UNIT - IV

SEMICONDUCTOR DEVICES

Direct and Indirect Band gap Semi-Conductors :-

→ Direct band gap Semiconductors :

In case of direct band gap semiconductors, minimum of conduction band and maximum of valence band are having same k-values in the E-k band structure.

In this semi-conductors, electrons at conduction band directly recombine with the hole in the valence band. During this recombination energy is released in the form of photon of light.

Ex: GaAs, InP..etc.

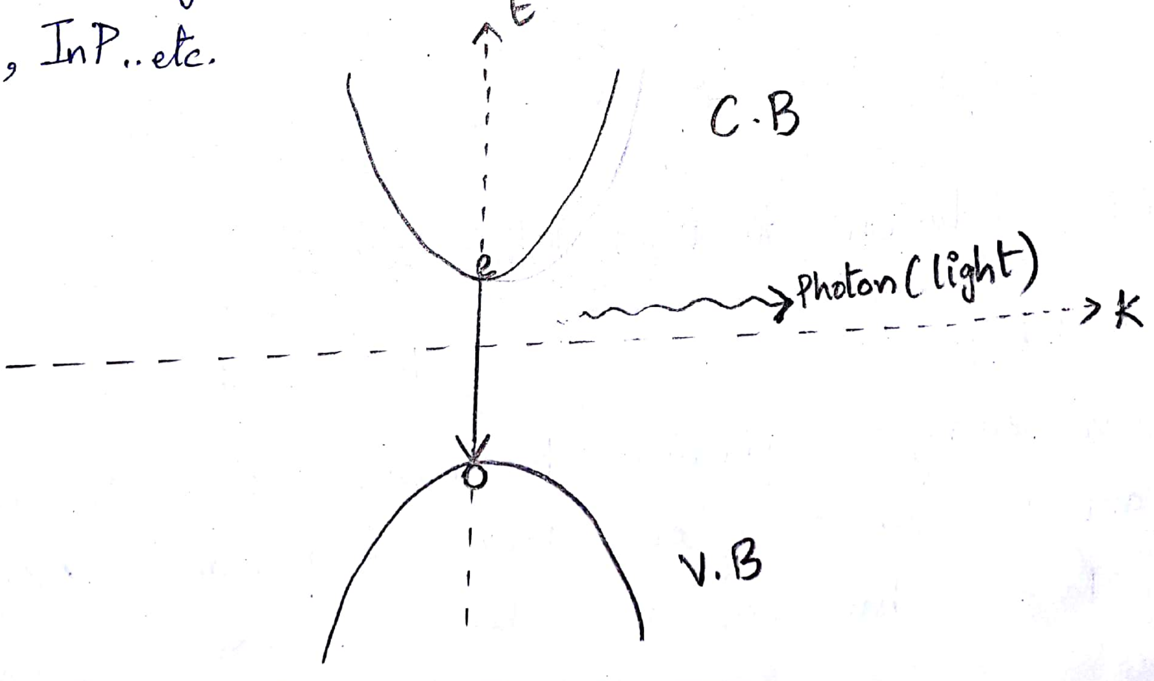


Fig :- Direct Band gap

→ Indirect band gap Semi Conductors:-

In case of indirect band gap SemiConductors, minimum of conduction band and maximum of valence band are having different K-values in E-K band structure.

In this semiconductor, electron should pass long distance to recombine with the hole, during the electron-hole recombination, energy is released in the form of phonon. (heat)

Ex: Si, Ge..etc.

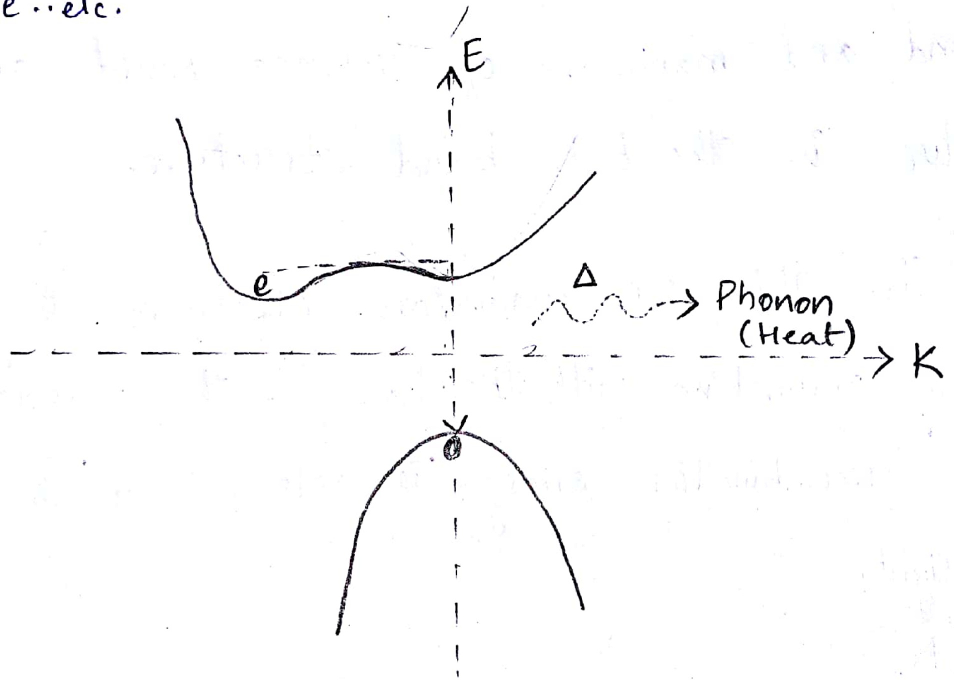


Fig:- Indirect Band-gap.

→ Difference between direct & indirect band gap semiconductors.

	Direct b.g. sc's	Indirect b.g. sc's
①	Minimum energy of conduction band and maximum energy of valence band are have same K-values.	Minimum energy of conduction band and maximum energy of valence band have different K-values.

	Direct b.g. sc's	Indirect b.g. sc's
2	Photon (light) is released during electron-hole recombination.	Phonon (Heat) is released during electron-hole recombination.
3	Life time of charge-carriers is very less.	Life time of charge-carriers is more.
4	Ex:- GaAs, InP	Ex:- Si, Ge

Formation of p-n junction:-

When a p-type semi-conductor layer is placed with the n-type semi-conductor layer in such a way that the atoms of p-type combine with the atoms of n-type across the surface of contact. The surface where combination has occurred is known as p-n junction.

In general, a p-n junction diode may be obtained in any of the following three methods.

→ 1) Grown junction type.

→ 2) Fused junction type.

→ 3) Diffused junction type.

① Grown junction type: When an extrinsic semiconductor is grown from melt, during the middle of the growth process impurities are added to the melt for desired crystal growth.

For example, when a n-type Si crystal containing phosphorus atoms (V group impurity). The growth process is stopped temporarily by addition of Boron (III - group impurities) atoms to the melt. This result in growth of p-type thereafter.

② Fused junction type: In this type, p-type and n-type materials are kept in contact and fused together by proper heat treatment to form junction.

③ Diffused junction type: In this process a p-type impurity is pointed on a n-type substrate and both are heated. Now impurity atoms diffuse into n-type substrate for a short distance and form p-n junction.

When two separate semiconductors p and n type are brought close to each other, electrons are diffusing from n-type to p-type and holes are diffusing from p-type to n-type. As a result, electric field E_B produced in the small region (W). This region is called "Depletion region". Due to the electric field (E_B)

potential difference V_B is produced is called potential barrier.

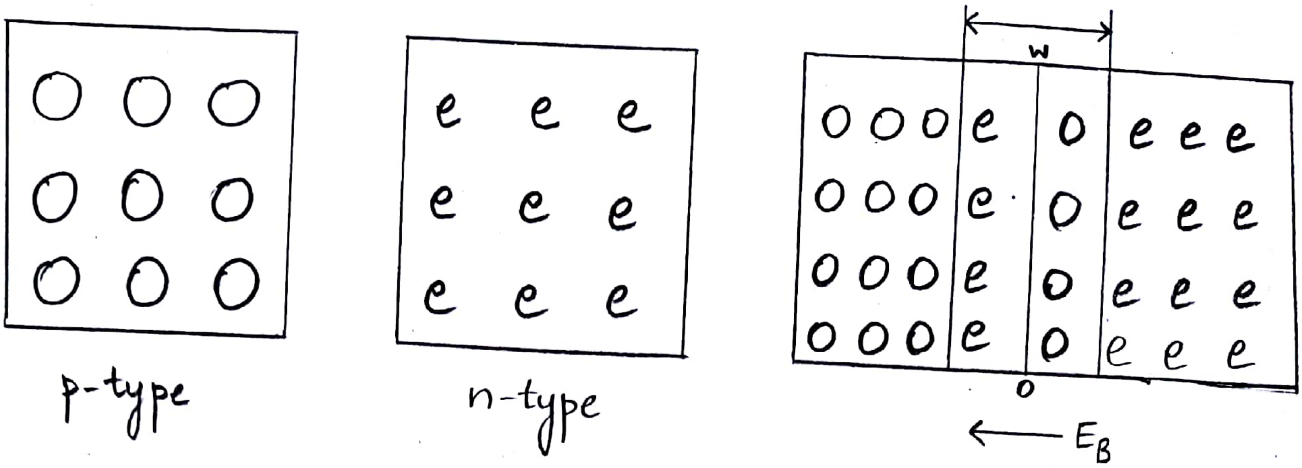
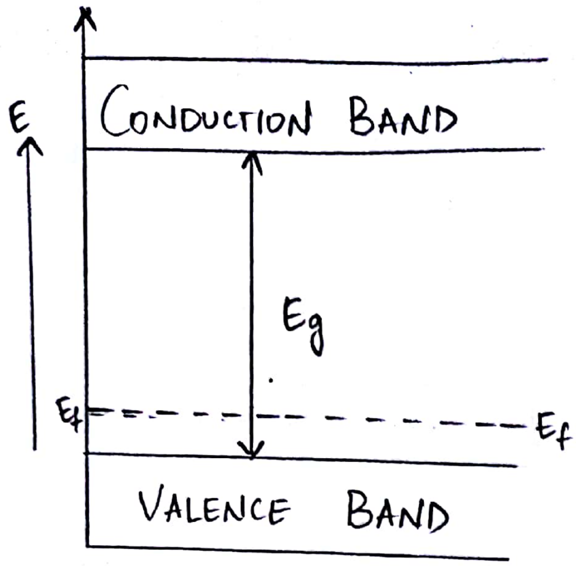


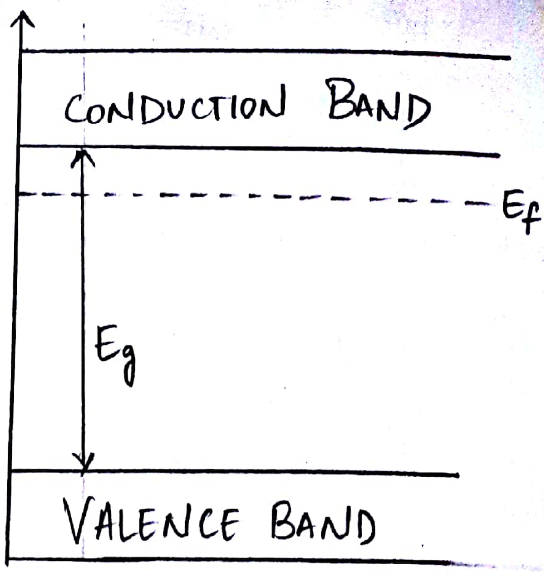
Fig:- Formation of p-n junction.

Energy Diagram of p-n junction :-

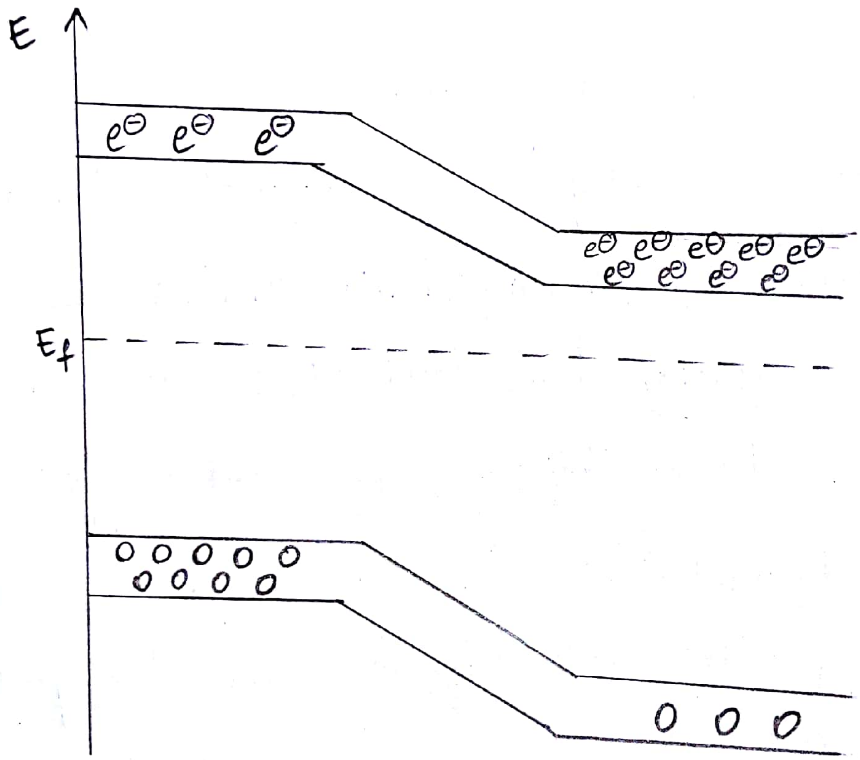
In case of p-type semi-conductor Fermi level (E_F) lies just above the valence band and in case of n-type of semi conductor fermi level (E_F) lies just below the conduction band. When both p and n type semi-conductors are brought close to each others, the fermi-level gets readjusted. The holes diffusing from the p-type region leave a negative charge raising its energy level. Similarly, the electrons diffuse from the n-type region, leaving a positive charge thus, lowering its level. At equilibrium, both fermi levels reach the same level. As a result, a potential difference (eV_0) is generated.



p-type semiconductor



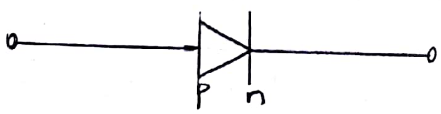
n-type semiconductor.



V-I Characteristics of PN junction diode :-

(i) Unbiased circuit :

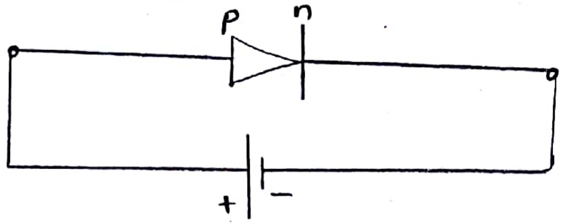
Symbol -



When the junction is not connected to any voltage source, it is said to be unbiased and due to barrier potential across the junction, there is no current flow through the junction.

(ii) Forward biased circuit:

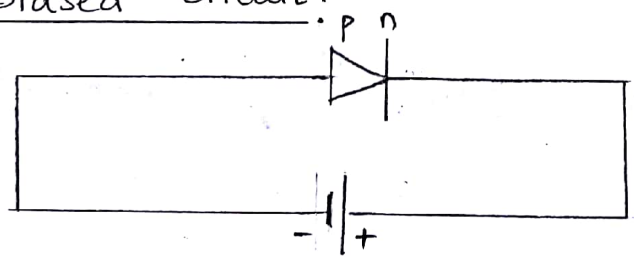
Symbol -



When positive terminal of the battery is connected to p-type and negative terminal to n-type then the junction is said to be forward biased. Since the potential barrier strength is very small (0.2V). When the applied voltage exceeds that value, the junction resistance becomes almost zero. Hence even for small increase of applied voltage, we observe large increase in current.

(iii) Reverse biased circuit:

Symbol:-



When diode is connected in reverse bias, a slight current flows in the circuit. Even for large applied voltage, there is negligible increase in reverse current. When applied voltage is very high to break the covalent bonds of the crystal, the current rises suddenly in the reverse direction. This voltage is known as break down voltage (or) Zener Voltage.

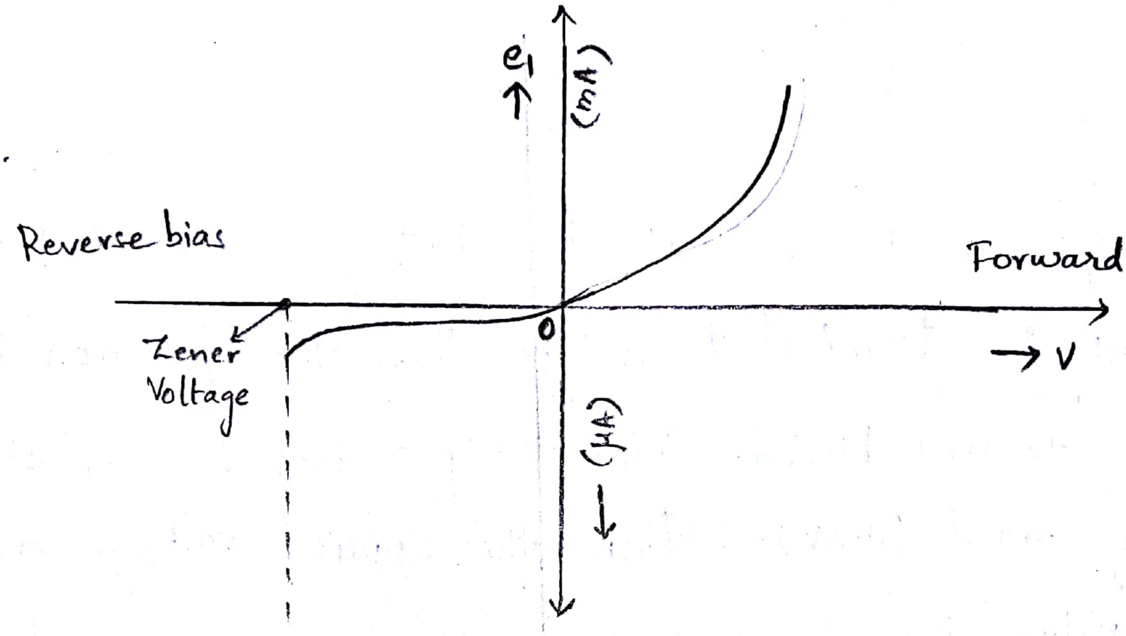


Fig:- V-I characteristics of PN Junction

Light Emitting Diode (LED) :-

A light emitting diode (LED) is a junction diode which emits light when it is connected in forward bias.

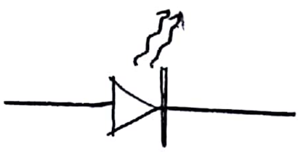


Fig:- LED symbol

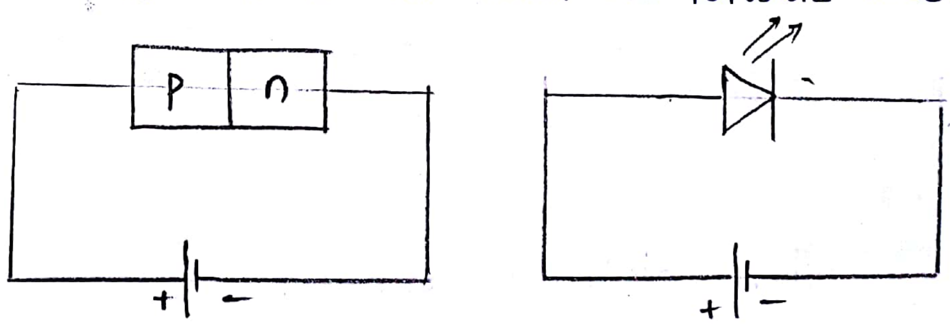


Fig:- Forward biased LED circuit.

Working:

When LED is connected in forward bias, the charge carriers injected into the opposite region. The recombination of holes and electrons takes place at the junction. During the recombination, difference in the energy will emit in the form of light i.e, photon.

The energy of photon is equal to the energy of band gap (E_g).

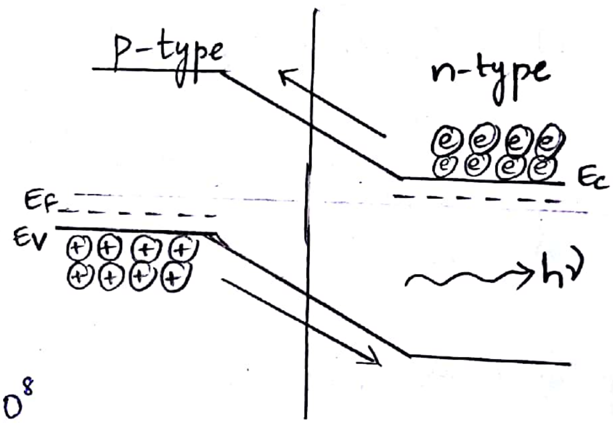
$$\therefore E_g = h\nu$$

$$E_g = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{E_g}$$

$$\lambda = \frac{6.625 \times 10^{-34} \times 3 \times 10^{8}}{E_g}$$

$$\boxed{\lambda = \frac{1.24}{E_g}} \ \mu m$$



$\therefore$ Above equation indicates that the wavelength of the emitted light depends on the energy gap in the semi-conductor.

Material	Wavelength	colour
Ga As P	650 nm	Red
Ga P	555nm	Green
Al In Ga P	570 nm	Yellow

Advantages:

1) → LED's are used to produced more light per watt then normal light.

2) → LED's light up very quickly

3) → The response time of LED's used in communication devices is much faster than normal source.

4) → Life time of LED's is more than 1,00,000 hours.

5) → The brightness of LED is more than the ordinary light source.

6) → Available in different colour.

7) → Very rugged and hence suitable for any environment.

8) → Low energy consumption.

9) → smaller / handy size.

Photo Diode :-

A photodiode is a semiconductor device that converts light into current.

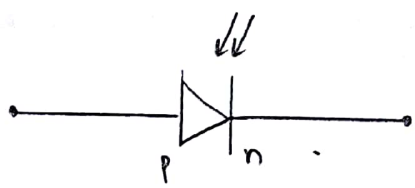


Fig- Photo diode symbol.

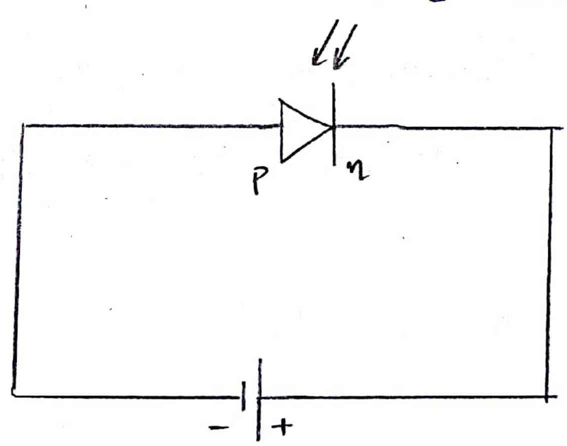


Fig :- Reverse biased photo diode circuit.

Working:-

A photo diode is a p-n junction diode (or) PIN diode. A photo diode operates in reverse biased mode. When light is incident on the junction it creates an electron-hole pair, these charge carriers sweep out from the junction by the barrier potential. Thus holes move towards the anode and the electrons move towards the cathode as a result, a photo current flows in the circuit.

Materials:

Materials commonly used to produce photo diodes are Si, Ge, SiC, In, Ga, As. etc.

V-I characteristics of photo diode -

The V-I characteristics of photodiode are shown clearly in the following figure. The photo current is nearly independent of applied reverse biased voltage. As optical power (incident light) rises the photo current also increases linearly.

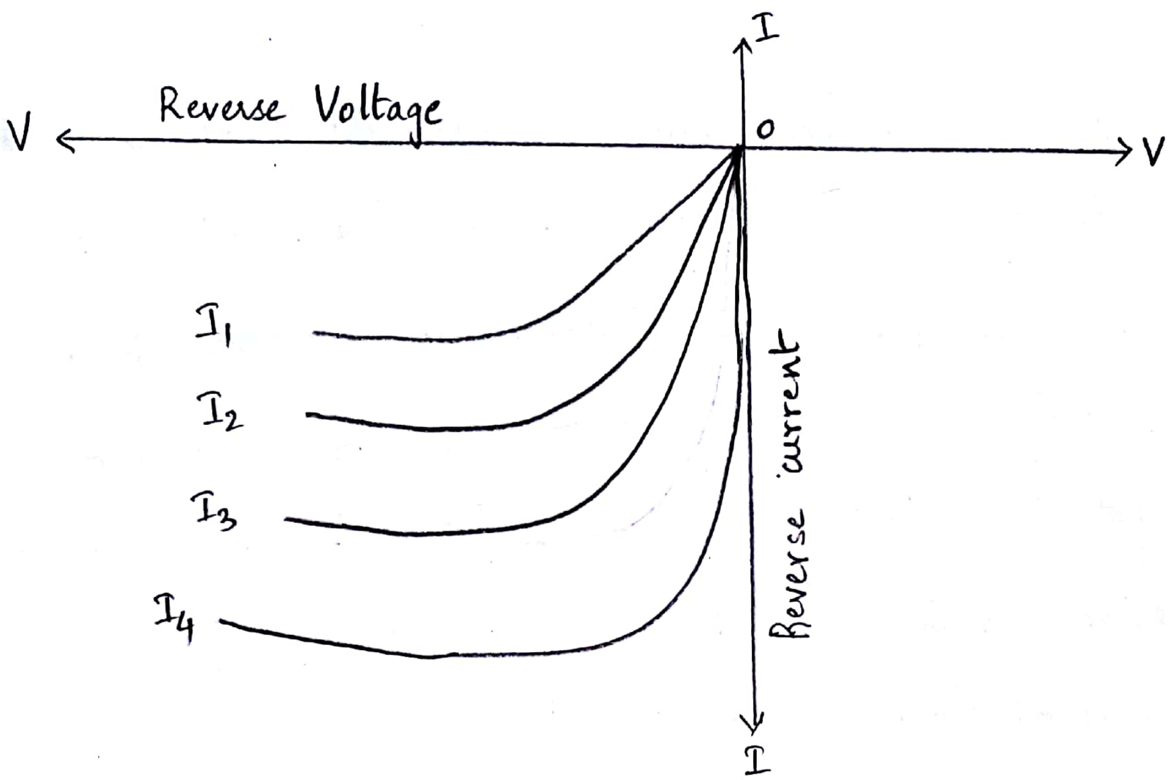


Fig:- V-I characteristics of photo diode.

Order of incident light intensity $\Rightarrow I_4 > I_3 > I_2 > I_1$

Applications:-

→ Photo diodes are used in photo directors (or) light sensors.

→ Smoke detectors, street lights, remote control devices, alarms.. etc.

→ They are used in moving object counters, exposure meters in cameras.

Solar Cell:

The solar cell is a semi-conductor device which converts solar energy to electrical energy. When a solar cell is exposed to sunlight, then voltage is developed at the junction known as open circuit voltage (V_{oc}) and this effect is known as photovoltaic effect. The working of solar cell depends upon its photovoltaic effect, hence it is also called as a photo voltaic cell.

Si, Ge, CdTe, GaAs, etc. are some materials used to prepare solar cells.

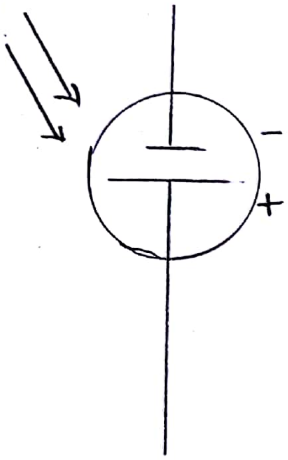


Fig:- Symbol of solar Cell.

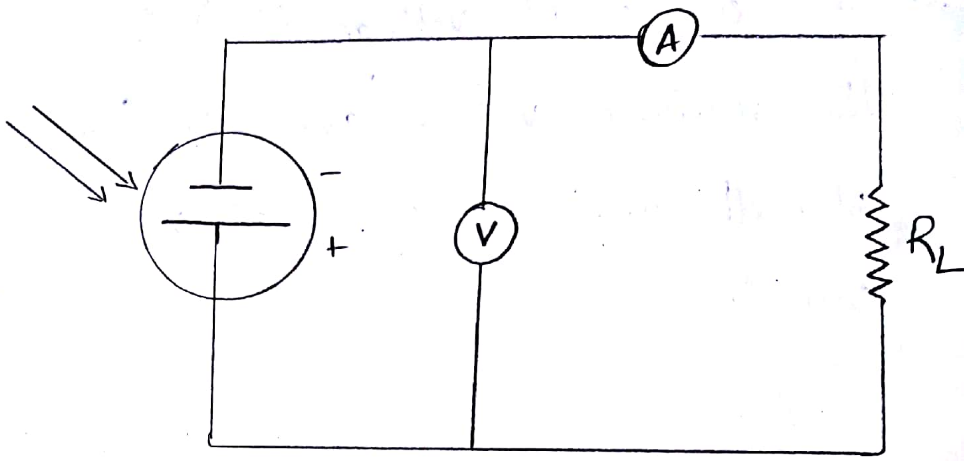


Fig:- Circuit Diagram of Solar Cell.

When sunlight falls on the solar cell, this light photon generates electron-hole pairs. These electron-hole pairs migrate respectively to n-side and p-side of the p-n junction due to field across the junction. In this way a potential difference is established between two sides of the cell. If these two sides are connected by an external circuit, current will start flowing from the positive to negative terminal of the solar cell.

V-I characteristics of solar cell is shown in the following figure.

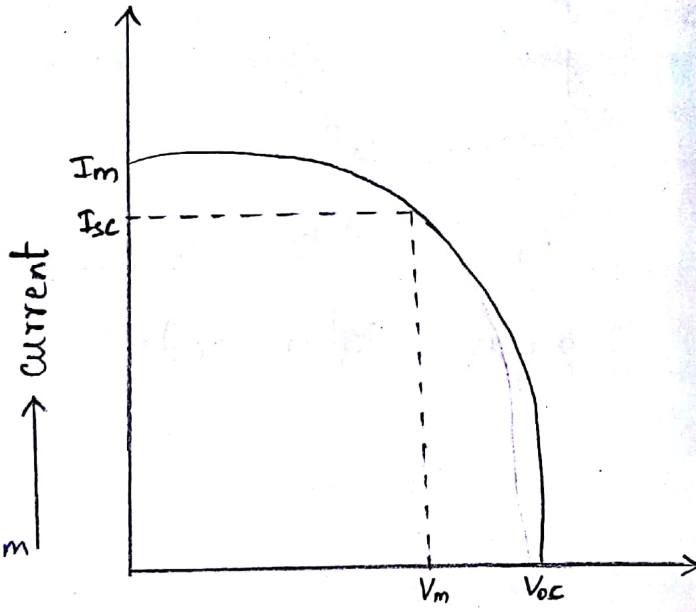


Fig:- V-I characteristics of solarcell.

→ The short circuit current (I_{sc}) is the current through the solar cell is zero.

→ The open circuit voltage (V_{oc}) is the maximum voltage available from solarcell, and this occurs at zero current.

Efficiency of Solar Cell :-

The efficiency is the parameter which is used to represent the performance of the solar cell.

Efficiency is defined as the ratio of energy output from the solar cell to input energy from the sun.

The efficiency of solar cell depends upon climate and latitude.

Solar cells are used in solar panels, power calculators, watches, irrigation system, artificial satellite...etc.

Semi Conductor Diode Laser :-

The semiconductor laser is also called Diode laser. A direct band gap semiconductor GaAs is used as active medium in this semiconductor laser. The wavelength of the emitted light depends upon the band gap of the material.

$$\lambda = \frac{hc}{E_g}$$

where $E_g \rightarrow$ the energy gap of a material

$\lambda \rightarrow$ Wavelength of emitted photon.

$c \rightarrow$ Light velocity. $h \rightarrow$ planck's constant.

$$\boxed{\lambda = \frac{1.24}{E_g}} \mu m$$

Construction:

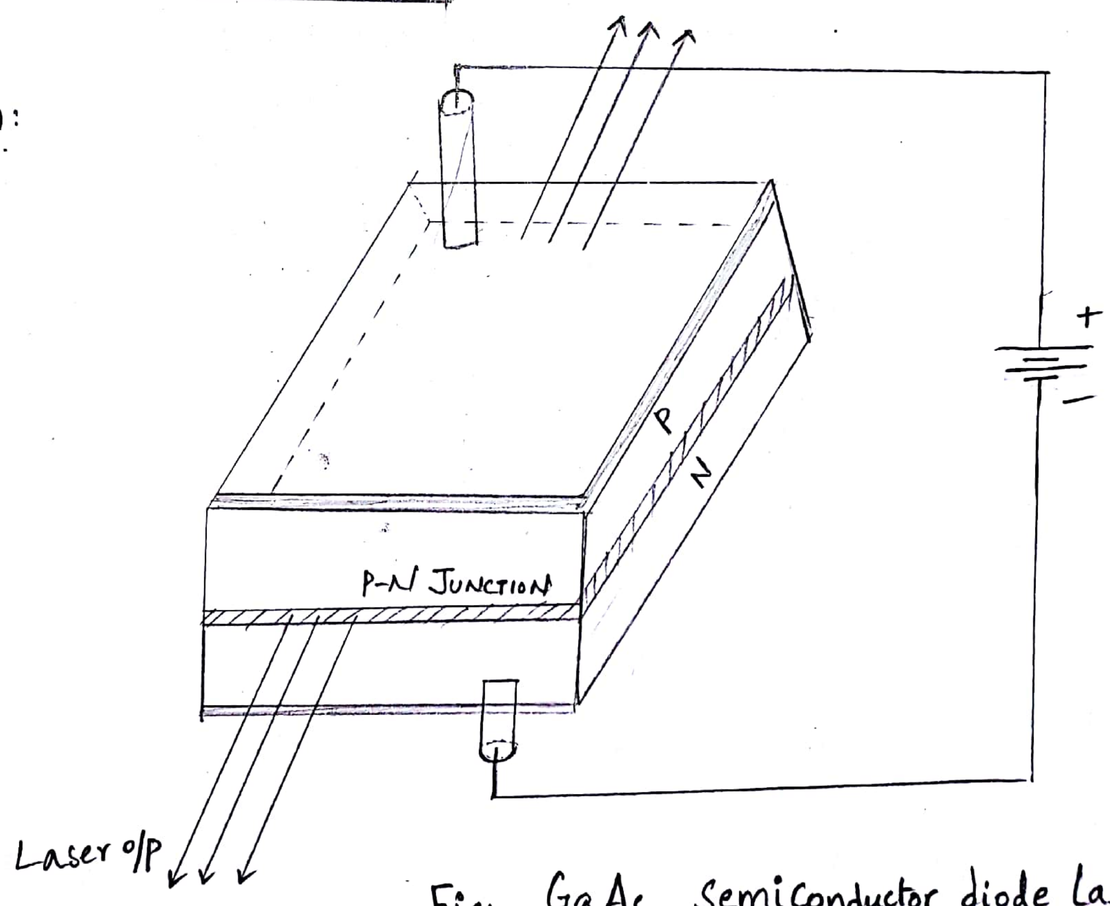


Fig:- GaAs Semiconductor diode laser

The active medium is a p-n junction diode made from crystalline GaAs. The p-and n-regions in the diode are obtained by heavily doping with suitable dopants (impurities). At the junction, the sides through which emitted light is coming out are well polished and parallel to each other. Since the refractive index of GaAs is high, so the external mirrors are not necessary to produce multiple reflections.
Now, this p-n junction circuit is connected in forward bias using one external battery. Then the electrons are injected from n-region into p-region & holes are injected from p-region into n-region as shown in following figure.

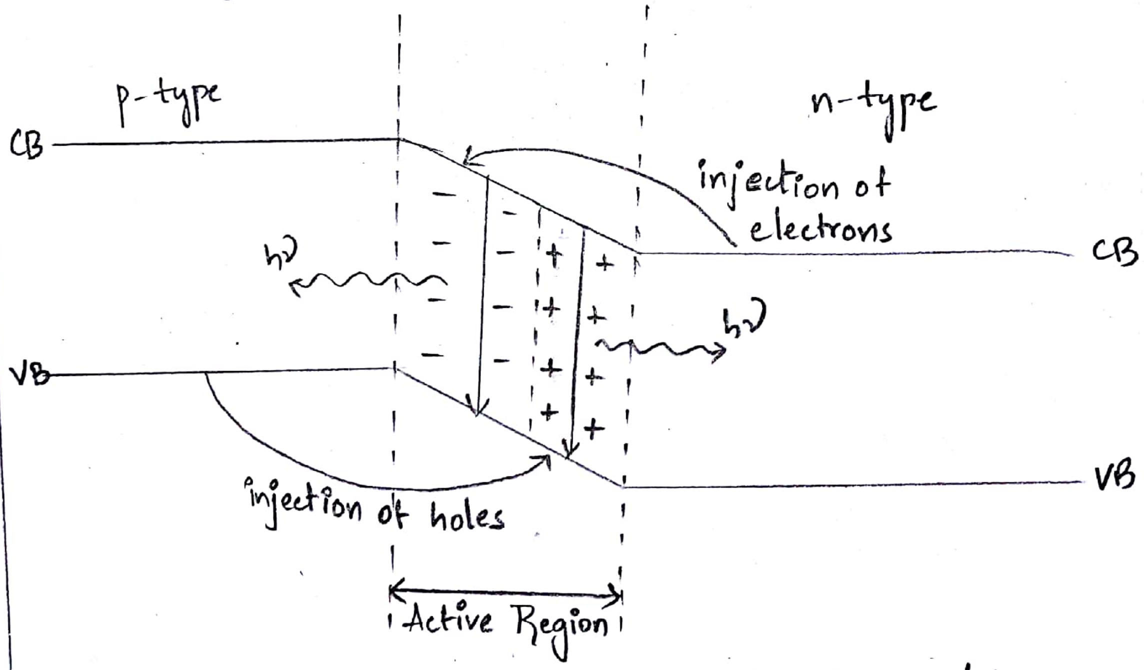


Fig: P-N Junction under forward bias.

The electrons are minority charge carriers in p-side and holes are the minority charge carriers in n-side. The continuous injection of charge carriers create the population inversion of minority carriers in n and p sides respectively. The electrons and holes recombine and release of photon takes place at the junction. Further, the emitted photons increase the recombination of injected electrons & holes. Thus the stimulated emission takes place more effectively.

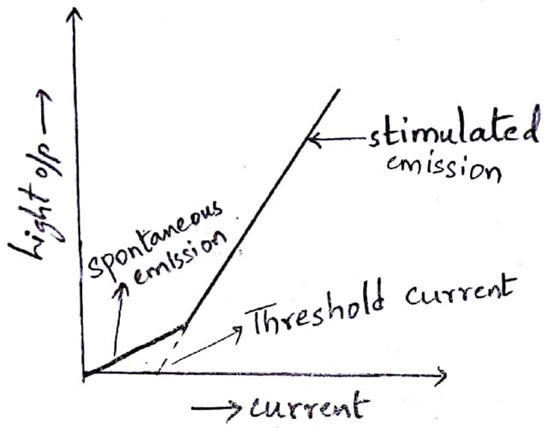


Fig: Light o/p - current graph of an ideal semi-conductor Laser

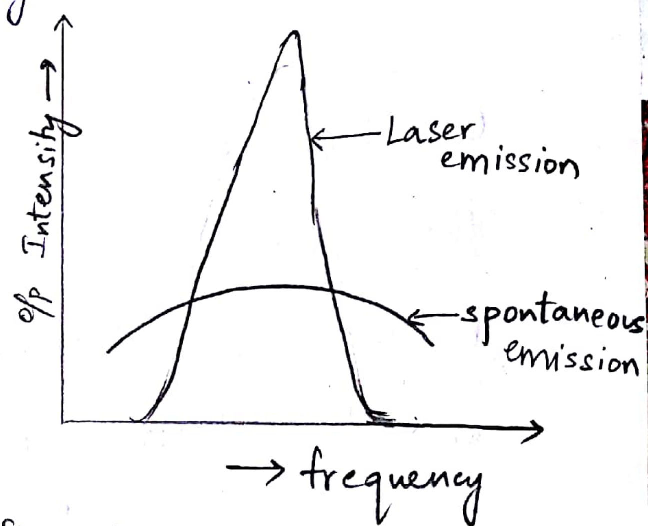
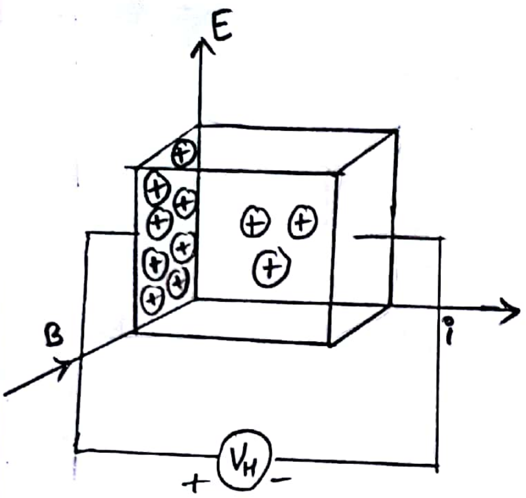


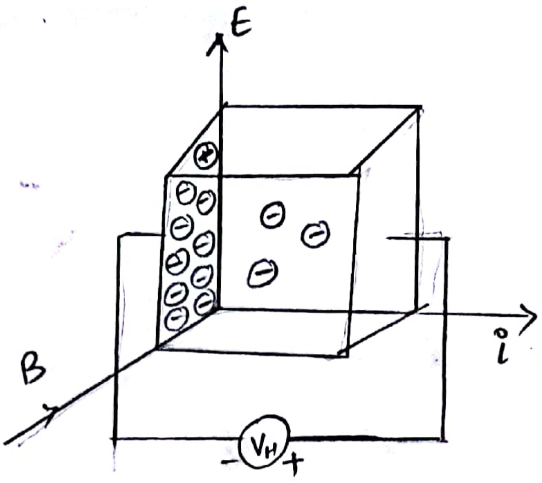
Fig: Radiation o/p at function of frequency for a p-n junction Laser.

Hall Effect :

When current carrying conductor or semi-conductor is placed in a perpendicular magnetic field then the electric field is generated in a direction perpendicular to the current and magnetic field. This effect is known as "Hall effect" and the generated voltage is known as "Hall voltage".



p- type semi-conductor



n-type semiconductor.

Consider 'e', 'v' are the charge and velocity of the electron when magnetic field 'B' is applied on the n-type semiconductor. The magnetic force which is acting on the electrons is

$$F_1 = Bev \quad \text{—— (1)}$$

The electrical force which is acting on the electrons due to created electric field is

$$F_2 = eE_H \quad \text{—— (2)}$$

At equilibrium

$$F_1 = F_2$$

$$Bev = eE_H$$

$$\Rightarrow E_H = Bv \quad \text{—— (3)}$$

The current density $J = nev$

$$\Rightarrow v = \frac{J}{ne}$$

$\therefore$ eq 3 becomes $E_H = \frac{BJ}{ne}$

$$E_H = R_H BJ \quad \text{—— (4)}$$

where $\boxed{R_H = \frac{1}{ne}}$ is Hall coefficient.

If 'b' is the width of the sample, the generated Hall Voltage (V_H) is

$$V_H = b \times E_H$$

$$= b \times R_H BJ \qquad [\because \text{from (4)}]$$

$$= b \times R_H B \times \frac{I}{bt} \qquad \left[\because J = \frac{I}{bt}\right]$$

where $I \rightarrow$ current
$b \rightarrow$ width
$t \rightarrow$ thickness

$$\Rightarrow \boxed{R_H = \frac{V_H t}{BI}}$$

Applications of Hall effect :-

→ 1 Determination of type of semi-conductor:

For n-type semiconductor, Hall coefficient is negative.

i.e, $\boxed{R_H = -\frac{1}{ne}}$

For p-type semiconductor, Hall coefficient (R_H) is positive.

i.e $\boxed{R_H = \frac{1}{ne}}$ or $\boxed{R_H = \frac{1}{pe}}$

∴ Based on the sign of the hall coefficient we can identify the type of semi-conductor.

→ ② Calculation of carrier concentration :-

$$\because R_H = \frac{1}{ne}$$

$$\boxed{n = \frac{1}{R_H e}}$$

by using above equation we can determine the carrier concentration of given semiconductor.

→ ③ Measurement of magnetic flux density :

$$R_H = \frac{V_H t}{BI}$$

$$\Rightarrow \boxed{B = \frac{V_H t}{R_H I}}$$

By using above equation we can measure the applied magnetic flux density (B).

→ ④ Hall effect semiconductor devices are used as sensors to detect magnetic fields.

→ ⑤ Hall effect is also used in magnetically activated electronic switches which are used in non-contacting keyboards and panel switches.

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