracted to the negative potential of the battery. This movement then generates high reverse current through the device.

With the rise in the light intensity, more charge carriers are generated and flow through the device thereby, producing a large electric current through the device. This current is then used to drive other circuits of the system.

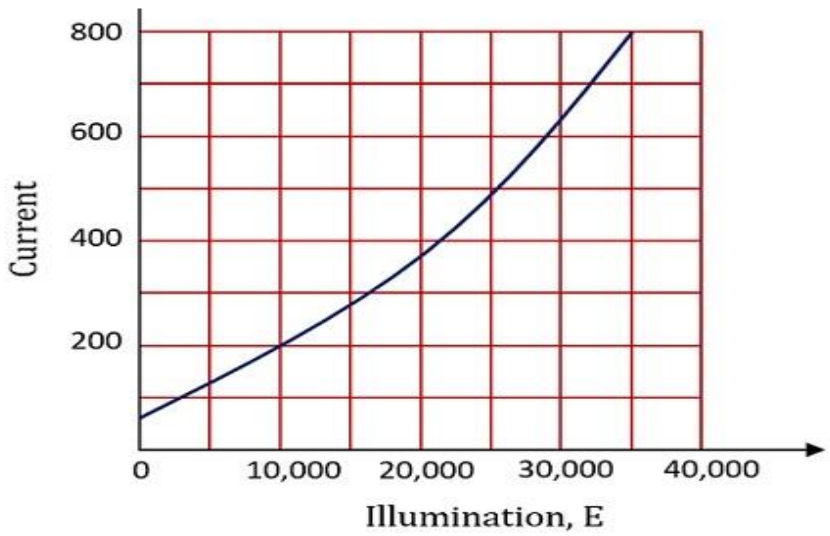
So, we can say the intensity of light energy is directly proportional to the current through the device. Only positive biased potential can put the device in no current condition in case of the photodiode.

CHARACTERISTICS OF PHOTODIODE

The figure below shows the VI characteristic curve of a photodiode: Here, the vertical line represents the reverse current flowing through the device and the horizontal line represents the reverse-biased potential. The first curve represents the dark current that generates due to minority carriers in the absence of light. As we can see in the above figure that the entire curve shows almost equal spacing in between them. This is so because current proportionally increases with the luminous flux.



The figure below shows the curve for current versus illumination:



Advantages of Photodiode

It shows a quick response when exposed to light.

Photodiode offers high operational speed.

It provides a linear response.

It is a low-cost device.

Disadvantages of Photodiode

It is a temperature-dependent device. And shows poor temperature stability

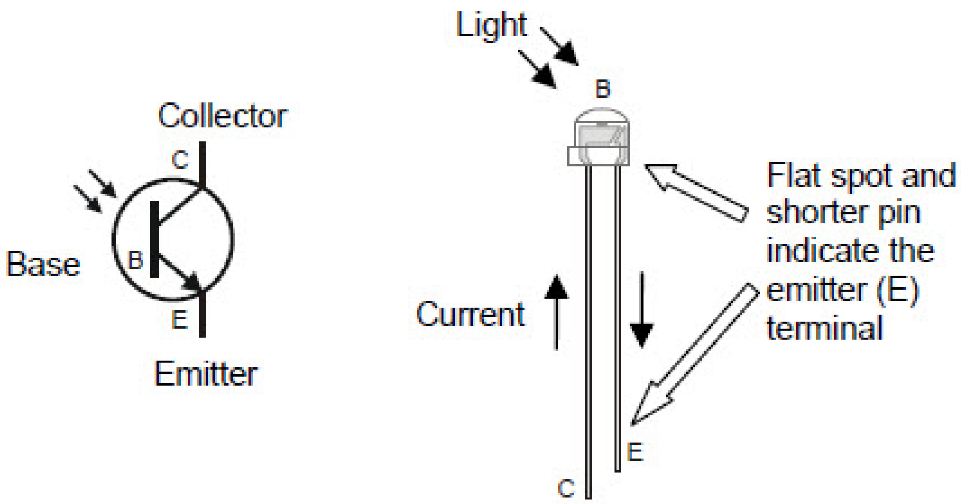
When low illumination is provided, then amplification is necessary.

Applications of Photodiode

- Photodiodes majorly find its use in counters and switching circuits.
- Photodiodes are extensively used in an optical communication system.
- Logic circuits and encoders also make use of photodiode.
- It is widely used in burglar alarm systems. In such alarm systems, until exposure to radiation is not interrupted, the current flows. As the light energy fails to fall on the device, it sounds the alarm.

1.6.7 Phototransistor:

Photo transistor has a combine ability to detect light and to provide gain.



Its construction is almost similar to that of an ordinary transistor except the top surface is exposed by a lens or a window. In the collector base junction (CB) junction, the incident photons generate electron – hole pairs.

The reverse voltage of the (CB) junction draws the induced holes to the base & electrons towards collector junction. The electrons flow from emitter to base. The flow of electrons constitutes a light induced collector current. Thus the photon induced electron – hole pairs contribute to the base current.

Applications:

- It is used as digital ON – OFF switch.
- It is used as light sensitive switch.

1.7 FIELD EFFECT TRANSISTOR (FET):

It is a three terminal device, in which the current conduction is only by one type of carrier (ie) either by electrons or by holes. To eliminate two drawbacks of a bipolar transistor FET are used they are,

- Emitter – base is always forward biased, it offer low input impedance.
- Due to the presence of the two junctions it creates noise.

1.7.1 TYPES OF FET:

1. Junction field effect transistor (JFET).
2. Metal oxide semiconductor field effect transistor (MOSFET).

1.7.2 JUNCTION FIELD EFFECT TRANSISTOR:

The current conduction in a FET is controlled by means of an electric field between the gate and channel. There are two types of FET.

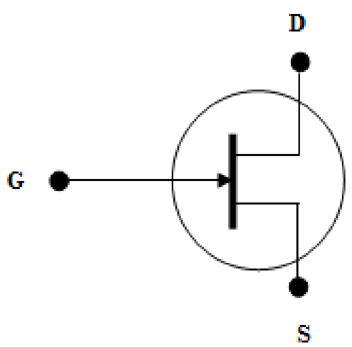
i) N-channel FET.

ii) P-channel FET.

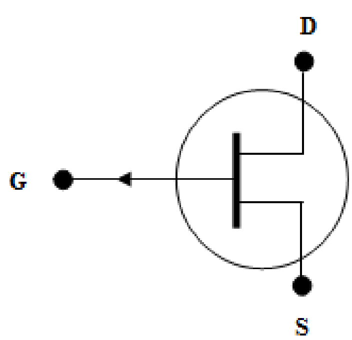
CONSTRUCTION:

In an N-channel FET, an n-type bar is uniformly doped. On both sides of this a p-type materials are heavily doped. These two PN-junction diodes are internally connected and have a common terminal "Gate" (G). These ends of semiconductor bar have terminals "Source" (S) and "Drain" (D).

Schematic Diagram:

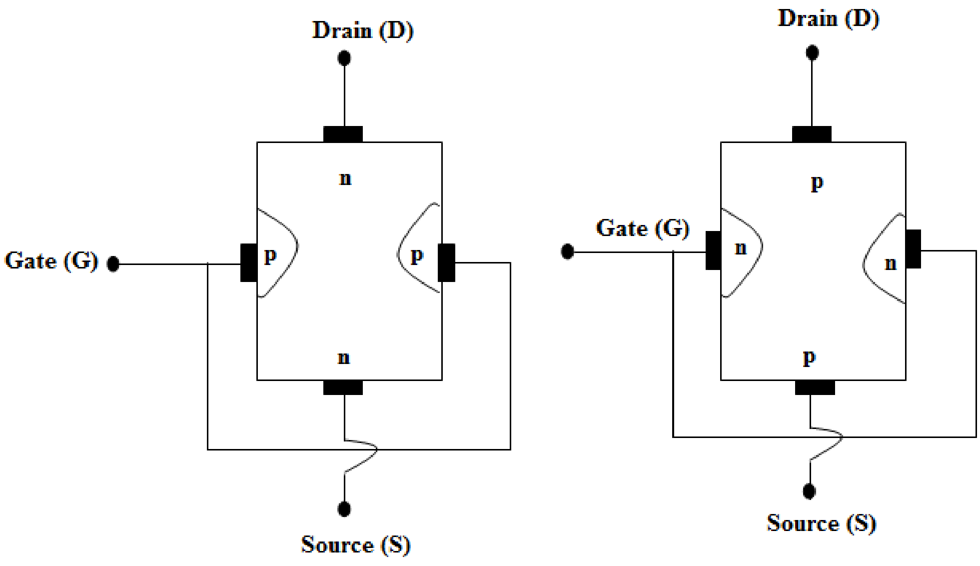


n- channel JFET



p - channel JET

In this n & p channel FET both source (S) and drain (D) are interchangeable. P-channel FET is constructed with two N-type materials are heavily doped. The region between the depletion layers is called "channel".



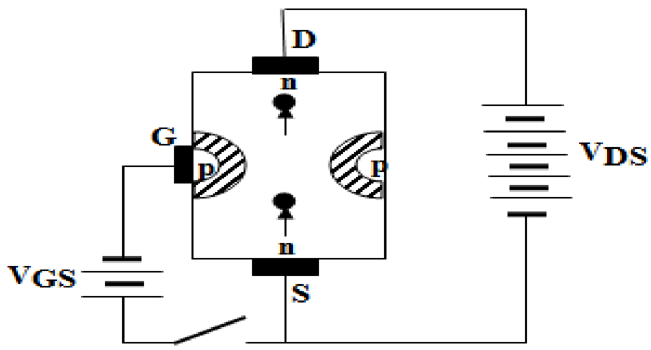
n channel JFET   p channel JFET

Working:

- **When V_{GS} is –ve ,V_{DS}=0:**

When V_{GS} is –ve ,the two pn diodes are reverse biased and hence the channel width decreases by the increase of the two depletion layer till the two layers touch each other and channel width becomes zero. When channel width becomes zero is called **"cut-off voltage"**

- **When V_{GS}=0, V_{DS} is constant:**

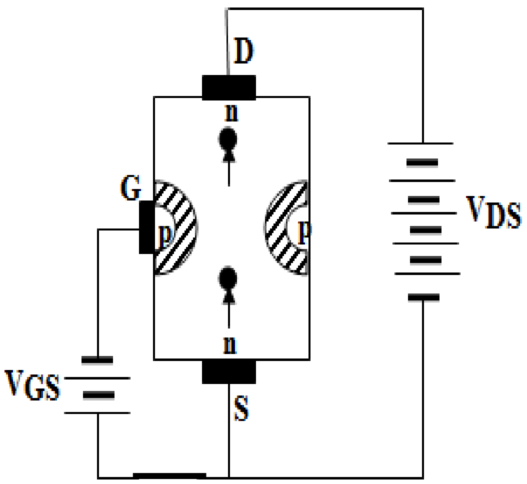


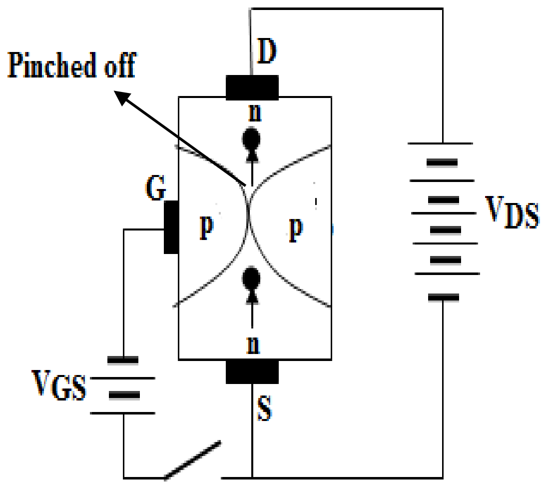
When V_{GS}=0 gate is open, the thickness of the two depletion layers becomes less and hence channel width becomes maximum when drain is +ve electrons flows from source to drain and hence the drain current (I_D) becomes maximum.

- **When V_{GS}=-ve and V_{DS} increased:**

When V_{GS} is –ve the diodes are reverse biased. V_{DS} is kept at +ve potential the electrons flows from the source to drain, constituting drain current (I_D).

Due to voltage drop along the channel the top end of the gate is larger than bottom end. So the depletion layer will be thicker near drain and becomes **"Wedge shaped"**.





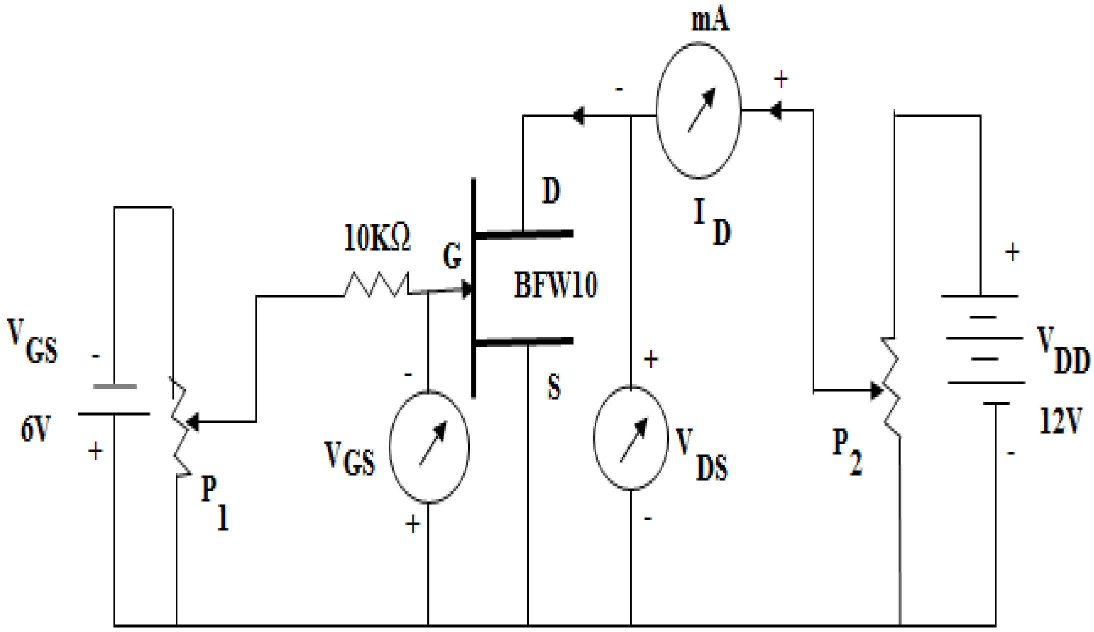
As V_{DS} increases, the wedge shape also increases. At V_P the channel is pinched off and the drain voltage is called **"Pinch off voltage"** and hence the drain current becomes constant.

- **When V_{GS} is –ve and increased at constant V_{DS}:**

When V_{GS} is –ve diodes are reverse biased V_{GS} increased, the depletion layer increases and channel width decreases and hence drain current (I_D) decreases. On the same time if the reverse voltage V_{GS} decreases and channel width increases and hence the flow of electrons increases so drain current increases. Thus the reverse voltage between gate and the source controls the flow of electrons and drain current. Hence it is called as Field effect transistor.

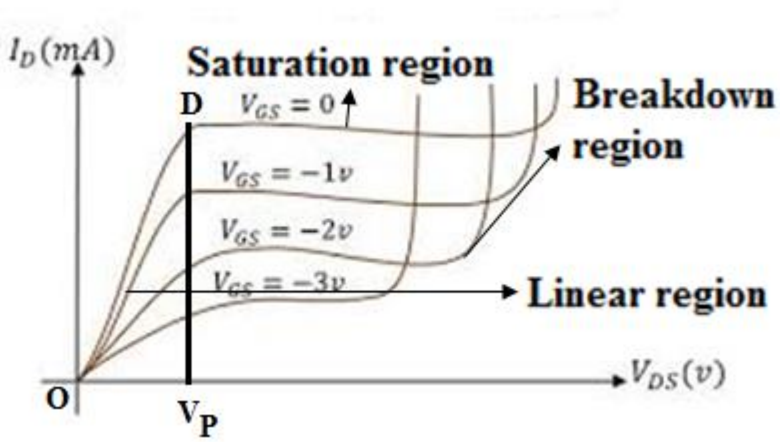
1.7.3 V- I CHARACTERISTICS OF FET:

The circuit diagram for static characteristics is given below. In which the V_{GS} is kept with a fixed value for various values of V_{DS} and the corresponding drain current (I_D) were noted. The following graphs (i) Output characteristics & (ii) Transfer characteristics.



OUTPUT CHARACTERISTICS:

The graph drawn between the drain current (**I_D**) and drain to source voltage (**V_{DS}**) at constant (**V_{GS}**) is known as output characteristics.



The output characteristics can be divided into 3 regions,

1. Linear region
2. Saturation region
3. Breakdown region

1. Linear region:

As drain-source voltage (**V_{DS}**) increases, drain current (I_D) also increases. This region is called Ohmic or Linear region.

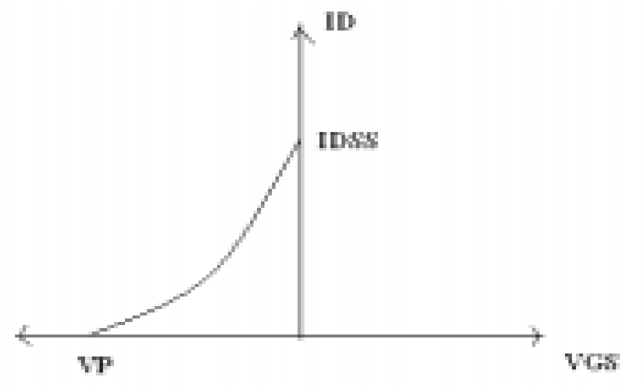
2. **Saturation region:**

   From the graph, OD is pinch-off voltage. After V_P there is an increase in depletion area and hence drain current remains constant.

3. **Breakdown region:**

   From the graph, the breakdown occurs at a lower value of $\mathbf{V_{DS}}$. When $\mathbf{V_{GS}}$ is increased, the drain current rises almost vertically with a slight increase of the drain to source voltage. This is known as breakdown voltage.

TRANSFER CHARACTERISTICS:



Transfer characteristics of FET

The graph draw between drain current (I_D) and gate to source voltages $\mathbf{V_{GS}}$ at constant $\mathbf{V_{DS}}$ is known as Transfer characteristics.

1.7.4 PARAMETERS OF FET:

- Drain resistance (r_d)
- Trans conductance (g_m)
- Amplification factor (µ)

Drain resistance (r_d):

It is defined as the ratio of change in drain-source voltage ($\Delta \mathbf{V_{DS}}$) to the drain current ($\Delta \mathbf{I_D}$) at constant $\mathbf{V_{GS}}$.

$$r_d = \left(\frac{\Delta V_{DS}}{\Delta I_D} \right)_{V_{GS}}$$

Trans conductance (g_m):

It is defined as the ratio of change in drain current Δ I_D to the change in gate to source voltage (Δ V_{GS}) at constant V_{DS}.

$$g_m = \left(\frac{\Delta I_D}{\Delta V_{GS}} \right)_{V_{DS}}$$

Amplification factor (μ):

It is defined as the ratio of small change in drain to source voltage, (Δ V_{DS}) to the change in gate to source voltage (Δ V_{GS}) at constant I_D.

$$\mu = \left(\frac{\Delta V_{DS}}{\Delta V_{GS}} \right)_{I_D}$$

1.7.5 Relation between amplification factor (μ), drain resistance (r_d) and trans conductance (g_m):

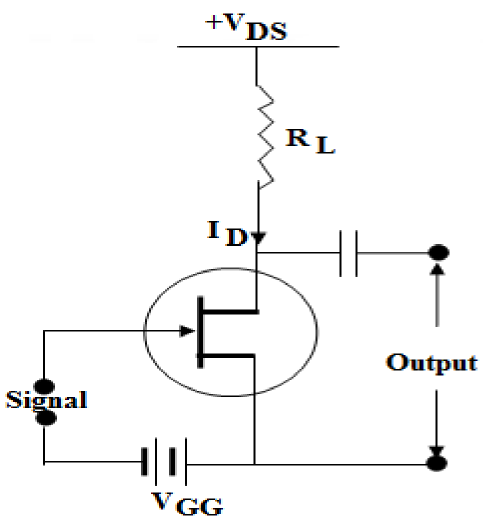
$$\mu = r_d \times g_m$$

$$\mu = \frac{\Delta V_{DS}}{\Delta I_D} \times \frac{\Delta I_D}{\Delta V_{GS}}$$

$$\mu = \frac{\Delta V_{DS}}{\Delta V_{GS}}$$

$$\therefore \mu = r_d \times g_m$$

1.7.6 FET AS AN AMPLIFIER:



The weak signal is applied between gate and source and amplified output is obtained in drain source. The input must be –ve with respect to source so circuit should always be reverse biased by using a battery V_{GG}.

A small change in the reverse bias on the gate produces a large change in drain current. This raises the strength of the weak signal. During +ve half signal, the reverse bias on the gate decreases. This increases the channel width, hence drain current increases.

During –ve half signal, the reverse bias on gate increases and the channel width decreases and hence drain current decreases. So small change in gate voltage produces large drain current. This variation in drain current large output across R_L thus FET acts as an amplifier.

References:

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2. **https://www.electronics-tutorials.ws/diode/diode_3.html**
3. **http://gn.dronacharya.info/EEEDept/Downloads/subjectinfo/IV/ANALOG_DIGITAL_ELECTRONICS/Unit-1/Lecture-1.pdf**
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5. **https://www.daenotes.com/electronics/industrial-electronics/fet-or-jfet#:~:text=FET%20stands%20for%20%22Field%20Effect,control%20by%20an%20electric%20field.&text=P%2DChannel%20JFET%20is%20similarly,two%20N%2D%20types%20of%20junctions.**
6. **https://electronicscoach.com/field-effect-transistor.html**

IMPORTANT QUESTIONS:

2 marks:

1. **Define valence band.**

   The valence band may be completely or partially filled. In the case of inert gases, the valence band is full whereas for other materials, it is only partially filled.

2. **What is meant by conduction band?**

   The range of energies corresponding to the higher unoccupied level is known as **conduction band.** All electrons in the conduction band are free electrons.

3. **Define forbidden energy gap.**

   The region in between the conduction and valence band is known as forbidden gap. No electrons of a solid can stay in a forbidden gap.

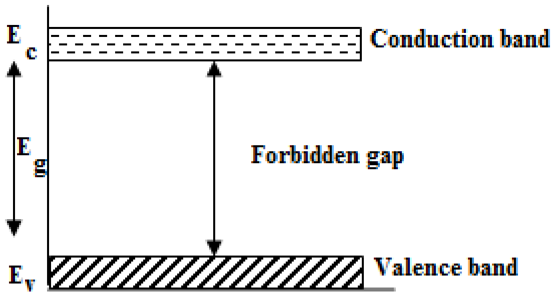
4. **How the solids are classified in terms of their energy gap?**

   On the basis of energy band theory, solids are classified into three groups,

   - Metals
   - Insulators
   - Semiconductors

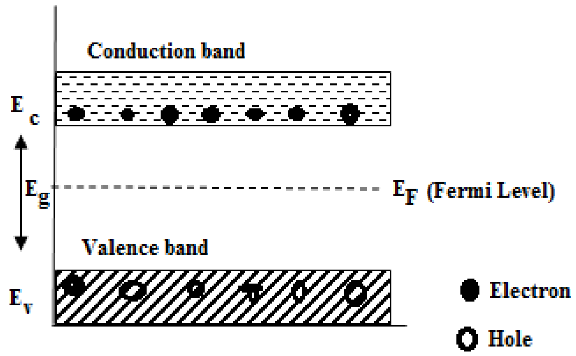
5. **Explain about insulators.**

   In insulators, the forbidden gap is very large. Since the forbidden energy gap is very large, large amount of energy is to be supplied to shift the electrons from the valence to the conduction band. So no electrons are available in the conduction band for conduction. Hence such types of material are known as insulators.



6. **Define semiconductors.**

In semiconductors, the energy gap is very small so that, even at ordinary temperature, electrons can jump into the conduction band. As a result, some states in the conduction band are occupied and equal number of states in the valence band is unoccupied. The vacancies produced in the valence band are called as **holes**. Such materials are known as semiconductors. At 0°K, a semiconductor behaves as insulator, but at or above room temperature, it behaves as conductor.



7. **What is meant by Fermi level?**

Fermi level is the maximum energy level up to which the electrons can be filled at 0K.

- It acts as a reference level which separates the vacant and filled states at 0K.
- It gives the information about the filled electrons states and empty states.

8. **Write the types of semiconductors.**

Semiconductors are divided into two types,

- Intrinsic (or) pure semiconductor
- Extrinsic (or) impure semiconductors

9. **Explain intrinsic semiconductor.**

A semiconductor in an extremely pure form is known as **intrinsic semiconductor.** In this type, even at room temperature, electron-hole pairs are created. When electric field is applied, the current conduction takes place by two processes namely, by free electrons and holes

10. Define extrinsic semiconductor.

The charge carriers are produced due to impurity atoms are called **extrinsic semiconductor.** They are obtained by doping an intrinsic semiconductor with impurity atoms.

11. Write the classifications of extrinsic semiconductor.

They are classified into two,

1. n – type semiconductors
2. p – type semiconductor

12. Write the Fermi Dirac distribution function.

Fermi function F (E) represents the probability of an electron occupying a given energy states. The Fermi – Dirac statistics deals with the particles (electrons) having integral spin, named as fermions.

$$F(E) = \frac{1}{1 + e^{(E - E_F)/KBT}}$$

E_F is the Fermi energy.

K_B is the Boltzmann constant.

13. Define PN junction diode.

When P – type semiconductor is suitably joined to N – type semiconductor, the contact surface is called P – N junction and this arrangement is known as **P - N junction diode.**

14. What is meant by diffusion?

There is a tendency for the electrons in the N – type to diffuse into the P – type and the holes from P – type to N – type. This process is called **diffusion.**

15. Explain potential barrier.

While crossing the junction, the electrons and holes recombines with each other, leaving the immobile ions in the nearby atom of the junction unneutralised, these immobile +ve and –ve ions, setup a potential across the junction called **potential barrier (V_B).**

16. Define depletion region.

No further diffusion of electrons and holes takes place, across the PN region. At the vicinity of the junction, since the mobile charge carriers are depleted, this region is called **depletion region or space charge region.**

17. What is meant by biasing and explain the types of biasing.

Applying an external voltage to the junction is known as **biasing**. When the +ve terminal of the external battery is connected to the P side and the –ve side to the N side, the junction is said to be **forward biased.**

When the +ve terminal of the external battery V is connected to the N side and negative terminal to the P side of the junction diode, then it is said to be in the **reverse bias.**

18. Define avalanche effect.

At a particular reverse voltage (p) the junction break down, there is random motion of carriers and hence current increases abruptly. Such a reverse voltage, at which junction breaks down is called **Avalanche break down voltage,** this effect is known as Avalanche effect.

19. What is breakdown voltage?

It is a minimum reverse voltage at which PN junction breaks down with sudden rise in reverse current.

20. What is Knee voltage?

It is the forward voltage at which the current through the junction starts to increase rapidly.

21. Explain Zener diode.

A properly doped crystal diode which has a sharp breakdown voltage is known as **Zener diode.** This diode was first designed by the American scientist **C.ZENER.** Therefore the breakdown voltage is sometimes called, Zener voltage and the current as Zener current

22. Write a note on Tunnel diode.

The **tunnel or Esaki** diode is a thin junction diode which exhibits negative resistance under low forward bias conditions. This thickness is only about $1/50^{th}$ of the wavelength of visible light. For such thin potential energy barriers, the electrons will penetrate through the junction rather than overwrite them. This quantum mechanical behavior is referred to as tunneling and hence, these high impurity density PN junction devices are called tunnel diodes.

23. List out the applications of Tunnel diode.

- It is used as an ultra -high speed switch of order of ns or ps.
- As logic memory storage device.
- As microwave oscillator.

- In relaxation oscillator circuits
- As an amplifier

24. Write advantages and disadvantages of Tunnel diode.

Advantages:

- Low noise
- Easy operation
- High speed
- Low power consumption

Disadvantages:

- Voltage range over which it can be operated is 1 V less.
- Being a two terminal device, there is no isolation between the input and output circuit

25. Define FET.

It is a three terminal device, in which the current conduction is only by one type of carrier (ie) either by electrons or by holes. To eliminate two drawbacks of a bipolar transistor

- Emitter – base is always forward biased, it offer low input impedance.
- Due to the presence of the two junctions it creates noise.

26. Mention the types of FET

Junction field effect transistor (JFET)

Metal oxide semiconductor field effect transistor (MOSFET).

27. Explain pinch off voltage.

As $\mathbf{V_{DS}}$ increases, the wedge shape also increases. At V_P the channel is pinched off and the drain voltage is called **"Pinch off voltage"** and hence the drain current becomes constant.

28. Define linear region of FET.

As drain-source voltage ($\mathbf{V_{DS}}$) increases, drain current (I_D) also increases. This region is called Ohmic or Linear region.

29. What is drain resistance?

It is defined as the ratio of change in drain-source voltage (Δ**V_{DS}**) to the drain current (Δ**I_D**) at constant **V_{GS}**.

$$r_d = \left(\frac{\Delta V_{DS}}{\Delta I_D} \right)_{V_{GS}}$$

30. Define transconductance

It is defined as the ratio of change in drain current Δ **I_D** to the change in gate to source voltage (Δ **V_{GS}**) at constant **V_{DS}**.

$$g_m = \left(\frac{\Delta I_D}{\Delta V_{GS}} \right)_{V_{DS}}$$

31. What is amplification factor of FET?

It is defined as the ratio of small change in drain to source voltage, (Δ **V_{DS}**) to the change in gate to source voltage (Δ **V_{GS}**) at constant I_D.

$$\mu = \left(\frac{\Delta V_{DS}}{\Delta V_{GS}} \right)_{I_D}$$

32. Show the relation between amplification factor, drain resistance and transconductance.

$$\mu = r_d \times g_m$$

$$\mu = \frac{\Delta V_{DS}}{\Delta I_D} \times \frac{\Delta I_D}{\Delta V_{GS}}$$

$$\mu = \frac{\Delta V_{DS}}{\Delta V_{GS}}$$

$$\therefore \mu = r_d \times g_m$$

5 mark questions:

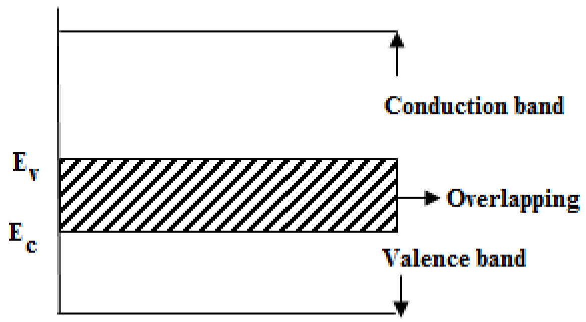
1. **Explain the classification of solids in terms of forbidden gap.**

   On the basis of energy band theory, solids are classified into three groups,

   1. Metals
   2. Insulators
   3. Semiconductors

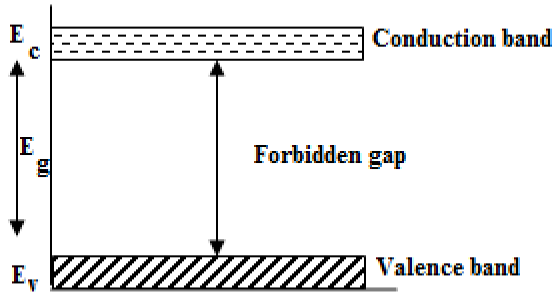
- **Metals: (conductors)**

In metals the upper portion of the valence band and the lower portion of the conduction band get overlapped and so there is no forbidden energy gap. Hence no energy is required to shift the electrons from valence to conduction band.



- **Insulators:**

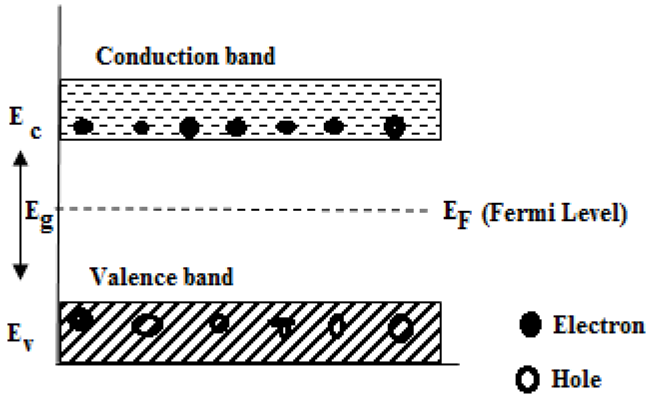
In insulators, the forbidden gap is very large. Since the forbidden energy gap is very large, large amount of energy is to be supplied to shift the electrons from the valence to the conduction band. So no electrons are available in the conduction band for conduction. Hence such types of material are known as insulators.



- **Semiconductors:**

In semiconductors, the energy gap is very small so that, even at ordinary temperature, electrons can jump into the conduction band. As a result, some states in the conduction band are occupied and equal number of states in the valence band is unoccupied. The vacancies produced in the valence band are called as **holes**. Such materials are known as semiconductors.

If the temperature of the semiconductor is increased, more of electrons jump from valence to conduction band and this increases the electrical conduction. Thus at 0°K, semiconductors behaves as insulator, but at or above room temperature, it behaves as conductor.



2. **Write a note on types of semiconductors.**

Types of semiconductors:

Semiconductors are divided into two types,

Intrinsic (or) pure semiconductor

Extrinsic (or) impure semiconductors

Intrinsic (or) pure semiconductor:

A semiconductor in an extremely pure form is known as **intrinsic semiconductor.** In this type, even at room temperature, electron-hole pairs are created. When electric field is applied, the current conduction takes place by two processes namely, by free electrons and holes.

The free electrons are created by breaking up of some covalent bonds by thermal energy. At the same time holes are created in the covalent bonds. Therefore, the total electrons are equal to the holes and the total current inside the semiconductor is the sum of currents due to holes and electrons. At absolute zero, the intrinsic semiconductor behaves as a perfect insulator.

Extrinsic (or) impure semiconductor:

The charge carriers are produced due to impurity atoms are called **extrinsic semiconductor.** They are obtained by doping an intrinsic semiconductor with impurity atoms.

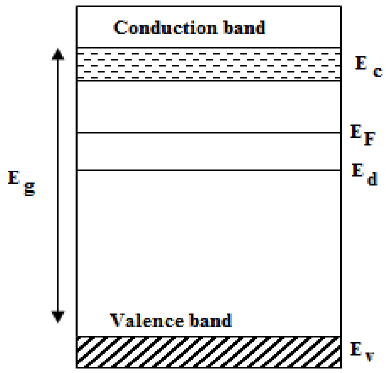
They are classified into two,

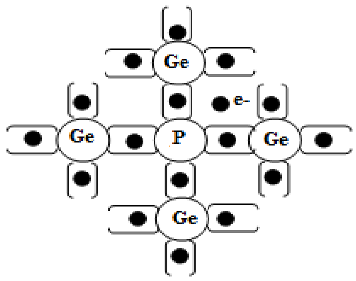
1. n – type semiconductors

2. p – type semiconductor

n – Type semiconductor:

n – Type semiconductor is obtained by doping an intrinsic semiconductor with **pentavalent** impurity atoms like phosphorous, arsenic, antimony etc. The 4 valence electrons of the impurity atom bond with 4 valence electrons and the remaining one electron is left free. Therefore the no. of free electrons increases. As the electrons are in excess, they are the majority carriers in n – type and holes are the minority carriers. Since electrons are donated the energy level of these donated electrons is called **donor energy level(E_d). E_d** is very close to conduction band and hence even at room temperature the electrons are easily excited to conduction band. The current conduction is mainly due to **electrons.**





P – Type semiconductor:

P – Type semiconductor is obtained by doping an intrinsic semiconductor with **trivalent** impurity atoms like boron, gallium, indium etc. The three valence electrons of the impurity atom pairs with three valence electrons of semiconductor atom and one position of the impurity atom remains vacant, this is called **hole.**

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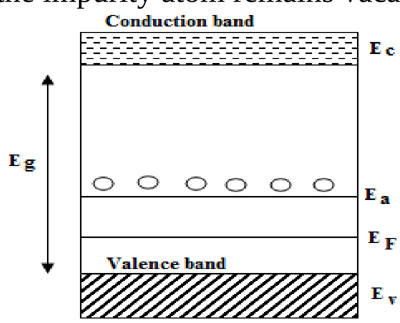
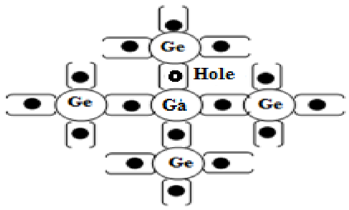




Therefore the number of holes is increased with the impurity atom. Since holes are produced in excess, they are the majority charge carrier and electrons are the minority carriers. Since the impurity can accept the electrons this energy level is called **acceptor energy level (E_a).** Here the current conduction is mainly due to holes

3. **Define Fermi Dirac function. Explain the effect of temperature on Fermi function.**

Fermi function F(E) represents the probability of an electron occupying a given energy states. The Fermi – Dirac statistics deals with the particles (electrons) having integral spin, named as fermions.

$$F(E) = \frac{1}{1+e^{(E-E_F)/KBT}} \qquad (1)$$

E_F is the Fermi energy.

K_B is the Boltzmann constant.

Effect of temperature on Fermi function:

At 0 Kelvin, the electrons can be filled only up to a maximum energy level called Fermi energy E_F, above E_F all the energy levels will empty.

1. When $E < E_F$, equ (1) becomes,

$$F(E) = \frac{1}{1+e^{-\infty}} = \frac{1}{1} = 1$$

100% chance for the electrons to be filled within Fermi energy level.

2. When $E > E_F$, equ (1) becomes,

$$F(E) = \frac{1}{1+e^{\infty}} = \frac{1}{\infty} = 0$$

Zero% chance for the electrons not to be filled within the Fermi level.

3. When $E = E_F$ equ (1) becomes,

$$F(E) = \frac{1}{1+1} = \frac{1}{2} = 0.5$$

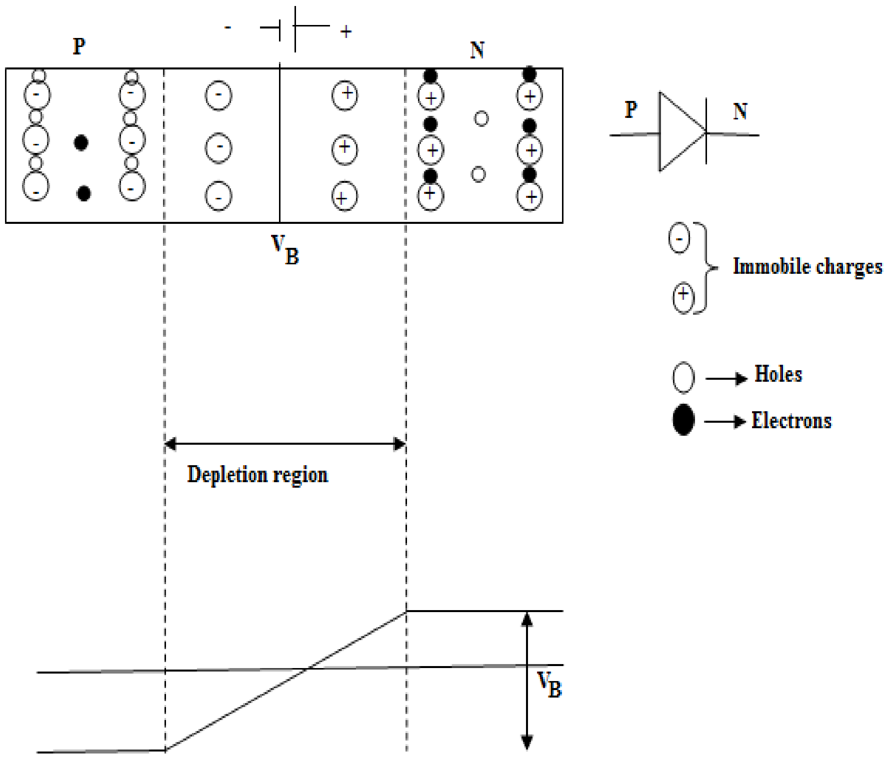
50% chance for an electron to be filed and not to be filled within the Fermi energy level.

4. **Explain PN junction diode.**

When P – type semiconductor is suitably joined to N – type semiconductor, the contact surface is called P – N junction and this arrangement is known as **P - N junction diode.**

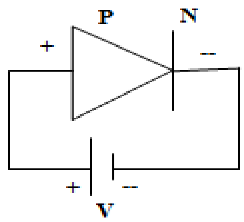
At the junction, there is a tendency for the electrons in the N – type to diffuse into the P – type and the holes from P – type to N – type. This process is called **diffusion.** While crossing the junction, the electrons and holes recombines with each other, leaving the immobile ions in the nearby atom of the junction unneutralised, these immobile +ve and –ve ions, setup a potential across the junction called **potential barrier (V_B).**

Due to this, no further diffusion of electrons and holes takes place, across the region. At the vicinity of the junction, since the mobile charge carriers are depleted, this region is called **depletion region or space charge region.**



Forward bias:

Applying an external voltage to the junction is known as **biasing**. When the +ve terminal of the external battery is connected to the P side and the –ve side to the N side, the junction is said to be **forward biased.** The holes in the P side move towards, the junction while the electrons in the N side move towards the junction this reduces the width of the barrier. If the applied voltage V is greater than the potential barrier V_B, then the majority carriers namely holes in P side and electrons in N side, crosses the barrier and some of them get neutralized. The remaining charges after crossing reach the other side to increase the forward current.

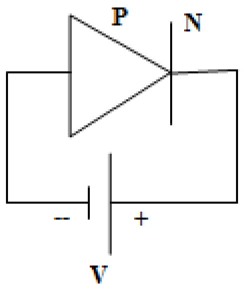


Reverse bias:

When the +ve terminal of the external battery V is connected to the N side and negative terminal to the P side of the junction diode, then it is said to be in the **reverse bias.**

Under reverse bias, the holes in the P type are attached by the –ve terminal of the external battery. Hence the width of the barrier is increased. So no majority carriers can cross the barrier to constitute current. When the applied voltage is greater than the barrier voltage these minority carriers, cross the barrier. During crossing some may get recombined. The remaining minority carriers after crossing reach the other side and constitute current. But this is very small.

As the applied reverse voltage increases, the minority current also increases, but with small value. At a particular reverse voltage (p) the junction break down, there is random motion of carriers and hence current increases abruptly. Such a reverse voltage, at which junction breaks down is called **Avalanche break down voltage,** this effect is known as Avalanche effect.



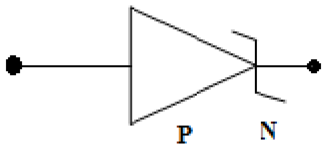
5. **Write a note on Zener diode and explain it as a voltage stabilizer.**

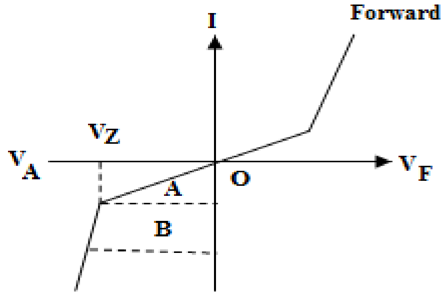
A properly doped crystal diode which has a sharp breakdown voltage is known as **Zener diode.** This diode was first designed by the American scientist **C.ZENER.** Therefore the breakdown voltage is sometimes called, Zener voltage and the current as Zener current.

When the reverse voltage reaches breakdown voltage in normal PN junction diode, the current through the junction will be high. Such an operation is destructive and diode gets damaged, whereas diodes can designed to operate in the breakdown region is known as Zener diode which is heavily doped than ordinary diode.

6.

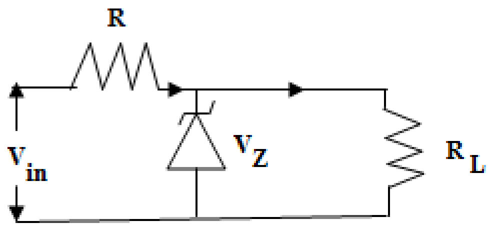
7.





From the V-I characteristics of the Zener diode, it is found that the operation of Zener diode is same as that of ordinary PN diode under forward biased condition. Whereas under reverse biased condition, voltage occurs. The breakdown voltage depends upon the doping. If the diode is heavily doped, depletion layer will be thin and breakdown occurs at lower reverse voltage

Zener diode as voltage stabilizer:



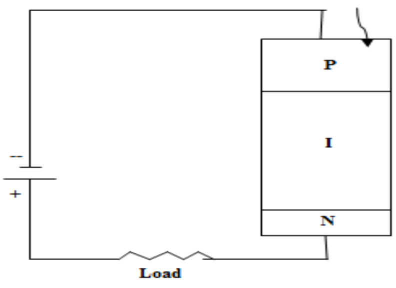
Under the reverse bias condition, the voltage across the diode remains almost constant although the current through the diode increases. Thus the voltage across the Zener diode serves as a reference voltage. Hence the diode can be used as a voltage regulator. Though the Zener breakdown occurs for lower breakdown voltage and avalanche breakdown occurs for higher breakdown, such diodes are normally called as Zener diodes.

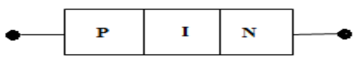
6. Write a note on PIN diode

It is compressed of three regions. In addition to the usual N and P regions, an intrinsic layer is sandwiched between them. Two advantages compared to an ordinary PN diode.

- Decrease in capacitance between P & N is inversely proportional to the separation between these regions and allows faster response time for the diode.
- Possibility of greater electric field between P & N junctions.

It is used for the detection of light at the receiving end in optical communication. It is a three region reverse biased junction diode. The depletion region extends almost to the entire intrinsic layer where most of the absorption of light photons takes place. The width of the intrinsic layer is large compared to the width of the other two layers. This ensures large absorption of light photons in the depletion region.Light photons incident on the PIN photodiode are absorbed which leads to the generation of electron-hole pairs, the reverse current flowing in the external circuit increases linearly with the level of illumination.



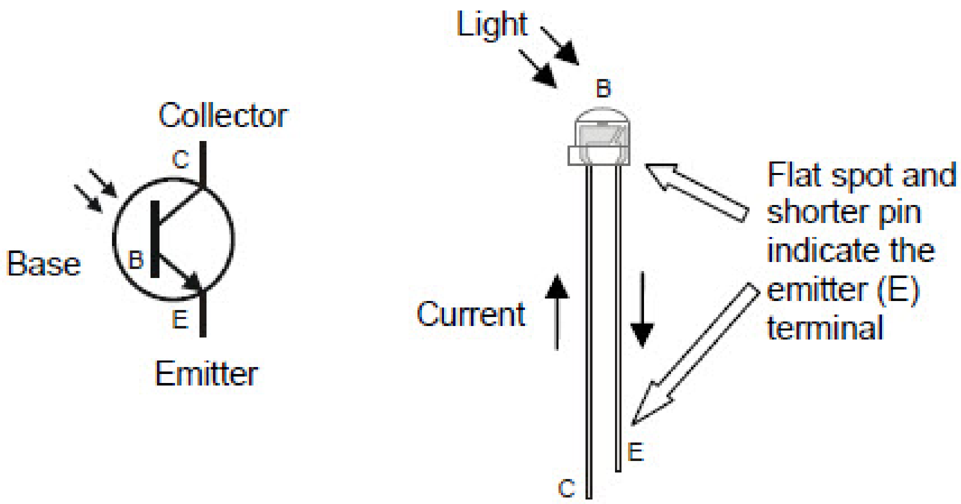


7.Explain avalanche photo diode.

APD is used in optical communication for detection of light at the receiving end. It converts the input light signal into electrical signal. The structure of an APD is shown in figure. It consists of reverse biased PN junction is formed by immobile positively charged donor atoms in the N type semiconductor material and immobile negatively charged acceptor atoms in the P type material. The electric field in this depletion region is very high where APD requires a high reverse bias voltage of 100 – 400V. Electron – hole pairs thus generated separate and drift under the influence of the electric field in the depletion region they are finally collected in the detector terminals. This leads to a flow of current in the external circuit which is proportional to the intensity of light incident on APD. Due to the internal gain mechanism in an APD, a large electrical response is obtained even for a weak input light signal.

8. With neat diagram explain Photo transistor

Photo transistor has a combine ability to detect light and to provide gain. Its construction is almost similar to that of an ordinary transistor except the top surface is exposed by a lens or a



window. In the collector base junction (CB) junction, the incident photons generate electron – hole pairs. The reverse voltage of the (CB) junction draws the induced holes to the base & electrons towards collector junction. The electrons flow from emitter to base. The flow of electrons constitutes a light induced collector current. Thus the photon induced electron – hole pairs contribute to the base current.

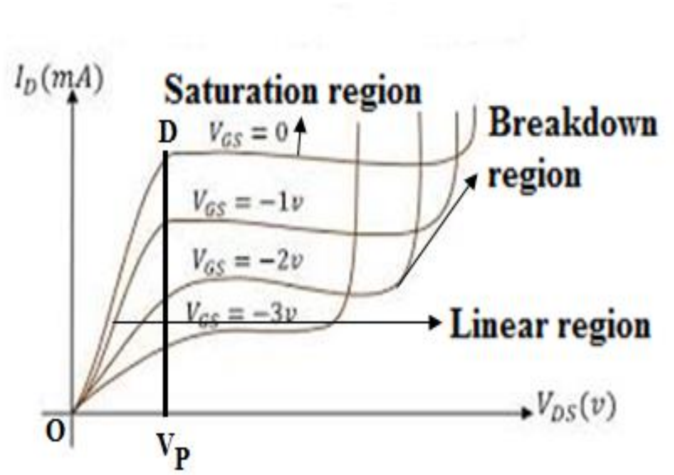
Applications:

- It is used as digital ON – OFF switch.
- It is used as light sensitive switch.

9. Explain the V-I characteristics of FET

The graph drawn between the drain current (**I_D**) and drain to source voltage (**V_{DS}**) at constant (**V_{GS}**) is known as output characteristics. The output characteristics can be divided into 3 regions,

- Linear region
- Saturation region
- Breakdown region



1. **Linear region:**

   As drain-source voltage (**V_{DS}**) increases, drain current (I_D) also increases. This region is called Ohmic or Linear region.

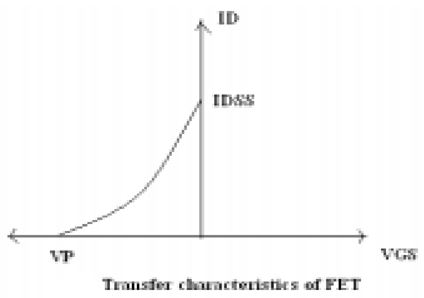
2. **Saturation region:**

   From the graph, OD is pinch-off voltage. After V_P there is an increase in depletion area and hence drain current remains constant.

3. **Breakdown region:**

   From the graph, the breakdown occurs at a lower value of **V_{DS}**. When **V_{GS}** is increased, the drain current rises almost vertically with a slight increase of the drain to source voltage. This is known as breakdown voltage.

- **TRANSFER CHARACTERISTICS:**



The graph draw between drain current (I_D) and gate to source voltages **V_{GS}** at constant **V_{DS}** is known as Transfer characteristics.

10. Explain parameters of FET

1. Drain resistance (r_d)
2. Trans conductance (g_m)
3. Amplification factor (μ)

Drain resistance (r_d):

It is defined as the ratio of change in drain-source voltage (ΔV_{DS}) to the drain current (ΔI_D) at constant V_{GS}.

$$r_d = \left(\frac{\Delta V_{DS}}{\Delta I_D} \right)_{V_{GS}}$$

Trans conductance (g_m):

It is defined as the ratio of change in drain current ΔI_D to the change in gate to source voltage (ΔV_{GS}) at constant V_{DS}.

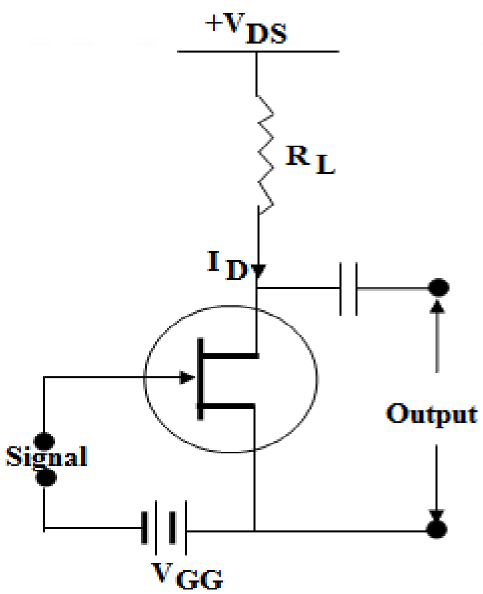
$$g_m = \left(\frac{\Delta I_D}{\Delta V_{GS}} \right)_{V_{DS}}$$

Amplification factor (μ):

It is defined as the ratio of small change in drain to source voltage, (ΔV_{DS}) to the change in gate to source voltage (ΔV_{GS}) at constant I_D.

$$\mu = \left(\frac{\Delta V_{DS}}{\Delta V_{GS}} \right)_{I_D}$$

11. Define FET as an amplifier.



The weak signal is applied between gate and source and amplified output is obtained in drain source. The input must be –ve with respect to source so circuit should always be reverse biased by using a battery V_{GG}.

A small change in the reverse bias on the gate produces a large change in drain current. This raises the strength of the weak signal. During +ve half signal, the reverse bias on the gate decreases. This increases the channel width, hence drain current increases.

During –ve half signal, the reverse bias on gate increases and the channel width decreases and hence drain current decreases. So small change in gate voltage produces large drain current. This variation in drain current large output across R_L thus FET acts as an amplifier.

10 marks:

1. **Derive an expression for the carrier concentration of intrinsic semiconductor.**

Refer (1.4)

2. Obtain an expression for n type extrinsic semiconductor.

Refer (1.4.1)

3. Derive an expression for p type extrinsic semiconductor.

Refer (1.4.1)

4. Explain Tunnel diode and give its applications, advantage & disadvantages

Refer (1.6.3)

5. Explain the construction and working of photo diode

Refer (1.6.6)

6. Explain the construction and working of FET.

Refer (1.7.2)