SEMICONDUCTOR - 14

Classification of Metals, Insulator and semiconductor on the basis of conductivity

1 **Metals or Conductors** ⇒ They have very high conductivity.
$\sigma \sim 10^{2} - 10^{8}\ Sm^{-1}$.

2 **Semiconductors** ⇒ They have conductivity intermediate to conductors and insulators. $\sigma \sim 10^{5} - 10^{-6}\ Sm^{-1}$

3 **Insulator** ⇒ They have very low conductivity
$\sigma \sim 10^{-11} - 10^{-19}\ Sm^{-1}$

ENERGY BAND

According to Bohr atomic model, in an isolated atom the energy of any of its electrons is decided by the orbit in which it revolves.

But when the atoms come close to form a solid their outermost electrons intefere with each other this makes the nature of motion of electron in a solid different from an isolated atom.

Inside a crystal each electron has unique position and no two electrons have same energy level. So each electron will have different energy level. These different energy level with continuous energy variation form "ENERGY BAND"

~~Conductions~~

VALENCE BAND ⇒ The energy band that includes the energy level of valence electron is called valence band.

Conduction Band ⇒ The energy band above the valence band is called conduction band.

ENERGY BANDGAP ⇒ The minimum energy required for shifting electron from Valence band to Conduction band.

Forbidden ENERGY GAP ⇒ The energy gap i.e difference b/w Conduction band and valence band is called the forbidden energy gap.

$$\Delta E_g = (CB)_{min} - (V.B.)_{max}$$ ☆☆

Fermi Energy ⇒ The highest energy level in the conduction band filled up with electrons at absolute zero is fermi level and the energy corresponding to fermi level is called fermi energy.

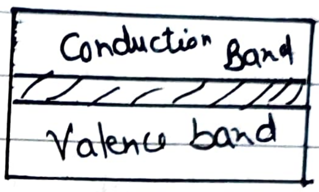
0K

It is maximum possible energy possessed by free electrons at 0°K.

Difference b/w Conductor, Insulator and Semiconductor on the basis of ENERGY BAND.

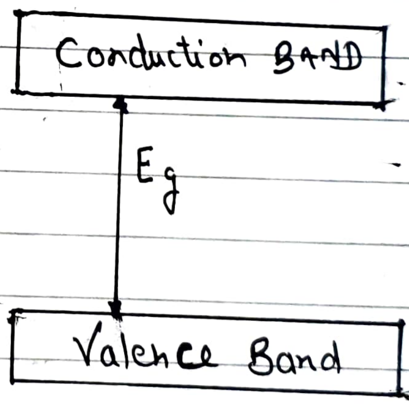
1. **Metal** ⇒ In this lowest level in the conduction band is lower than highest level of ~~con~~ valence band
i.e valence band and conduction band overlap with each other.

In this electrons can freely move from valence band to conduction band.



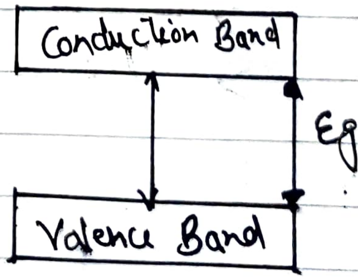
2. **Insulator** ⇒ In this there is gap b/w valence band and conduction band.

In this electrons can not freely move from V.B to C.B. They can not move even with application of electric field.



3. **Semiconductor** ⇒ In this the gap b/w conduction band and valence band is intermediate to that of metal and insulator.

☆ Electrons can not jump from valence band to conduction band at low temp but they can jump at high temp



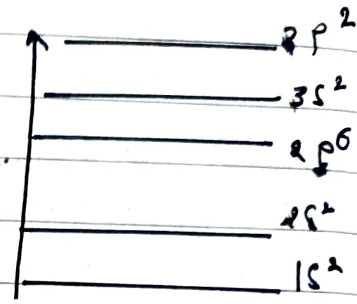
BAND THEORY OF SOLID

Let us consider a silicon crystal having N atoms

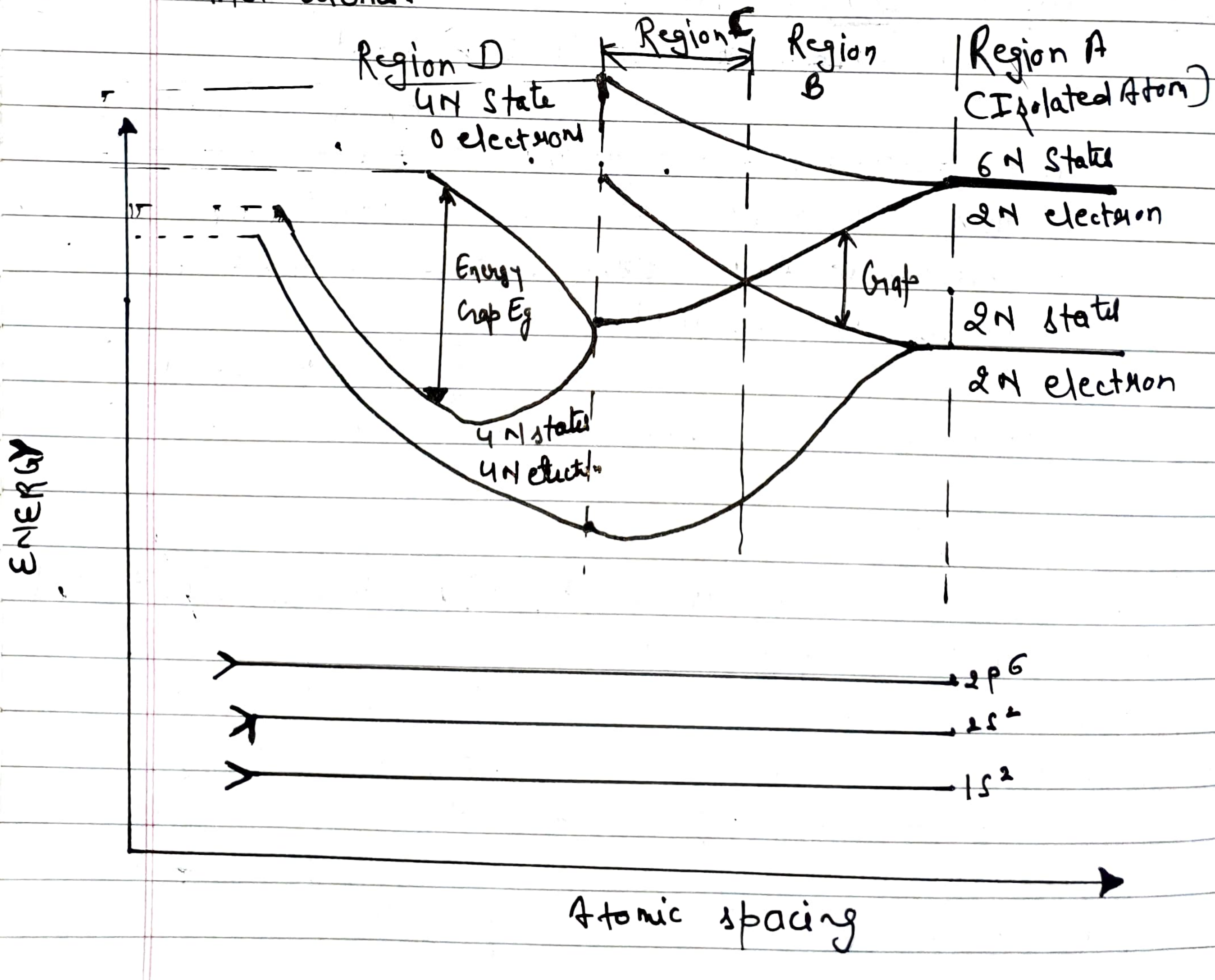
★ When all the atoms of the crystal are isolated then each electron has discrete energy

$Si(14) = 1s^2 2s^2 2p^6 3s^2 3p^2$

Inner shell ($1s^2 2s^2 2p^6$), Outer shell ($3s^2 3p^2$)



★ But when these atoms are brought closer to eachother (2 to 3A°) then electrons starts interacting with each other and also with the core of other atoms.



- The overlap (interaction is more felt by outermost electron then the inner electrons.

- The maximum possible no. of outer electron in silicon is 4 in the orbit is 8 [2s + 6p]. But out of 8 possible places for electron only 4 is filled [2N in s and 2N in p]

- Suppose when these atoms start coming nearer to each other to form solid the energy of these electrons in outermost shell change [both increase and decrease] due to interaction b/w the electrons of different atom.

- When these atoms comes of more closer to each other the 6N state for l=1 and 2N states for l=0 starts spliting out and forms band in region B. There is small energy gap exist b/w l=0 and l=1

- When the distance b/w atom is further reduced then there comes a region in which these bands merges with each other. The lowest energy state that is a split from the upper atomic level appears to drop below the upper state that has come from the lower atomic level. In region C no energy gap exist. and upper and lower band gets mixed.

- And Finally if the distance b/w the atom is further reduced the energy band again splits apart and separated by some energy gap E_g. The total No. of energy state 8N divides into two bands each having 4N in upper state and 4N in lower state.

Semiconductor ⇒ The solid whose conductivity is intermediate to that of conductor and insulator is called semiconductor.

Classification Of Semiconductors

(1) On the Basis Of chemical composition

(a) Elemental Semi conductor ⇒ Si and Ge
(b) Compound Semiconductor ⇒ They are of two type
(i) Inorganic ⇒ CdS, GaAs, InP
(ii) Organic Polymer ⇒ Polyaniline, Polythiophene

2 Classification on the basis of the source and charge carrier's Nature

a) **Intrinsic Semiconductor** ⇒ The pure Semiconductor is called intrinsic semi conductor

{In this number of hole = number of electron}

* Conductivity is low

b) **Extrinsic Semiconductor** ⇒ The semiconductors which are obtained by adding impurities in the pure semiconductor is called extrinsic semiconductor.

* They have high conductivity
* In This number of hole and electron are not equal

15th group element are known as donor impurities because they donate extra electron

Date 07

Dopping ⇒ The process of adding impurities to a pure semiconductor is dopping.

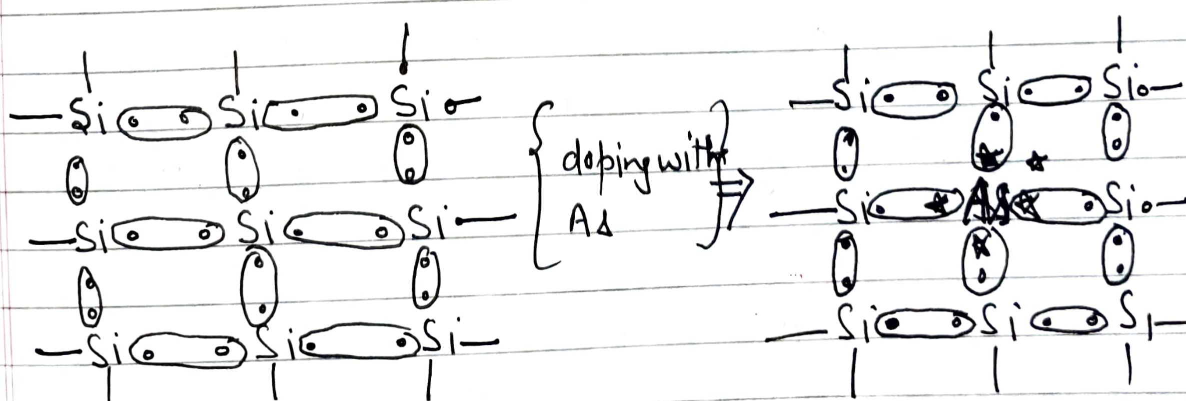
Reason behind dopping

1. Intrinsic semiconductors have low conductivity and low charge carriers.
2. Intrinsic charge carriers are always thermally generated so in order to have free charge carrier even at low temp we do dopping.

✱ After doping intrinsic semiconductor converts into extrinsic semiconductor.

Extrinsic Semiconductors are of two type

I. **N-type Semiconductor** ⇒ This type of semiconductor is formed by doping tetravalent (Si, Ge) semiconductor by pentavalent (As, P) impurities.



intrinsic Semiconductor
$n_e = n_h$

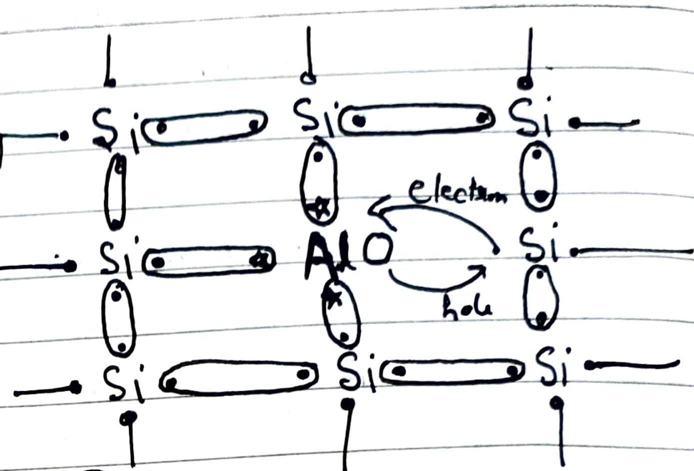
$n_e > n_h$

✱ The impurity atom become positively charge as it donate extra electron to semiconductor and known as donor impurities.

(II) **P-type Semiconductor** ⇒ This type of semiconductor is formed by doping tetravalent semiconductor [Si or Ge] with trivalent impurities.

☆ Trivalent impurities is known as acceptor impurity

☆ Impurity atom acquire negative charge



$n_h > n_e$

☆☆☆ Both in P type crystal and N type crystal electrical neutrality is maintained

Thermodynamic relation b/w the number density of electrons and holes for an extrinsic semiconductor

When ~~and~~ conduction electrons and holes are created in a semiconductor a process of destruction occurs simultaneously in which electron and hole recombine with each other.

At equilibrium the rate of generation of charge carrier is equal to the rate of destruction of charge carrier

Rate of recombination for extrinsic semiconductor $\propto n_e n_h$

0K

Rate of recombination $= R n_e n_h$ —— (1)

Rate of recombination for intrinsic semiconductor $\propto n_i^2$ $\{ n_h = n_e = n_i$

Rate of recombination $= R n_e n_h$ —— (2)

at equilibrium

Rate of recombination for extrinsic = rate of recombination for intrinsic

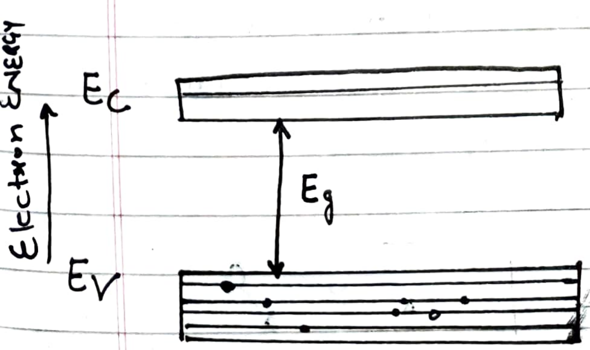
$$R n_e n_h = R n_i^2$$

$$n_e n_h = n_i^2$$

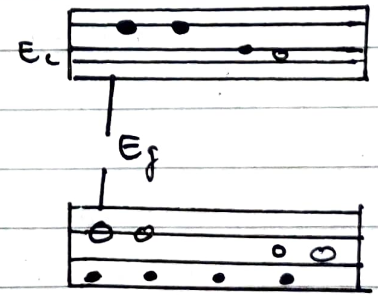
☆☆☆☆ No. of electron in conduction band is equal to No. of hole in valence band

ENERGY BANDS

(1) For intrinsic Semiconductor



(I) at T = 0K



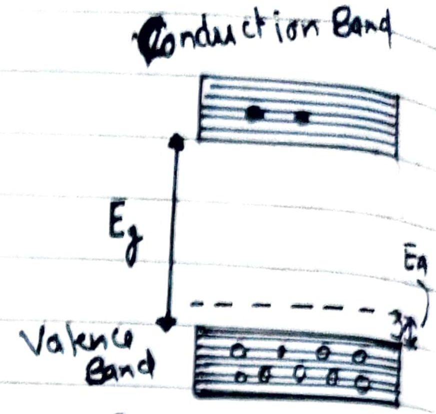
(II) at T > 0K

(I) at low temperature electrons are only in valence Band and hence it acts as a insulator

(II) At high temperature electrons gain energy and jump to conduction Band hence act as conductor.

ENERGY BAND DIAGRAM FOR EXTRINSIC SEMICONDUCTOR

(1) P type Semiconductor ⇒



(i) In p-type semiconductor each acceptor impurity creates a hole.

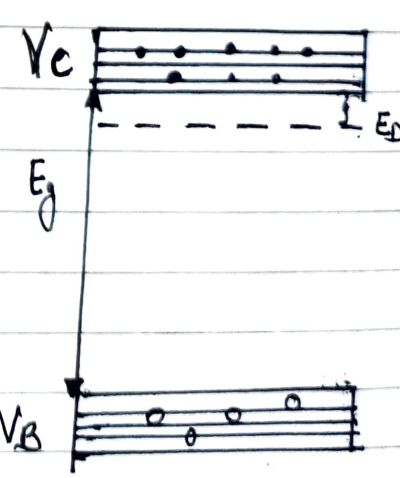
(ii) These holes can be easily filled by an electron of Si-Si covalent bond i.e electron from valence band.

(iii) At room temperature many electrons from the valence band jumps to acceptor energy level leaving behind equal number of hole in valence band. These holes can conduct electric current.

T > 0K

No. of holes in valence Band is greater than no. of electrons in Conduction Band

2 N-type Semiconductor ⇒



(i) In N-type semiconductor each donor impurity has extra electron. These extra electron are weakly attracted by donor impurity.

(ii) They can easily jump to conduction band when very small amount of energy (~0.1eV) is supplied.

(iii) The energy of Donor electron is slightly less than conduction band.

~~E_D = Energy of donor electron~~

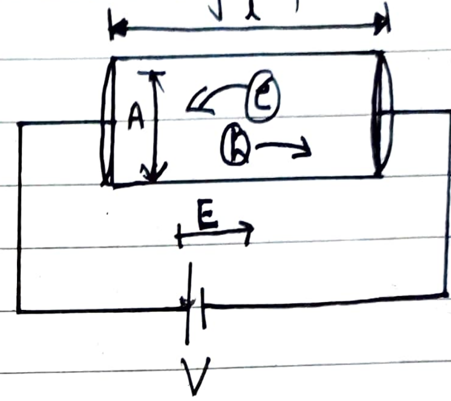
E_D = donor energy level.

No. of electron in conduction band is greater than No. of hole in valence band

Electrical Conductivity Of A Semiconductor ⇒

Consider a block of semiconductor having length l and cross-sectional area A and free electrons density n_e and hole density n_h

Suppose a potential difference V is setup across the semiconductor due to which Electric field will be provided



$$E = \frac{V}{l}$$

Due to these field electrons begins to drift with velocity v_e in opposite direction and holes with velocity V_h in the direction of field.

$$I = I_e + I_h$$

$$I = n_e e A V_e + n_h e A V_h$$

$$I = eA[n_e V_e + n_h V_h] \quad \text{—} ①$$

$$I = \frac{V}{R} = \frac{El A}{\rho l}$$

$$\left\{ \begin{array}{l} V = El \\ R = \frac{\rho l}{A} \end{array} \right.$$

$$I = \frac{EA}{\rho} \quad \text{—} ②$$

from equation ① and ②

$$\frac{EA}{\rho} = eA[n_e V_e + n_h V_h]$$

$$\left\{ \begin{array}{l} \mu_e = \frac{V_e}{E} \\ V_e = \mu_e E \\ V_h = \mu_h E \end{array} \right.$$

$$\frac{E}{\rho} = e[n_e E \mu_e + n_h E \mu_h]$$

$$\boxed{\frac{1}{\rho} = e[n_e \mu_e + n_h \mu_h]}$$

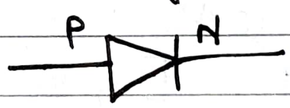
Hole ⇒ The vacancy or absence of an electron in the bond of a covalent bonded crystal is called a hole.

Characteristic of hole ⇒

(1) A hole is just a vaccancy created by the removal of an electron from covalent bond of semiconductor.
(2) It is having positive charge and has same mass as an electron.
(3) The energy of a hole is higher, the further below it is from the top of the valence band.

P-N Junction Diode

It is a single crystal of Ge or Si doped in such a manner that half of the portion behave as n-type and other half as p-type semiconductor.



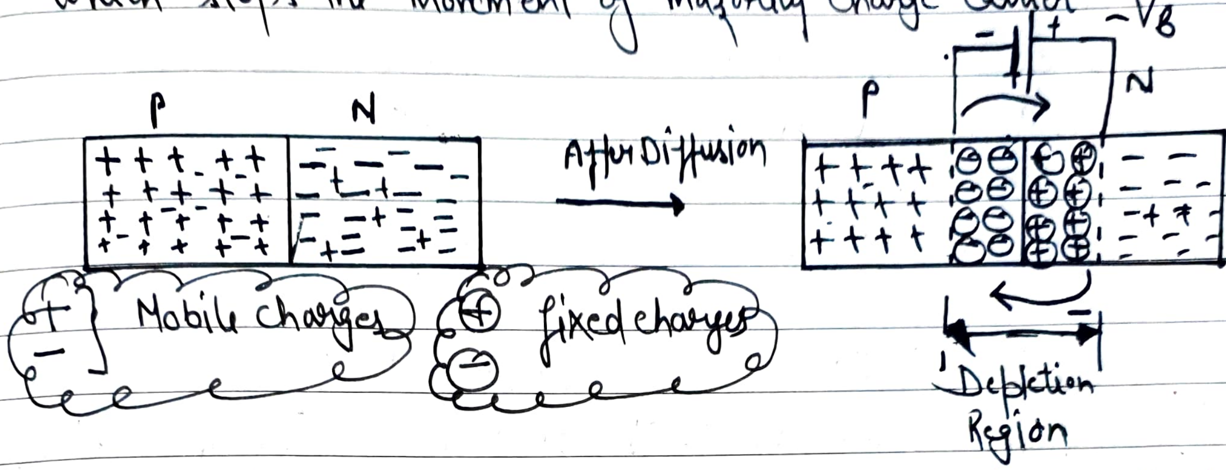
Processes taking place During formation of P-N Junction Diode

(1) **Diffusion** ⇒ It is the process in which majority charge carriers flow from higher concentration to low concentration.

(i) When P and N type crystal are brought together then electron from N side move towards P side and hole from P side to N side.

(ii) While migrating they create a fixed charge at their location having opposite charge.

(III) These four fixed charge will create a potential difference which stops the movement of majority charge carrier.



Drift ⇒ The diffusion process stops due to creation of barrier potential.

(I) Once diffusion process stops majority charges stops migrating and minority charges starts flowing.

(II) Electrons from P side move to N side and hole from N side move towards P side. This process also stops after some time.

Some Important Defination ⇒

(i) Depletion Region ⇒ It is the space around the junction of P-N junction diode which is free from mobile charge carrier.

Factor on which depletion Region depend

(i) Doping → Greater the doping thinner will be depletion layer.

(ii) Biasing → In forward biasing depletion layer decreases while in reverse biasing it increases.

(II) Barrier Potential (V_B) ⇒

The potential difference developed at the junction of P-N junction diode due to fixed charges which prevents migration of majority charge is known as barrier potential.

Factors Affecting Barrier potential ⇒

(i) Doping ⇒ With increase in dopping V_B incr

(ii) Biasing ⇒ Forward biasing ~~decrease~~ decreases V_B and Reverse biasing increase V_B

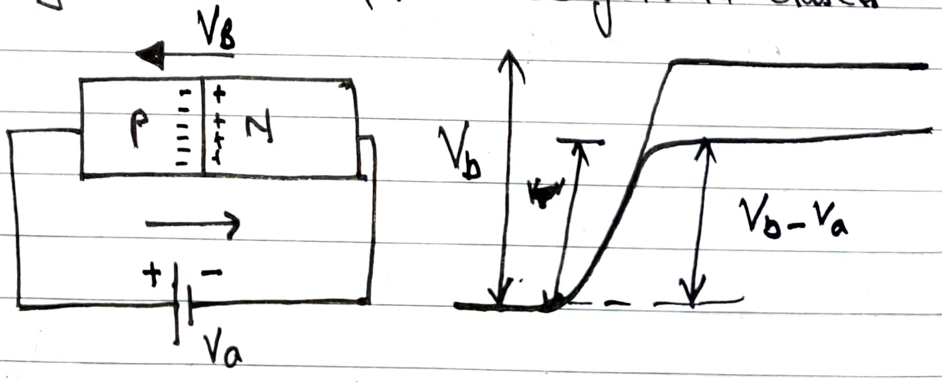
(iii) Temperature ⇒ ~~when~~ With increase in temperature barrier potential increases.

Biasing

When we apply battery across the P-N junction then this process is known as biasing.

There are two types of Biasing

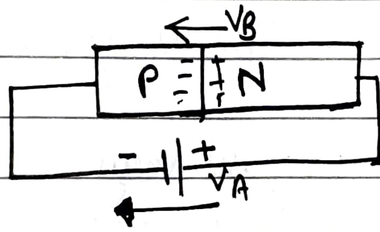
(1) **Forward Biasing** ⇒ If the positive terminal of the battery is connected to p side and negative terminal of the battery is connected to n-side then the p-n junction is said to be forward biased.

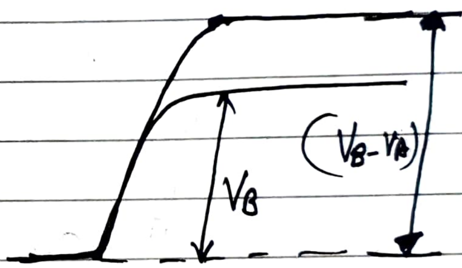


Impact Of Forward Biasing ⇒

(i) Width of depletion layer decreases
(ii) Barrier potential will decrease
(iii) Resistance of diode will decrease.

Reverse Biasing ⇒ If the positive terminal of the battery is connected to N-side and negative terminal of the battery is connected to P side then the diode is said to be in reverse biased.





Impact Of reverse Biasing ⇒

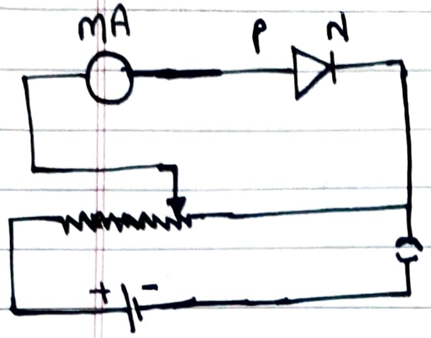
(i) Width of depletion layer increases.
(ii) Barrier potential will increase.
(iii) Resistance of diode will increase.

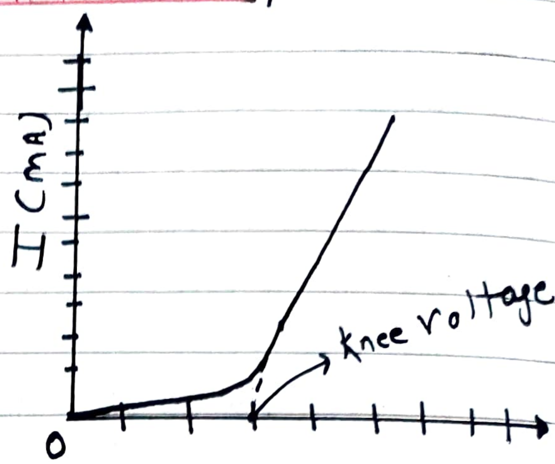
V-I Characteristic Of P-N Junction Diode

A graph showing variation of current flowing through p-n junction with voltage applied across it is called V-I Characteristic curve.

There are two type of V-I Characteristic curve

(I) Forward Biased Characteristic curve ⇒





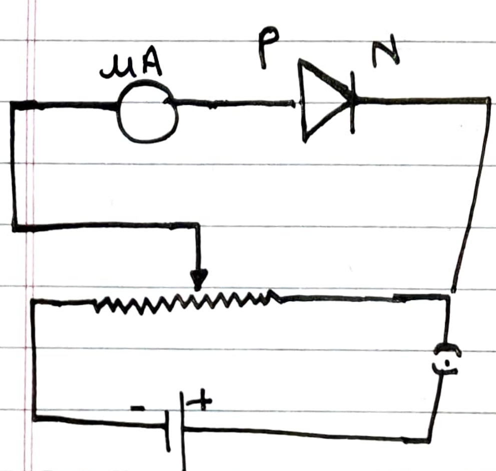
Important Features of the graph

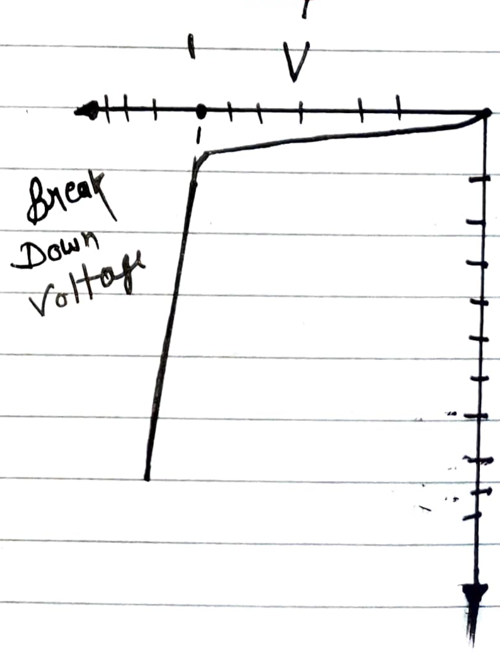
(i) V-I graph is not straight as junction diode does not follow ohm's law

(ii) Initially the current increases very slowly almost negligibly till the voltage across the diode crosses a certain value called knee voltage.

(iii) After knee voltage the diode current rises sharply even for small change in voltage.

(II) Reverse Biased Characteristic curve ⇒





Important feature of the graph ⇒

(i) When the diode is reverse biased, the reverse biased voltage produces a very small current which remains nearly constant with reverse biased voltage. This current is also known as reverse saturation current

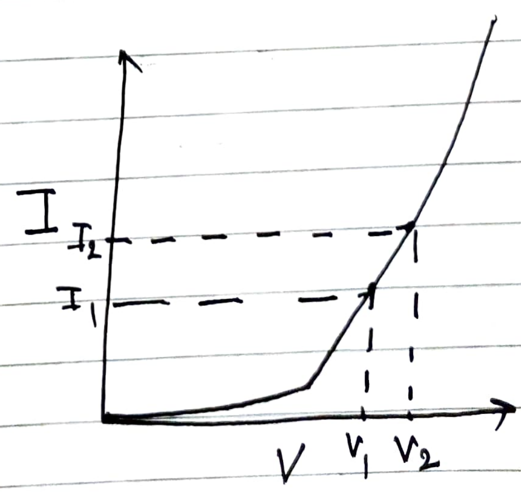
(ii) After certain voltage known as break down voltage the current rises sharply.

(iii) After break down voltage the current remain constant even with change in applied voltage.

Dynamic Resistance of Diode ⇒ It is the ratio of small change in the applied voltage to corresponding change in the current

Dynamic Resistance ($R_{dynamic}$) = $\frac{\Delta V}{\Delta I}$
or
ac resistance

$$R_{ac} = \frac{V_2 - V_1}{I_2 - I_1}$$



RECTIFIER

Rectifier is a device which converts alternating current into direct current.

Principle ⇒ When p-n junction diode is under forward biased then it offers low resistive path and when it is forward biased it offers high resistive path to the flow of electric current.

Types Of Rectifier

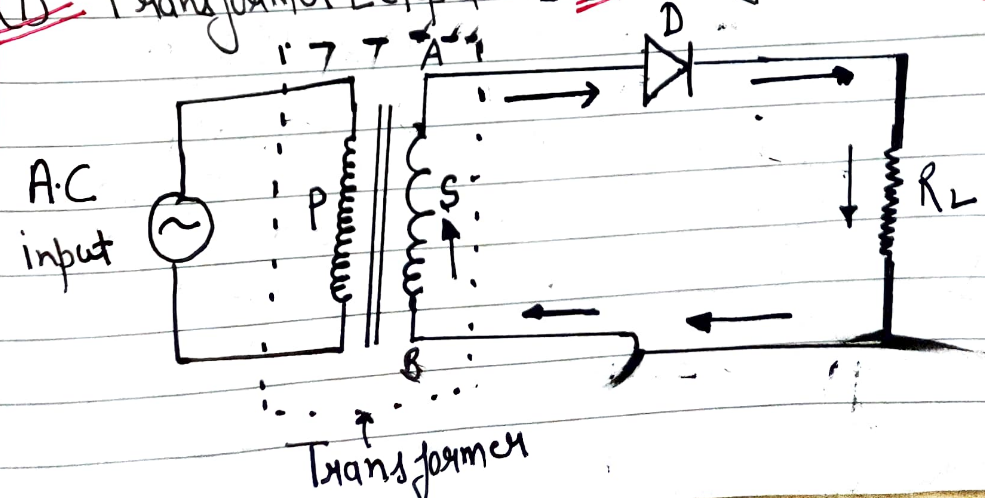
- Half wave Rectifier
- Full wave Rectifier

Half Wave Rectifier

It is a type of rectifier which converts only half cycle of the alternating current into direct current.

Construction ⇒ It consist of following things →

(i) Transformer [Step down] (ii) PN junction Diode (iii) Load Resistance



Working ⇒

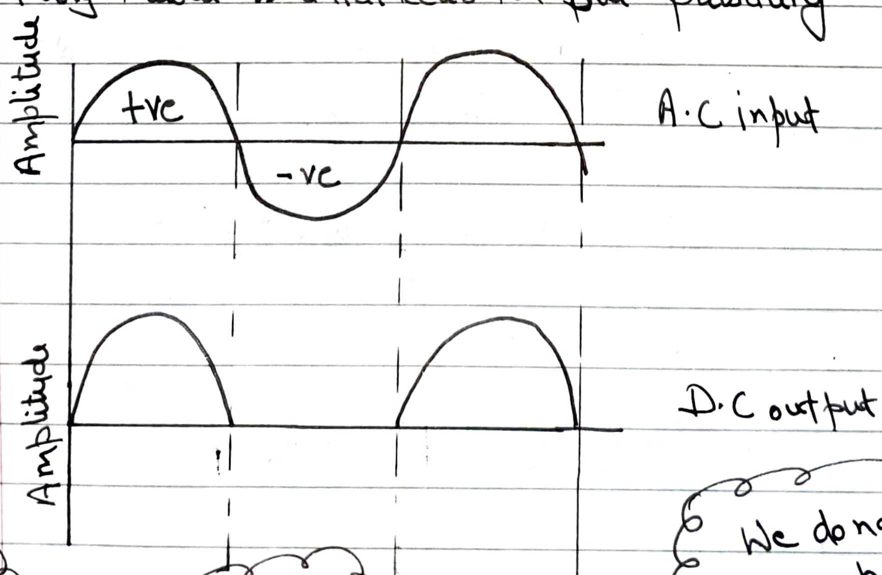
(i) When a.c is supplied to the primary, the secondary of the transformer supplies desired alternating voltage across A and B.

(ii) During the positive half cycle of A.C. the end A is positive and the end B is negative so the diode D becomes forward biased and a current I flows through load resistance R_L.

(iii) When negative half of alternating current is applied then the end A becomes negative and B becomes positive making the diode reverse biased.

(iv) Due to reverse biasing the resistance of diode becomes high and no current flows through resistance.

(v) In the next positive half cycle the diode becomes forward biased again and current flow across it. The current passing through diode is unidirectional but pulsating.



Pulse frequency of half wave rectifier is equal to AC

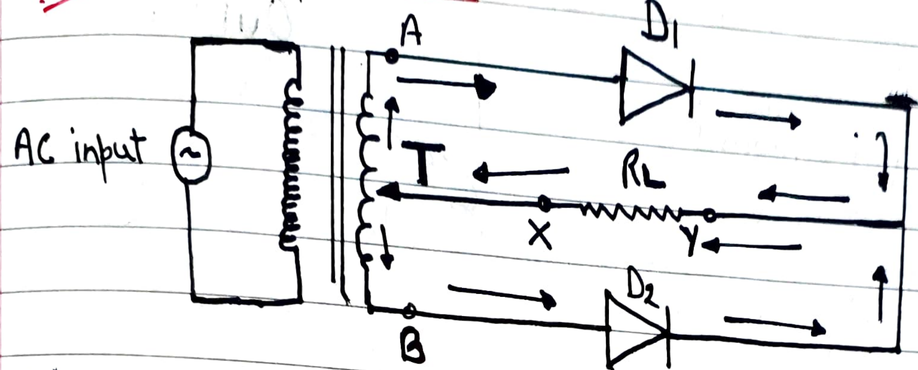
$I_{avg(DC)} = \frac{I_0}{\pi}$

We do not prefer half wave because it waste energy

Full Wave Rectifier

Construction ⇒ It consist of following things

(i) Step down transformer (ii) Two junction diode D_1 and D_2
(iii) Load Resistance



Working ⇒

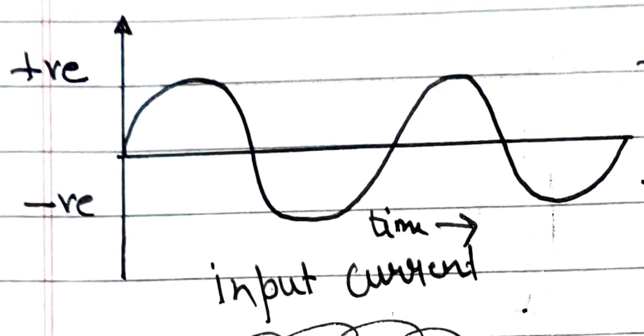
(i) When positive half of alternating voltage is applied then end A becomes positive and end B becomes negative due to which diode D_1 becomes forward biased and D_2 becomes reverse biased.

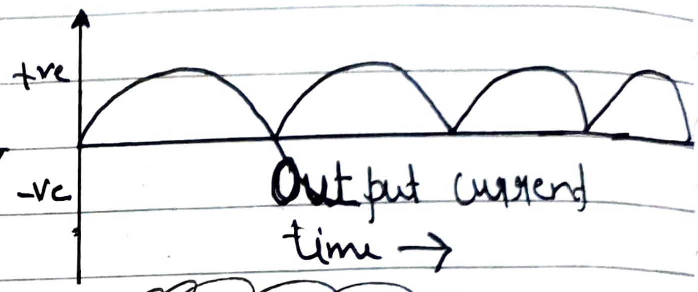
(ii) So current will passed through D_1 but D_2 will block the current and output will be obtained across R_L b/w point X and Y.

(iii) When negative half of alternating current is applied then end A becomes negative and end B becomes positive due to which the diode D_1 becomes ~~negat~~ Reversed biased and D_2 becomes forward biased.

(iv) So the current will flow through the diode D_2 and D_1 will block the current and output will be obtained across the R_L b/w point X and Y

(v) During both the half cycle of A.C the output is along the same direction across R_L.





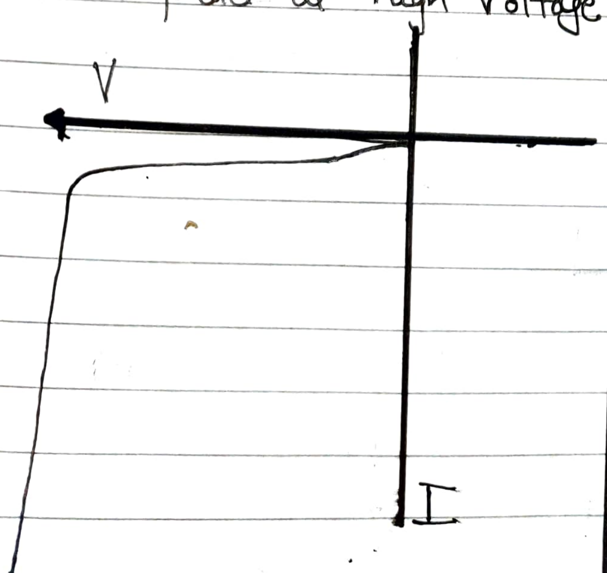
Average current of full wave rectifire is $\frac{2I_0}{\pi}$

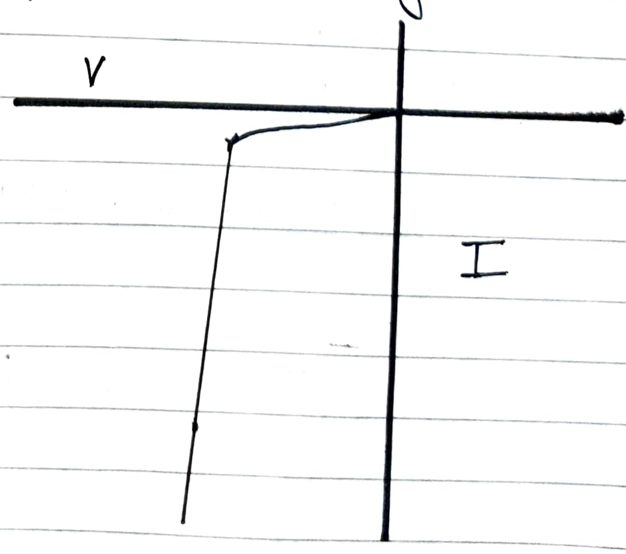
Pulse frequency of full wave rectifire is double of ac

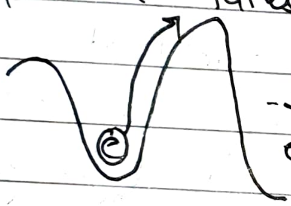
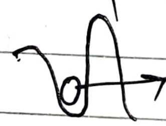
No power loss takes place in full wave rectifier.

Difference Between Conventional P-N Junction Diode and Zener Diode:

	Conventional PN Junction Diode	Zener Diode
(i)	In this P and N type semiconductor are lightly dopped.	In this P and N type semiconductor are heavily dopped
(ii)	In this depletion region is ~~narrow~~ wide	In this depletion region is ~~wide~~ narrow.
(iii)	Electric field at the junction is weak	Electric field at the junction is very high due to presence of more ions at the junction
(iv)	Barrier potential is low $V = \frac{E}{d}$	Barrier potential is high
(v)	In this reverse break down takes place at high voltage	In this break down takes place at low voltage.

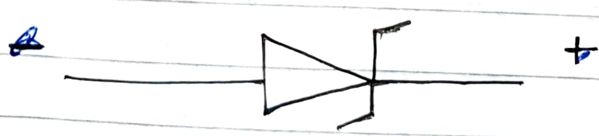




(vi)	In this break down is Known as Avalanche Break down	In this break down is known as Zener break down.
	In this break down takes places due to knocking down other bonded electrons by accelerated electrons.	In this break down takes place due to pulling down of electron by electric field
(vii)	In this large amount of heat is generated.	In this less amount of heat is generated.
VIII	In this tunneling effect does not takes place.  -It can be explained on the basis quantum mechanics	In this tunneling effect takes place.  since it has thin depletion layer.

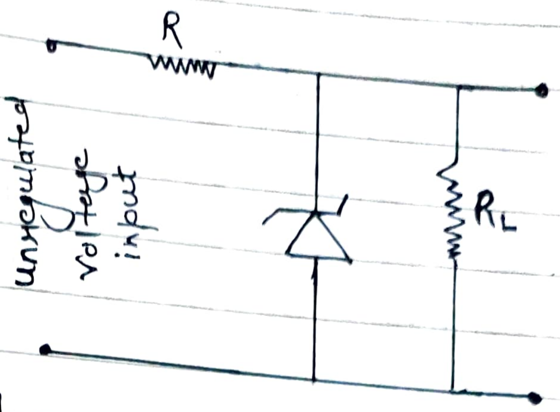
Zener Diode ⇒ It is a specially designed diode which is designed to operate under reverse break down region with getting damaged.

It is heavily dopped



Zener Diode As Voltage Regulator ⇒

Construction



(i) In this zener diode is connected in series with a resistance R known as dropping resistor whose function is to limit the flow of current through the zener diode.

(ii) The output is taken across the zener diode.

Working

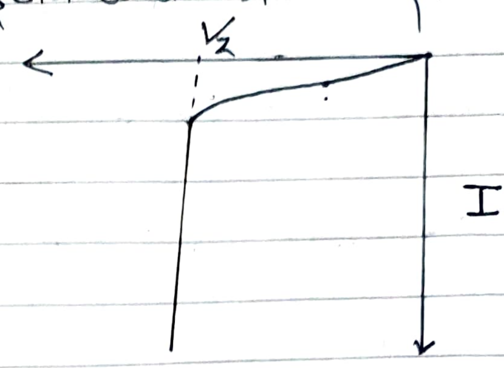
(i) When the fluctuating voltage is applied across the series combination of resistance and zener diode. Current through resistance and zener diode flows.

(ii) When the input voltage increases then current through the dropping resistance and zener diode increases. But we know that voltage across zener diode remains constant how-soever value of current is increased. But voltage drop across dropping resistance increases.

(iii) If the input voltage decreases then current through resistance and zener diode decreases. This lead to voltage drop across dropping resistance decreases. But the voltage across zener Diode remain constant

(iv) So wether input voltage increases or decreases the

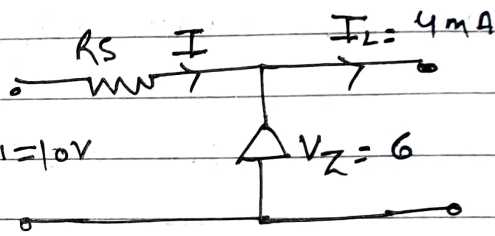
the voltage across zener diode remain same.



Q→ In a zener regulated power supply a zener diode with $V_Z = 6V$ is used for regulation. The load current is to be 4 mA. and the unregulated voltage is 10V. What should be the value of series resistance.

Sol

For proper voltage regulation current Through zener diode must be greater than load current



For Best regulation Let $I_Z = 5 I_L$

$$I_Z = 5 \times 4 = 20\,mA$$

Now using Kirchhoff's law

$$I = I_L + I_Z$$

$$I = 4 + 20 = 24\,mA$$

The voltage drop across Resistance $V_s =$ (Supply voltage − Zener Voltage)

$$V_s = (10 - 6) = 4V$$

Now from ohm's law = $V_s = I R_s$

$$R_s = \frac{V_s}{I} = \frac{4}{24 \times 10^{-3}} = \frac{4 \times 10^3}{24} = 167\,\Omega$$

So we can use a resistance from $(150 - 200)\,\Omega$

Photo Diode

Photo Diode ⇒ A photo diode is a special purpose P-N junction Diode fabricated with a transparent window to allow light to fall on the diode.

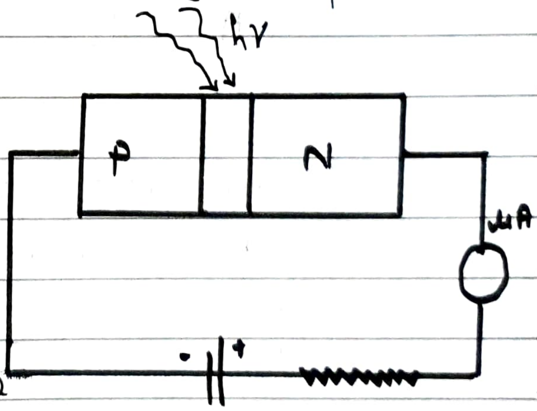
It is operated under reverse biased condition.

Working ⇒

(i) When photodiode is illuminated with light (photons) with energy greater than the energy gap of semiconductor then electron-hole pair are generated due to absorption of photons.

(ii) The diode is fabricated such that the generation of electron-hole pair takes place near in or near the depletion region of the diode.

(iii) Due to electric field at the junction they are separated before they re-combine.



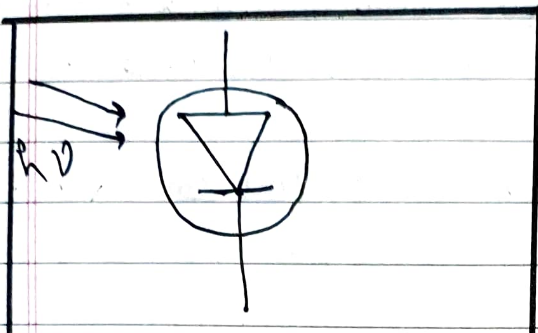
(iv) The direction of electric field is such that electrons reach N side and hole reach P side.

(v) The electrons are collected on P side and hole are collected on N side which then move to external circuit giving rise to current in external circuit.

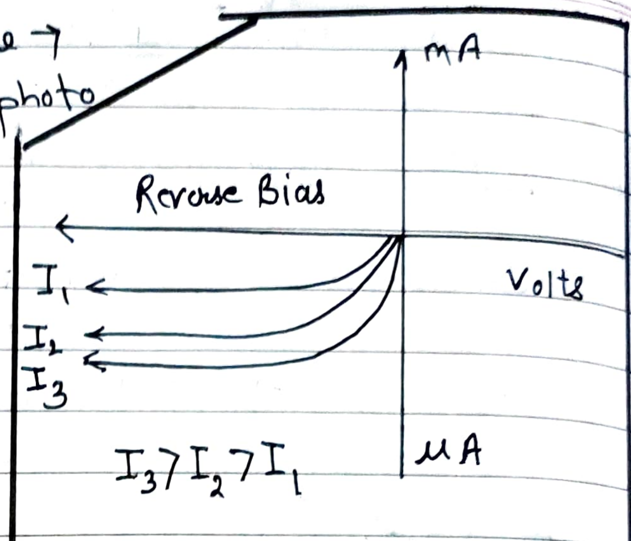
(vi) The current in external circuit depends upon the intensity of light

Application of Photo diode →

(i) It is used to detect the photo signals.



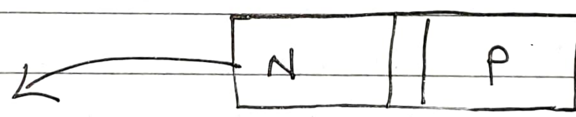
Symbol of Photo Diode



I-V Characteristic curve

Q→ Why we use photodiode in reverse biased condition even though we get more current in forward biased condition than reverse biased?

Sol



Consider N side of Diode

$n_e > n_h$

But when light fall on photo diode hole and electrons are generated ~~ ~~ in equal amount

$n_e' = n_e + \Delta n_e$

$n_h' = n_h + \Delta n_h$

Now change in majority charge carriers $= \dfrac{\Delta n_e}{n_e}$

" " " minority charge carriers $= \dfrac{\Delta n_h}{n_h}$

Since $n_e > n_h$ so fractional change in minority carriers is more than majority charge carrier so change in minority

Charge carriers is more visible then majority charge carriers so Photo diode is used in reverse biased region.

LIGHT EMITTIG DIODE [LED]

It is a heavily doped PN Junction diode which under forward bias emits spontaneous radiation.

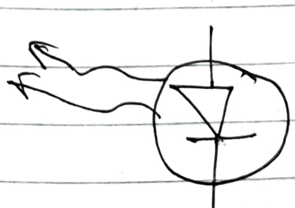
Working -

1. When the diode is forward biased electrons from n side move towards P where they are minority and holes are sent from P to N where they are minority.

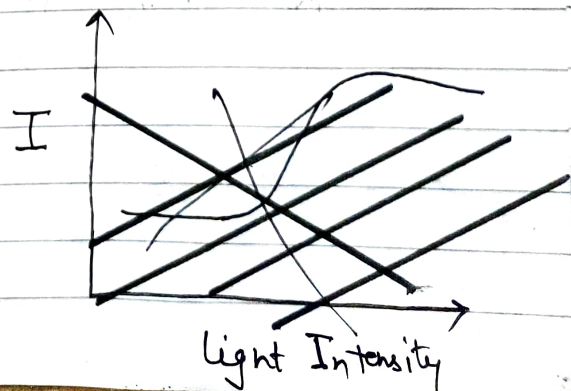
2. At the junction boundary electron and hole combine with each other and energy is radiated and whose ~~frequency~~ energy is nearly equal to the band gap.

3. As the forward ~~bias~~ current decreases intensity of emitted light decreases.

4. When the forward current increases the intensity of emitted light ~~dec~~ increases and reaches to a maximum point. After that if intensity of light will decreases with increase in forward current.



Symbol of LED



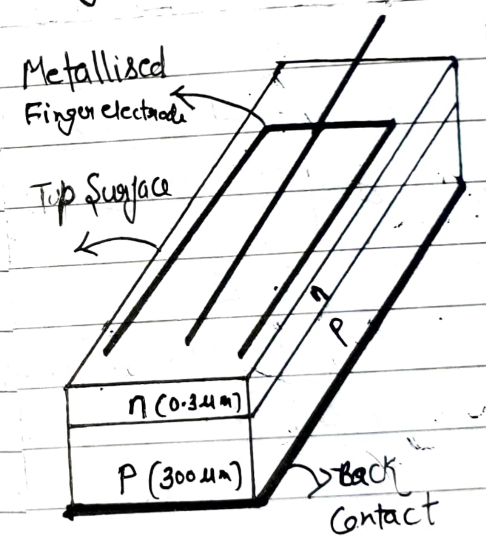
Solar Cell

Solar cell ⇒ It is a device which converts light energy into electrical energy.

Principle ⇒ It works upon the principle of photo voltaic effect.

Construction

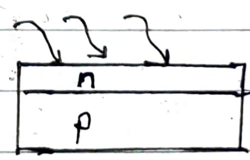
1. A p-Si wafer of about 300 μm is taken over which a thin layer (~0.3 μm) of n-Si is grown on one side by diffusion process.



2. The other side of P-Si is coated with a metal

3. On the top of n-Si, metal finger electrode is deposited. This act as front contact.

4. This metallic grid only occupies a very small fraction (15%) of cell area so that light can incident on the cell from the top.



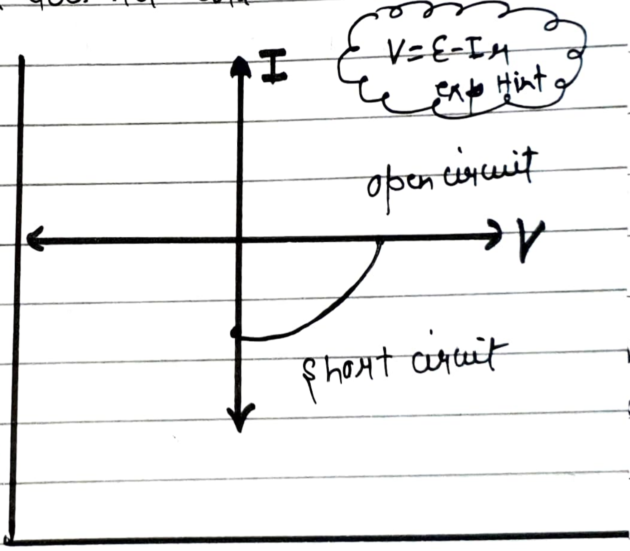
Working ⇒ The working of solar cell consist of following three steps

(i) **Generation ⇒** Generation of electron hole pair due to light ($h\nu > E_g$) falling on it.

(ii) **Separation** ⇒ Separation of electrons and holes due to electric field of the depletion region

(iii) **Collection** ⇒ Electrons are swept to n-side and holes to p-side. Thus P side become more positive and n-side becoming more negative giving rise to photovoltage

I-V Characteristic of solar cell ⇒ The I-V characteristic of solar cell is drawn in fourth quadrant because solar cell does not draw current but supplies to the load.



Important criteria for selection of material for solar cell

(i) Band gap (~1 to 1.8 eV)
(ii) High optical absorption (~$10^4 cm^{-1}$)
(iii) Availability (iv) Cost

Q→1 Why silicon is not preferred over GaAs even though it has low energy gap? [Hint → High absorption of coefficient of GaAs]

Q→2 Why we donot use material like PbS (E_g ~ 0.4 eV) which satisfy the condition ($h\nu > E_g$).

Ans:- This because most of the light will be absorbed on the top layer and radiation will not reach the junction

Q→3 Why n-side is made very thin compare to P.
Hint (Mobility of electron] [Passing of light to junction]