UNIT-III : Opto Electronics

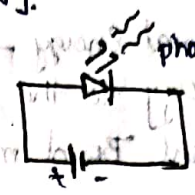
→ Opto : Which are using the light energy.

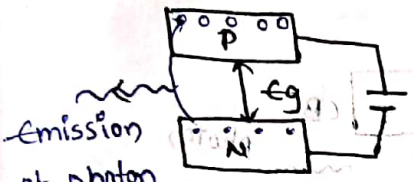
→ electronics : Deals the working of devices.

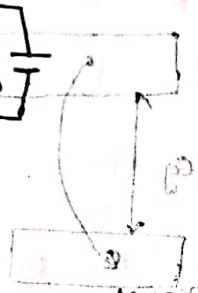
light energy $\rightleftharpoons$ converted electical energy.

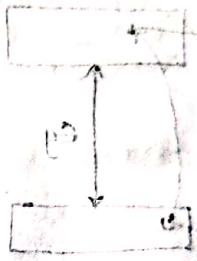
LED light emitting diode

works Under FB (Forward Bias)









Syllabus

⇝ Radiative and Non-radiative recombination mechanism in semiconductors

⇝ LED and Semiconductor lasers : Devive structure, Materials, characteristics and figures of merit

electrical energy converted into light energy (F.B)

⇝ S.C photo detectors : Solar cell, PIN and Avalanche & their structure, materials, Working principle and characteristics

Light energy converted into electrical energy (R.B)

Laser : Input → photons

output → photon I, photon II

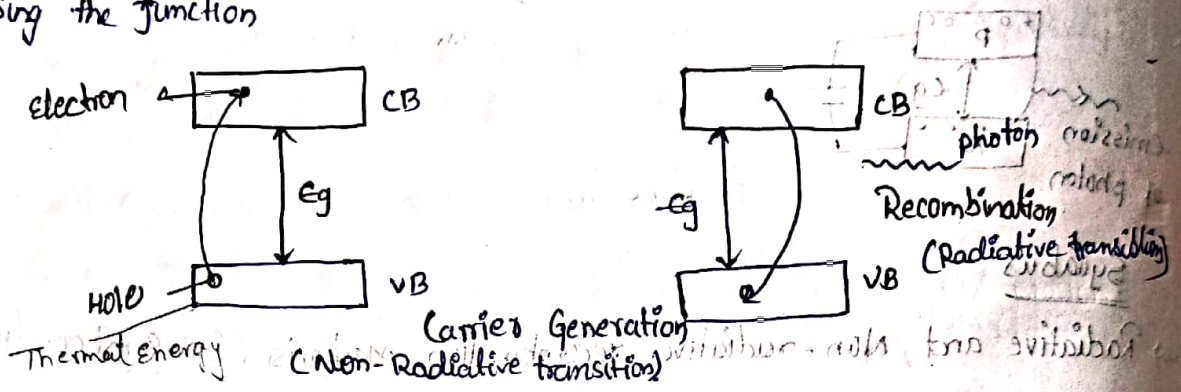
Radiative and Non-Radiative :-

Q) What is Radiative & Non-Radiative Recombination mechanism in S.C?

→ In S.C Breaking of covalent Bond leads to the Generation of 2 charge carriers i.e $\bar{e}$ - hole pair Generation. this process may be Represented as [Covalent Bond + Thermal energy]

∴ Covalent Bond + Thermal energy — Rupture → (-electron + Hole) pair

⇝ By given the thermal energy to the S.C covalent bond is Broken & The $\bar{e}$'s is released from the covalent Bond moving like a free $\bar{e}$ & recombine with the hole (by crossing the junction



Condition :- $E_g = h\nu$

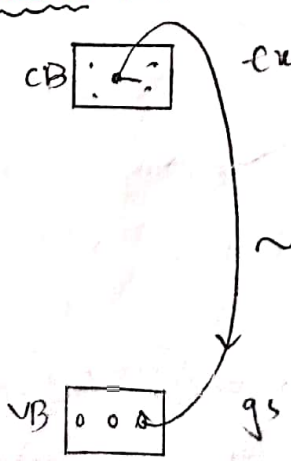
Where E_g is known as Energy gap, $h\nu$ is the energy of emitted photon

∴ $E_g = \frac{hc}{\lambda}$ $\left[\nu = \frac{c}{\lambda}\right]$

λ is the wave length of emitted photon
c is the velocity of light
h is the plank's constant

⇒ E_g values are 1.4eV to 3eV [depending on the type of the diode E_g values changes]

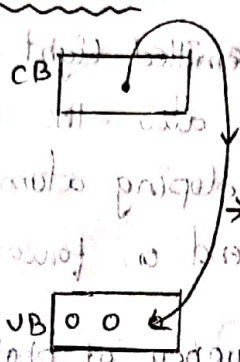
⇒ Radiative Recombination :-



→ Radiative Recombination occurs when an electron in the conduction Band Recombines with a hole in the valancy Band and the excess is emitted in the form photon.

(In recombination Process if their exist a emission of photon it is known as Radiative Recombination)

Non-Radiative Recombination:-



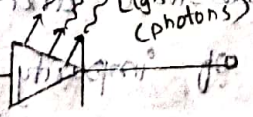
→ Non-Radiative Recombination occurs when an electron in the CB recombines with a hole in the VB and the excess in energy is transmitted (emitted) in the form of Heat in the S.C Crystal lattice.

(In recombination Process only heat is the transmitted to the S.C crystal is known as non-radiative Recombination)

Note 1 :- 1) Spontaneous Emission & Stimulated Emission is case of laser diode is known as Radiative Recombination Process

2) In Hetro junction Diode laser their exist a leakage of current due to heat energy transmitted to the crystal. This is the phenomenon of non-radiative recombination.

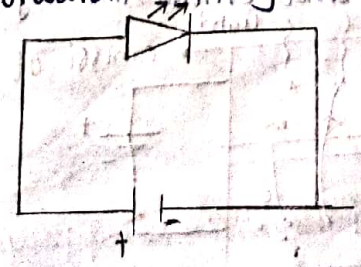
Q) What is LED? write short note on construction & working of LED



LED:

Light emitting Diode: Which converts the electrical energy into light energy

→ LED works under forward Biasing condition.



→ NOTE:- The Amount of light emitted by the LED under forward bias in condition is directly proportional to forward current (I_f)

→ Fabrication of LED:- It is fabricated by using 3rd (III) - IV compound semiconductors such as Ga, As which have direct bonding

→ Ga (which is direct band gap s.c), $Ga_x As_x P$ (Gallium, arsenite, phosphite)

Gap (Gallium phosphid

→ Out Put of LED: The colour of emitted light by the LED is depend on Percentage of doping atoms and also the wave length of emitted light is also depend on percentage of doping atoms.

→ The Amount of emitted light depend on forward current (I_f)

Equation:- $E_g = h\nu$ ν frequency of photon.

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

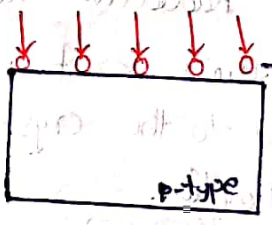
$$\lambda = \frac{hc}{E_g}$$

$\nu = \frac{c}{\lambda}$, λ wavelength of emitted photon

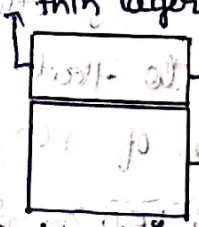
E_g energy gap (eV)

Construction :-

Diffusion method:



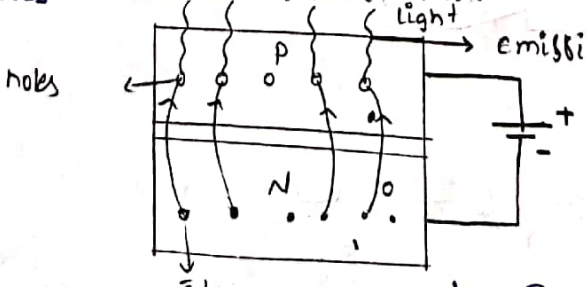
→ atoms are diffuses



→ N- layer is grown on the substrate and also P-layer is grown which is contact By diffusion of impurity atoms P & N layers are developed

Working:-

→ electrons Recombines with holes. and Emitts the light in the form of photons



LED under Forward Bias

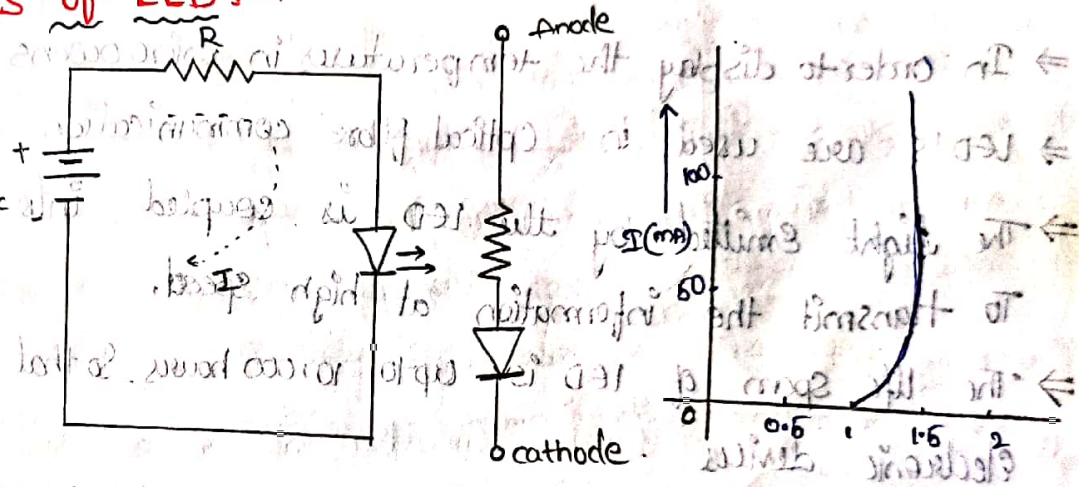
⇒ LED is always forward Bias to give the out put in the form of photons the light energy is realesed at the junction when the recombination of $\bar{e}$'s with holes takes place.

⇒ The difference of energy in case of $\bar{e}$'s which are recombine with the holes is radiated in the form of light energy

NOTE:- (i) in ordinary diodes the difference of energy in case of electron hole recombination is radiated in the form of heat

(ii) Ordinary diode works under forward & Reverse Biase byt LED works under forward Bas is condition only.

V-I characteristics of LED :-



⇒ the out put is constant emitted by the LED is depend on input voltage & current Supplied to the diode.

⇒ The intensity of the light is depend on magnitude of forward current (I_f)

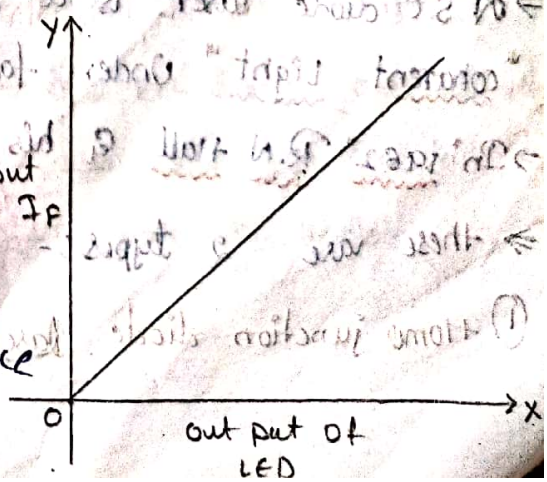
⇒ The break down voltage of LED is different as compare to normal diode [voltage drop V_D = 1.5 V to 2.5 V] current = 10 mA to 50 mA

⇒ LED's are not able with stand Reverse Bias of even very Small voltages. for this Reason it is neccessary to Assure that Reverse bias is never applied to an LED

⇒ Applications of LED :-

↝ LED used Burgulars alarm which make Emitts light in IR region

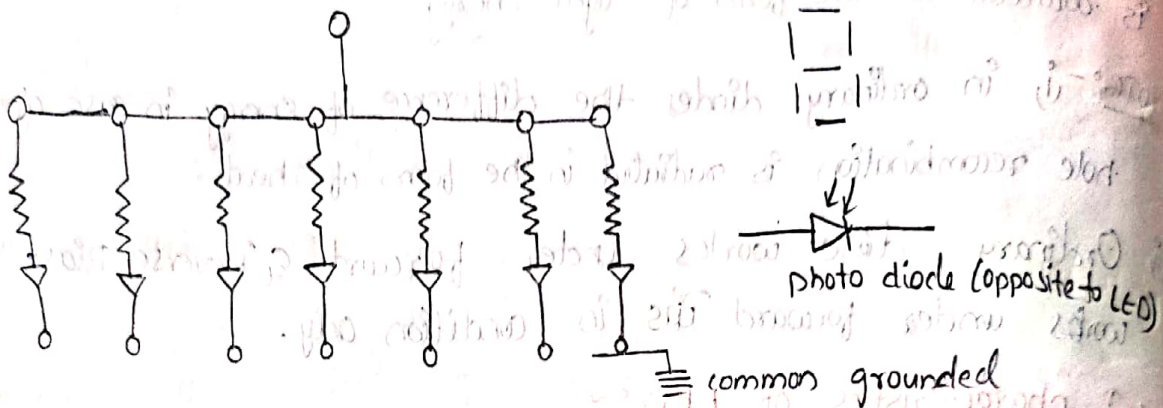
↝ LED can be used as indicator weather the device is in on (or) off condition.



⇝ CRT 's are replaced By LED's is solid state video display.

⇝ LED's can be used in display Sigment

⇝ In order to display the number [Numaric] LED's are used in Seven Sigment display.



⇒ In order to display the temperatures in micro ovens LED are used

⇒ LED's are used in Optical fibre communication System.

⇒ The light Emitted by the LED is coupled into the optical fibre To transmit the information at high speed.

⇒ The life Span of LED is upto 10,000 hours. So that it can be used in Electronic devices

⇒ With nano Second there Exist a out put from the LED So that LED operation quick process. It is used to trasfer the energy one circuit to another

Semiconductor laser :- (Semiconductor Diode laser)

⇒ What is Semiconductor laser? write a note on construction & working of S.C laser with neccessary diagrams what are the applications of S.C laser

⇒ A S.C diode laser is a specially made P-N junction Diode that emits "coharent Light" Under -forward bias

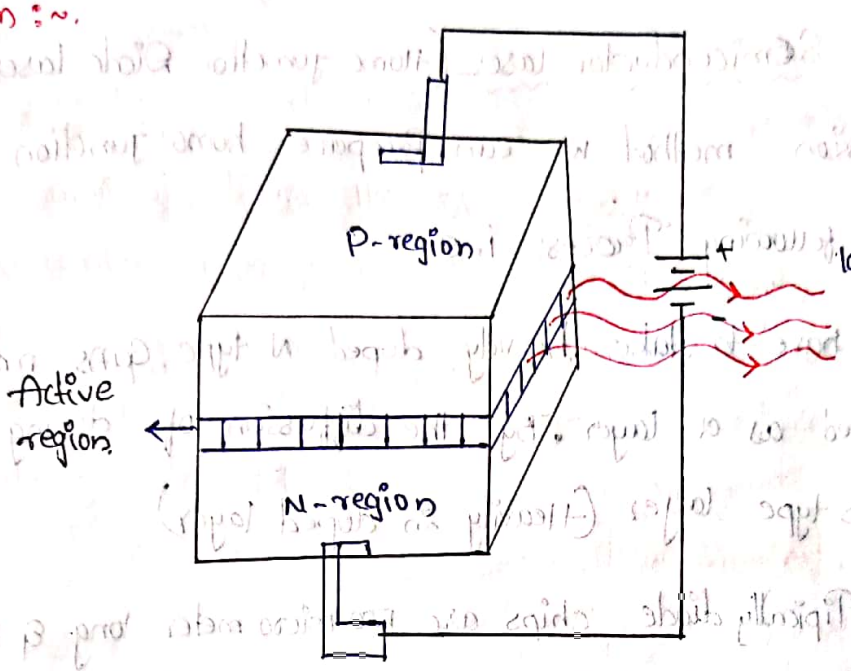
⇒ In "1962" R.N Hall & his co-workers made the first S.C laser.

⇒ these are 2 types :-

① Homo junction diode laser :- P&n materials Prepared from Same material.

② Hetero junction diode lasers:- p & n materials prepared from different materials

Construction :-



⇒ Semiconductor laser is also called as diode laser.

⇒ The light Emitting diodes are basically s.c laser.

⇒ Semiconductor lasers are classified as homo junction Semiconductor laser & Hetero Junction s.c laser

⇒ GaAs is well known example of direct band gap Semiconductor so that GaAs Semiconductor diode laser having the important applications

Construction of semiconductor laser :-

As shown in the above figure, the p-type & N-type materials are prepared by adding suitable dopent elements.

The shaded Area is known as "depletion layer" (Active region)

The thickness of the depletion layer is usually very small (0.1 micro mt)

To obtaine the laser action, the end phases are polish flat & parallel the other two phases are left unpolished to suprus the Oscillation

Working of Semiconductor laser:~ (working of GaAs laser) (or) (Homojunction S.C laser):~

⇒ Homo Junction Semiconductor laser (Homo junction Diode laser)

By diffusion method we can Prepare homo Junction S.C laser in the following Process i.e.

(i) Initially we have to take heavily doped N-type GaAs material it has been formed as a layer. By the diffusion of doping atoms we can form p-type layer (Heavily Zn doped layer)

(ii) Dimensions:~ Tipically diode chips are 500 micro meter long & 100 micro meter wide & thick the top & bottom phases are mettalised to connect to the Battery terminals

working:~

(i) Under forward Biasing condition electrons are injected from N-region to p-region & also holes are injected from p-region to N-region, so that the "population inversion" was achieved, it is neccessary for the laser Operation (for emission of out put from laser)

(ii) In Order to achieve the population inversion pumping mechanism is required. In case of S.C laser electrical pumping mechanism was used

(iii) The $\bar{e}$ s & holes recombine & releases the light energy inthe form of photons that is knoons as out put of the S.C laser

Recombination of electron with hole:-

when electron recombine with the hole the excessive energy is emitted in the form of photon. On

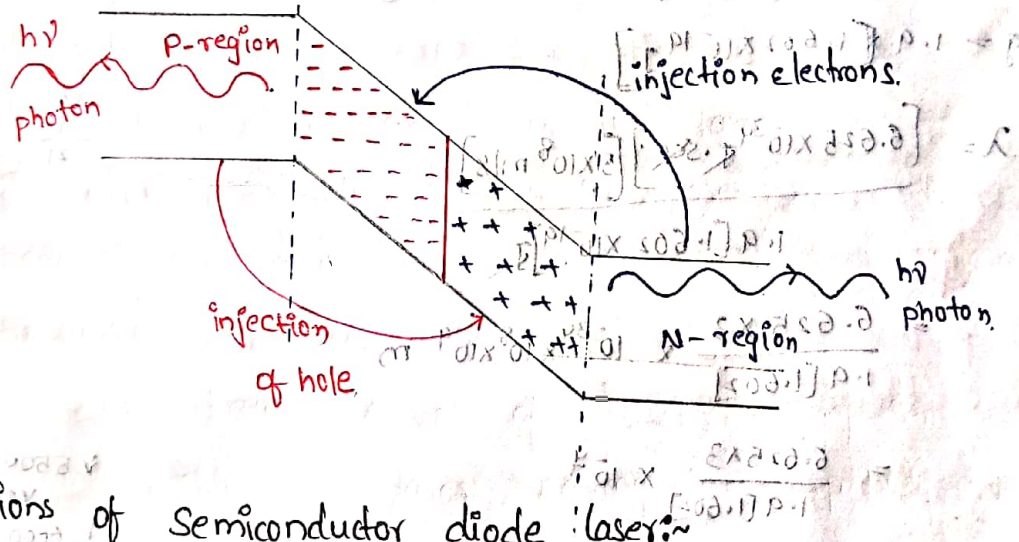
→ under forward biasing condition theire exist a more recombinations. So that more no. of photons are emitted as out put

→ Due to the external voltage the recombination takes place in case of minority charge carriers also.

→ The operation point of Semiconductor laser is controlled by input voltage

→ The intesity of light depend on the input voltage

→ Schematic Reprasentation of Injection of carriers:- [electrons & holes]



Applications of Semiconductor diode laser:-

→ S.C lasers are the chiepest & smallest lasers so that they are employed in various speed fields [S.C lasers occupies less space, small in size so that they are preferable]

→ The light emitted from the semiconductor laser can be used as input for the Optical fibre in modren communication field can be:

→ In Order to launch the light in electronic circuits S.C lasers are used.

→ In Order to Read the data which is in the enolog form (or) in binary form. S.C lasers are used.

→ S.C laser emitts the light in the range of UV region - IR region used in detecting circuits.

→ S.c lasers are employed in computer field.

Problems:- Based on:- $E_g = \frac{hc}{\lambda}$, $E_g = h\nu$

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

*****

Q) A light emitting diode is made up of GaAs p having a band gap of 1.9 eV determine the wavelength & colour of Radiation emitted.

Sol: Given: $E_g = 1.9\,eV$

Let λ be the wave length of emitted hole

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

h planck's constant $h = 6.625 \times 10^{-34}$ J sec

c is the velocity of light $= 3 \times 10^8$ m/s

$E_g = 1.9\,[1.602 \times 10^{-19}\,J]$

$$\lambda = \frac{[6.625 \times 10^{-34}\,J.sec][3 \times 10^8\,m/s]}{1.9\,[1.602 \times 10^{-19}]\,J}$$

$$= \frac{6.625 \times 3}{1.9\,[1.602]} \times 10^{-34} \times 10^8 \times 10^{19}\ m$$

$$= \frac{6.625 \times 3}{1.9\,[1.602]} \times 10^{-7}$$

$\lambda \simeq 6.529 \times 10^{-7}$ m

$1A^\circ = 10^{-10}$ m

$\lambda = 6.529 \times 10^{-7}\,m \times \frac{10^{-3}}{10^{-3}}$

$\lambda = 6.529 \times 10^{3} \times 10^{-10}$

$\lambda = 6.529 \times 10^{3}\,A^\circ = 6529\,A^\circ$

∴ The colour of Radiation (out put of the laser is in red colour)

Q) calculate the wave length of emission from GaAs diode laser, if the band gap in GaAs is 1.44 eV

↓ 5500 to 6000 yellow

↑ 6000 → Red

→ $E_g = 1.44 eV$

$= 144 \times 1.602 \times 10^{-19} J$

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

$\lambda = \frac{6.625 \times 10^{-34} \times 3 \times 10^8}{1.44 \times 1.602 \times 10^{-19}}$

$= \frac{6.625 \times 3}{1.44 \times 1.602} \times 10^{-34+8+19}$

$= 8.6156 \times 10^{-7} m \times \frac{10^{-3}}{10^{-3}} \frac{m}{m}$

$\lambda = 8.6155 \times 10^{-10} \times 10^{+3} m$

$\lambda = 8.6155 \times 10^{3} A^0$

② The In Ga As P diode laser has peak emission wavelength of 1.55 μm. determine its Band Gap.

Soln:- $\lambda = 1.55 \mu m$

$= 1.55 \times 10^{-6} M$

$E_g = hc/\lambda$

$E_g = \frac{6.625 \times 10^{-34} \times 3 \times 10^8}{1.55 \times 10^{-6}}$

$= \frac{6.625 \times 3}{1.55} \times 10^{-34} \times 10^8 \times 10^6$

$= 12.822 \times 10^{-20}$ joules ⟶ (1)

Generally eg was expressed in eV

$1 eV = 1.6023 \times 10^{-19}$ joule

$1 joule = \frac{1}{1.6023 \times 10^{-19}} eV$ ⟶ (2)

$\therefore E_g = 12.822 \times 10^{-20} \times \frac{1}{1.6023 \times 10^{-19}}$

$E_g = 0.8002 eV$

- Semi Conductor photodetectors:-

→ These are the devices that absorb optical energy (light energy) and convert into to electrical energy.

→ The operation of photodetectors is based on the "internal photo electric effect"

characteristics of photodetectors:-

→ The maximum photocurrent flows when each incident photon produces one electron hole pair contributing to the photo current.

→ photo current depends on absorption of photons recombination electron hole pair surface area of the light incidented region

* What is solar cell? write a note on construction and working of Solar cell ?. what are the V-I characteristics. and applications of Solar cell?

The cell which converts light energy into electrical energy is known as "Solar cell"

→ Solar cell is also known as "photo voltaic cell", which converts solar energy into electrical energy.

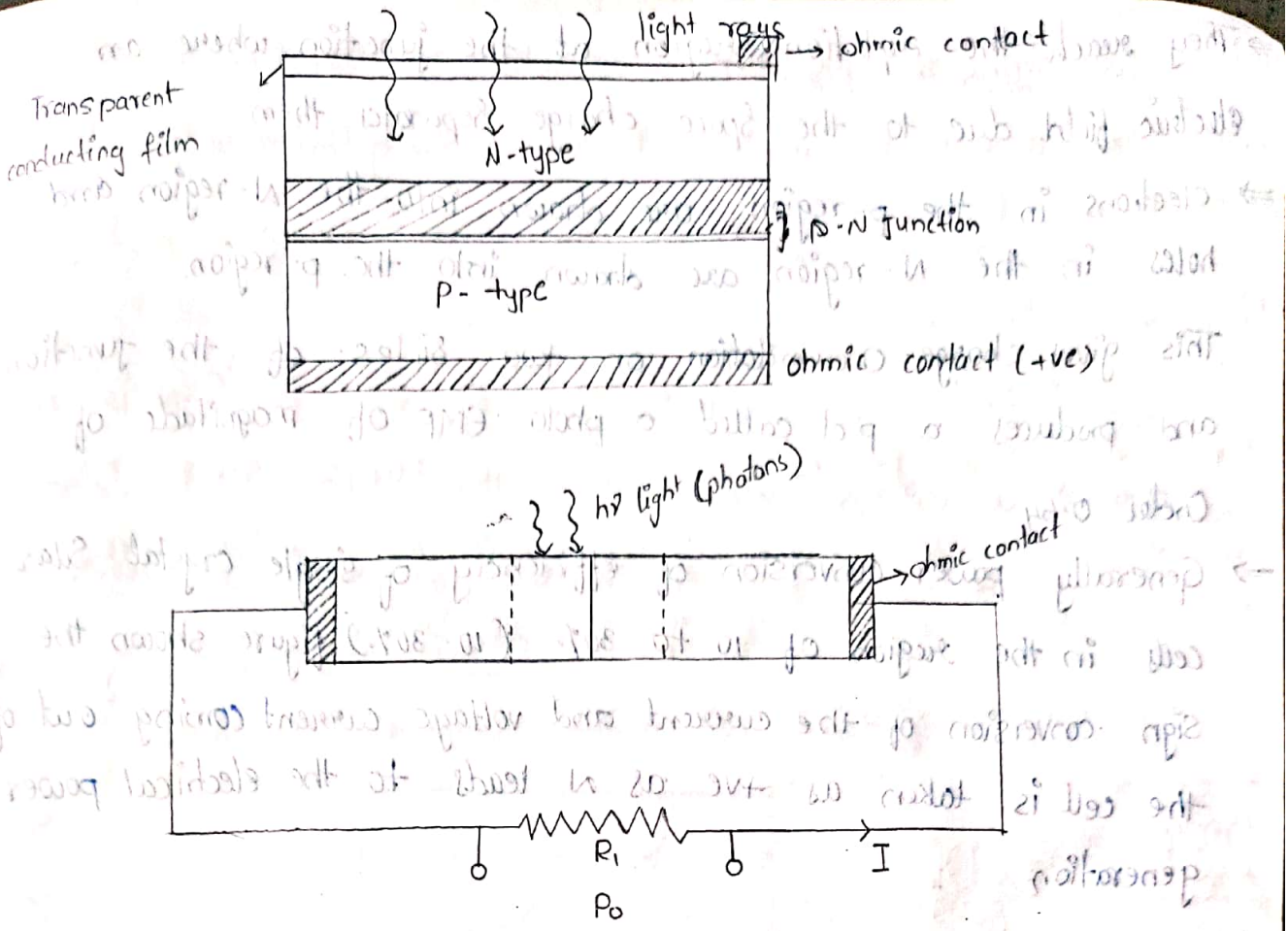
→ History of solar cell:.

→ In 1839, "Edmond Becquere" french scientist built the words first Solar cell based on photo voltaic effect.

construction:-

⇒ with the help of p-type and N-type layers prepared from a Si (or) Ge are fabricated into a solar cell;

⇒ By attacting the ohmic contacts to p-type and n-type layers Solar cell was constructed.



⇒ The skematic diagram of solar cell is shown in the above figure. It consists p-type chip and which a thin layers of N-type material is grown by diffusion method.

Note:-

⇒ P-layers prepared with dopant atoms Boron atoms added to Si crystal water.

⇒ N- type layer was prepared by adding phosphorous atoms to Si- crystal water.

Working:-

⇒ It consists of a p-type chip on which a thin layer of N-type material is grown

→ when the solar radiation is incidented on the cell electron hole pairs are generated in the N & P region

⇒ They reach the depletion region at the junction where an electric field due to the space charge separates them.

⇒ Electrons in the p-region are drawn into the N-region and holes in the N-region are drawn into the p-region.

This gives charge accumulation on two sides of the junction and produces a p.d called a photo EMF of magnitude of order 0.54

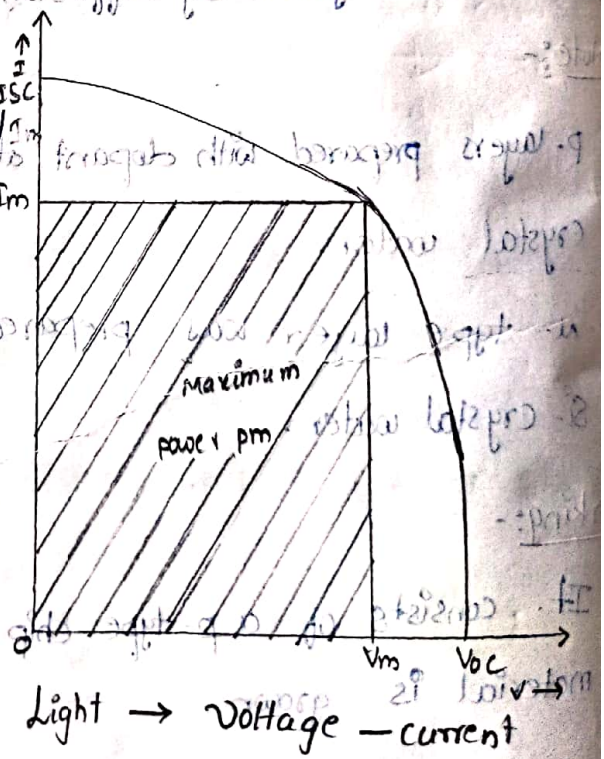
⇒ Generally power conversion of efficiency of single crystal solar cells in the region of 10 to 30%. (10-30%) figure shows the sign conversion of the current and voltage current coming out of the cell is taken as +ve as N leads to the electrical power generation

⇒ The power generator depends on solar cell itself and the load connected to it.

V-I characteristics of Solar cells:-

* The open circuit voltage across the illuminated cell at zero current and the short circuit current (I_{sc}) is the current through the illuminated cell if the voltage across the cell is zero.

* The short circuit current is close to the photocurrent while the open circuit voltage is close to the turn on voltage of the diode.



Light → voltage – current

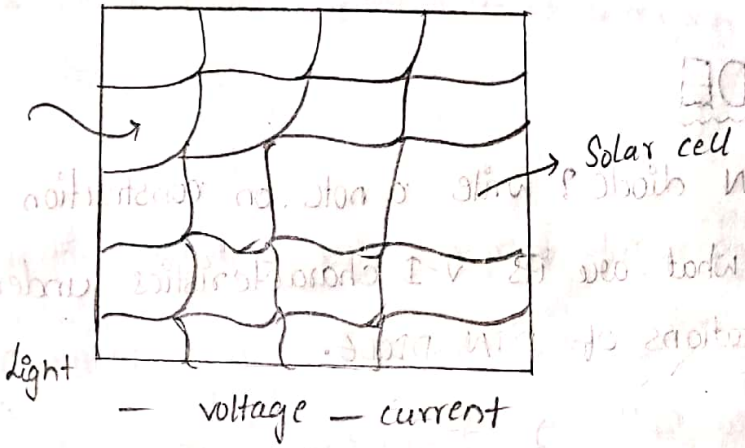
* The maximum power is attained at Vm (maximum voltage) with Im (maximum power)

Maximum power · $P_m = I_m \cdot V_m$ —— (1)

$P = IV$

* Solar cell can be connected in parallel (or) series into solar pannels. which can delives power output of several kilowatts.
* conversion efficiency of solar cell is defined as

$$\eta = \frac{\text{electrical power delivered}}{\text{Solar power received (or) (incident)}}$$



Note :-

Single crystal Solar cell has efficiency of 30% only.

Applications of Solar cell in various fields :-

a) Industrial applications :-

cathode protection to prevent corossion of pipelines.

b) Space applications :

Solar cells are used in satellites and space vehicles to supply to electronic and charge storage batteries.

c) Ocean navigation aids :-

Number of light houses are powered by Solar cells.

d) Teli communication Systems:-

Radio trans receivers on - Mountain tops. (or) telephone boxes are powered by Solar cells.

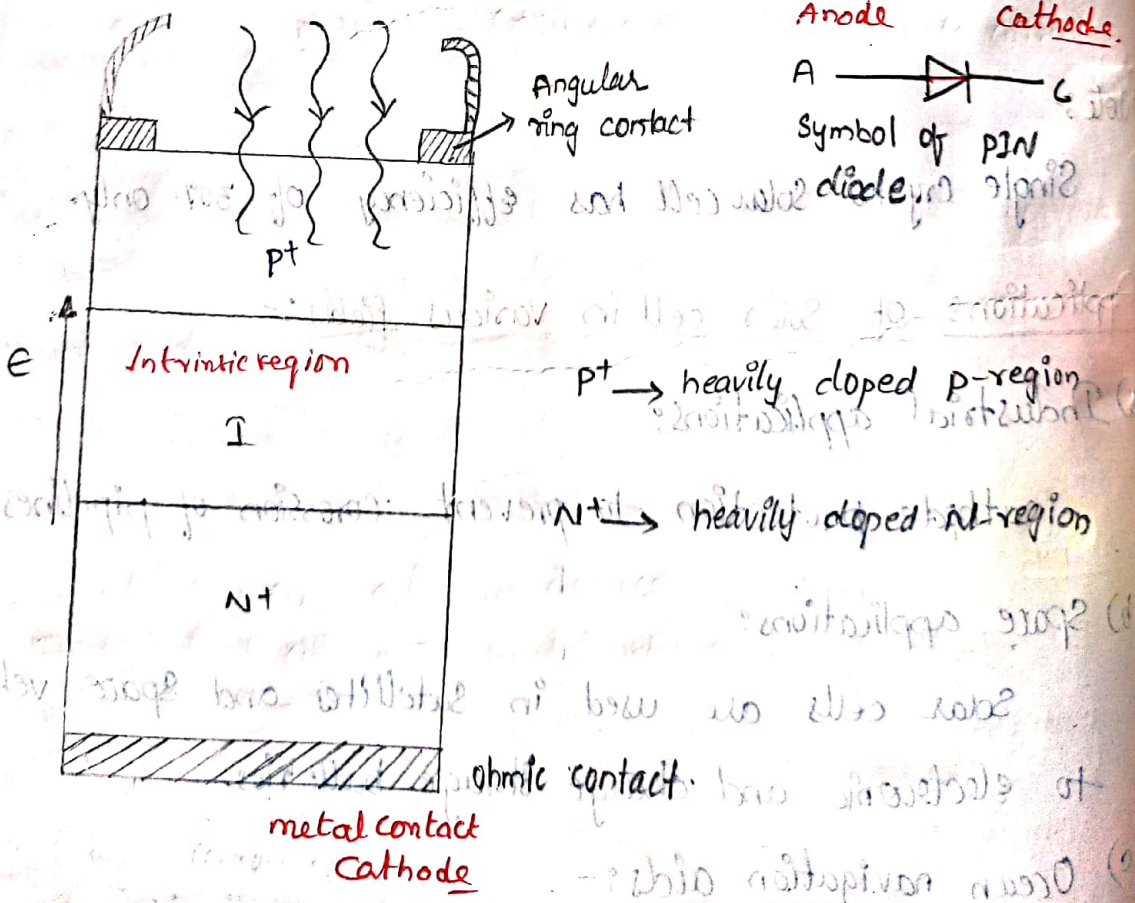
e) Social applications:-

-electrical power to the remoted villages was provided with the help of solar pannels (pv power water pumps, PV powered refrigerators, washing machines) Solar cells are used to supply the power to the calculators to the wrist watches.

Solar cells are used to provide commercial electricity.

PIN DIODE

What is PIN diode? write a note on construction and working of PIN diode what are its V-I characteristics under biasing condition write the applications of PIN DIODE.



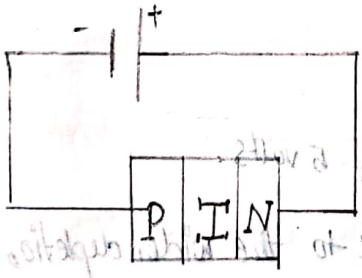
* PIN diode is known as positive intrinsic negative diode.
* It consists of P & N regions separates by a intrinsic region
* P & N regions are heavily doped because they are used used for ohmic contact attachment and intrinsic region is very lightly doped.
* PIN diodes are usually made up of silicon (Gallium Arsendine is also to be used)
* PIN diode structure is planes structure in this structure epitoxial film as grown on substrate material and p+ region is introduced by diffusion method.

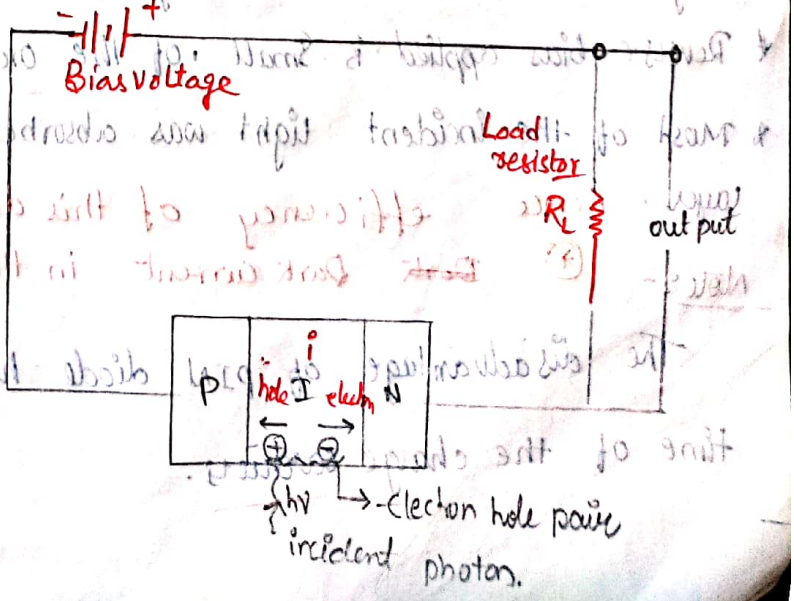
Note:-

Thickness of the intrinsic layer is about 10 microns - 200 microns.

Working of PIN Diode:-

It works under reverse biasing condition (p-region is connected to -ve terminal & n-region was connected to +ve terminal)





* The light is allowed to incident on intrinsic region then eletron hole pairs are created in the depleted intrinsic region.
* The high electric field in the depletion region causes the free carriers to seperate and move across the reverse bias junction
* This gives rise to a current flow in the external circuit.

V-I characteristics:-

* There exists a reverse break down voltage due to intrinsic layer
* There exist a low level of capacitance when it is in forward bias
* There exists a low level of carries storage in forward bias
* Under reverse biasing condition there exists a greater seperation b/w PN regions.

Applications:-

* Used as high voltage rectifies (due to intrinsic region it is possible)
* PN diode makes an Ideal RF Switch (Radio frequency Switch.
* It can be used as photo detactor. (Conversion of Light into current)

Advantages:-

* Reverse bias need not be varied to change the width of the depletion layer.
* High reverse breakdown voltage.
* Reverse bias applied is small, of the order of 5 volts.
* Most of the incident light was absorbed due to the widen depletion layer. hence efficiency of this device is high

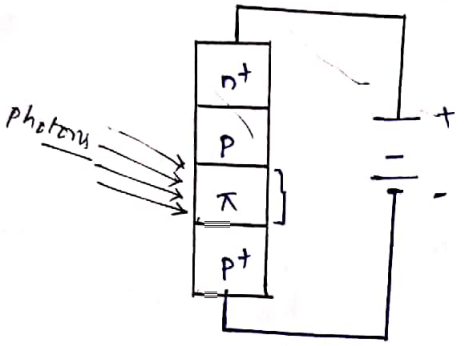
Note:- (*) ~~Dark~~ Dark current in this device is smaller.

The disadvantage of PIN diode high reverse recovering time of the charge carriers.

Avalanch photodiode (APD):-

⇒ The number of carriers multiplies in Geometrical progression and this phenamenon is called Avalanch effect. It has been absorved in case Avalanch photo Diode

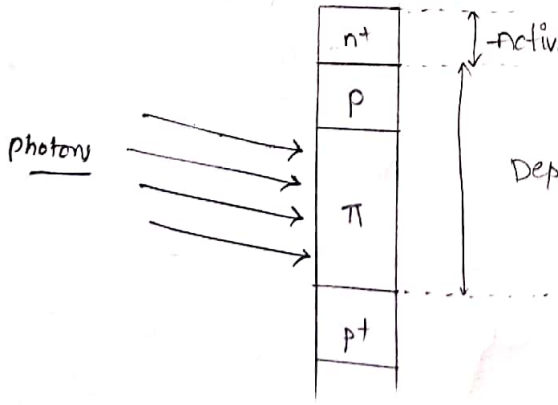
⇒ Avalanch → Suddenly more no. of charge carriers released, it is in Riverse Biased.



APD:- Ap D is highly sensitive Semiconductor electronic device that Exploiseds the photo electric effect to convert light into electricity thought of as photodetector that provide a built in - first stage of gain through avalanche multiplication.

Structure and Construction of APD:-

It has p^+ π p n^+ configuration of different layers



p^+ ~ heavily doped p region.

→ π region very lightly doped region (It can be an n-type material made of low resistance contact)

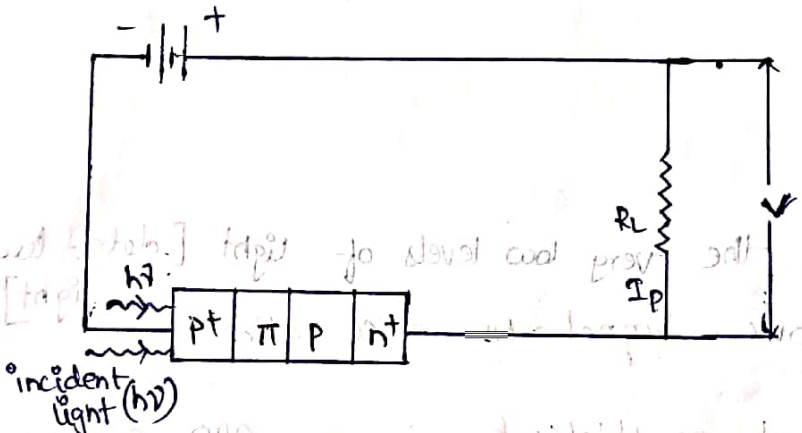
→ n^+ region heavily doped n- region.

The materials used for the preparation of APD is Si, Ge, crystal & III - V group compounds

→ The device is essentially reverse Biased p-N Junction

→ The π region is very lightly doped and hence is nearly intrinsic. Most of the incident light passes into intrinsic region through the p^+ region so that electron hole pairs are Generated in the intrinsic region. (π-region)

Working:-

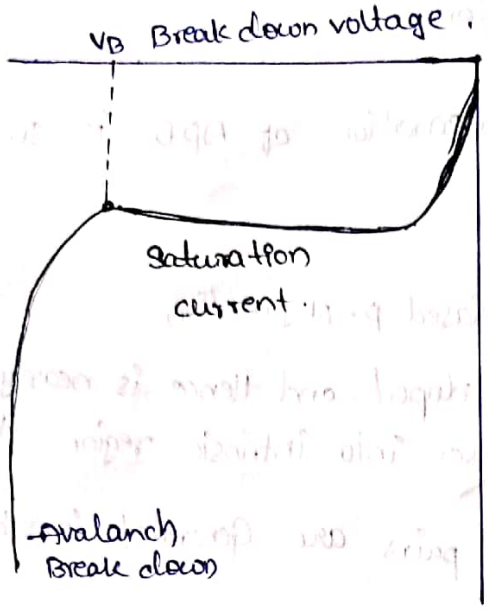


→ In the RB most of the applied voltage drops across the $p\pi n^+$ region (Junction). By increasing the Reverse Bias voltage the depletion region across this junction widens. [width increases]

→ In this condition the internal field intensity near the junction becomes very high and the junction approches the Break down condition. therefore electrons & holes Generated in the depletion layer. they acquire Sufficient energy from the field to liberate secondary electrons & holes. with in the layer by a process of impact ionization.

→ The newly generated carriers also accelerated by the high electric field, thus gaining enough energy to cause further impact ionisation.

V-I characteristics:-



→ Their exist a sudden change in the current after the Break down voltage

→ The sudden change in the current is due to liberation of more no. of electron hole pairs

Application of APD:-

1) photo detector

2) It is used to identify the very low levels of light [detect low level of light]

(3) APD can improve Signal-to-noise ratio

Increasing avalanch multiplication in an APD can improve the signal-to-noise ratio (S/N R) of an optical receiver as long as the APD noise is less than the preamplifier noise floor.