UNIT-V

Special purpose Devices

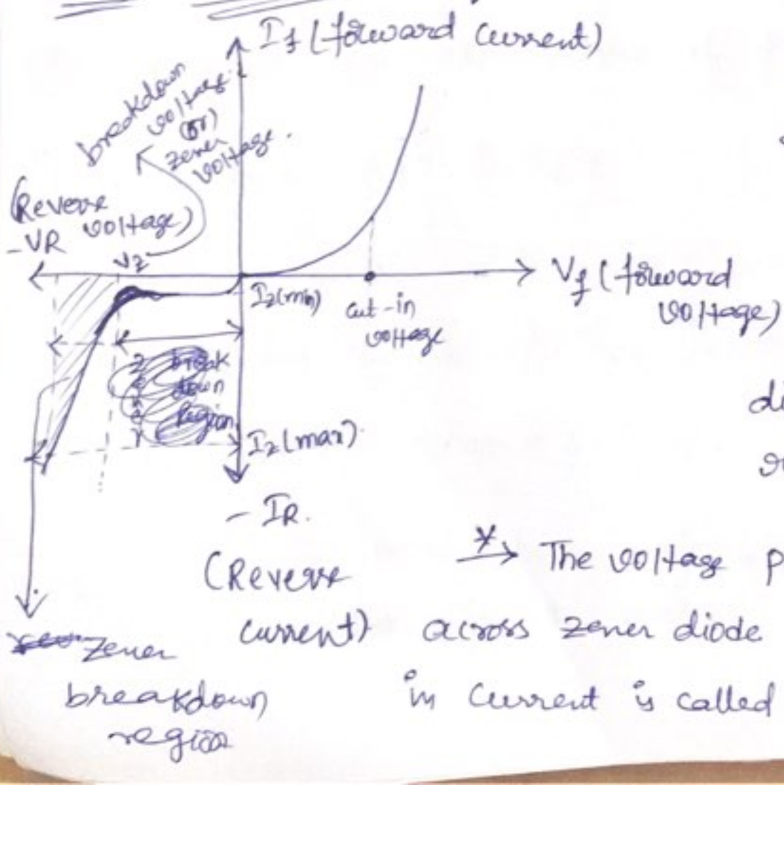
Zener diode: A special purpose, PN junction semiconductor device, which is designed to operate in reverse breakdown region is said to be "Zener diode".

→ Zener diode is heavily doped when compared with PN junction diode.

Symbol :- Anode Cathode.

→ electric current in zener diode flows both from Anode & Cathode

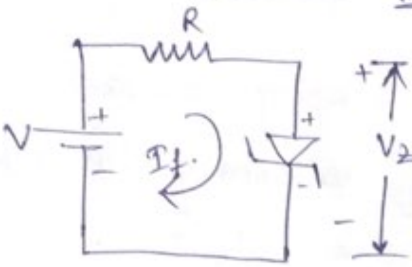
V-I characteristics of zener diode :-



→ Zener diode functions like a PN junction diode when forward biased and behaves differently when reverse biased.

*→ The voltage point at which voltage drop across zener diode is const & there is rise in current is called "Zener voltage V_Z".

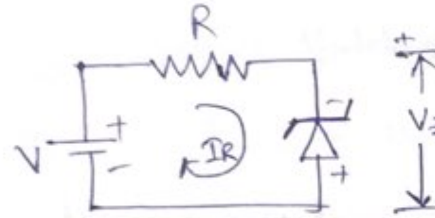
Case (1): forward biasing of Zener diode :-



→ Zerener diode is forward biased by connecting anode of Zener diode to (+ve) terminal of battery and cathode to (-ve) terminal.

→ Forward biased Zener diode behaves like forward biased PN junction diode.

Case (2): Reverse biased Zener diode :-



→ Zenere diode is reverse biased by connecting Anode to (-ve) terminal & cathode to (+ve) terminal of battery.

→ When reverse bias voltage is applied to zener diode, only a small amount of current flows through diode, untill the Zenere voltage (V_z).

→ When reverse bias voltage reaches to zener voltage, then it allows large amount of current to flow through it.

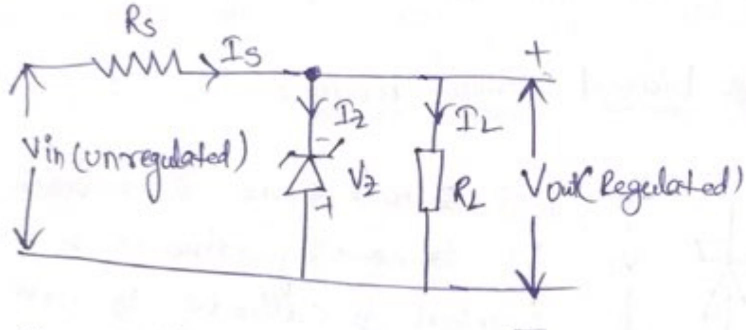
→ At this point. small variation in reverse bias voltage causes ~~large amo~~ sudden increase in current

→ A breakdown known as "Zener breakdown" occurs as a result of this sudden increase in current. The reverse current must be in b/w $I_z(min)$ & $I_z(max)$ to operate zener diode in breakdown Region.

Zener diode as a voltage Regulator :-

Voltage Regulation :- The process of keeping constant voltage across the load regardless of variation of i/p voltage (or) load current is called "voltage regulation".

→ Zener diode has the ability to maintain constant voltage across load.



→ Zener diode is always reverse biased w.r.t input voltage V_{in}

→ The Resistance R_S (Series resistor (or) Current limiting resistor) is used to limit reverse current through Zener diode.

→ Vin & Rs are selected in such a way that diode should operate in "breakdown region".

→ voltage across diode in breakdown region is called as Zener voltage V_Z, and $\boxed{V_Z = V_{out}}$

→ if $V_{out} < V_Z$ then diode doesn't conduct and hence $I_L = I_S$. ($I_Z = 0$)

→ if $V_O \geq V_Z$ then diode starts conducting

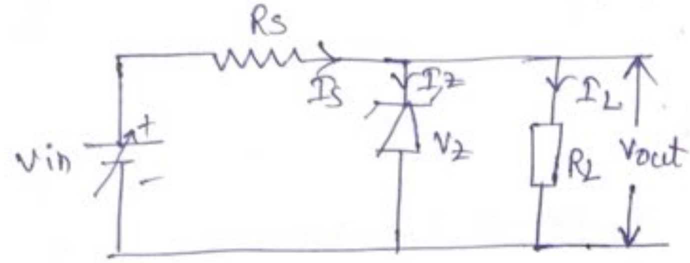
$I_S = I_Z + I_L$.

→ zener diode as voltage regulator is explained in following two cases.

(1) Regulation with varying input voltage V_{in}

(2) Regulation with varying load resistance R_L.

Case (1) : Regulation with varying input voltage V_{in}.



$I_S = I_Z + I_L$ rough

$\boxed{5 = 3 + 2}$

$6 = 4 + 2$

$4 = 2 + 2$.

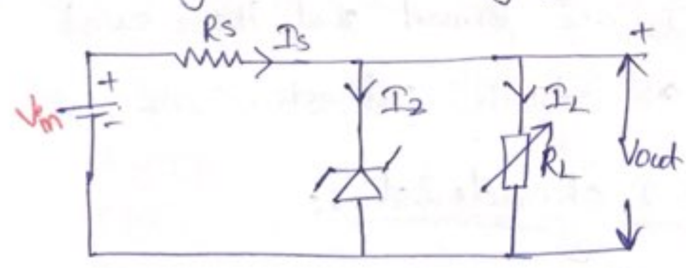
→ As i/p voltage increases. i/p current I_S also increases.

→ This increases the current through zener diode. I_Z without affecting I_L, There by keeping Vout constant.

→ As i/p voltage decreases, i/p current I_S also decreases.

→ This decreases the I_Z without affecting I_L, there by keeping Vout constant.

Case (2): Regulation with varying load resistance R_L.



$I_S = I_Z + I_L$ rough.

$5 = 3 + 2$

if $I_L \uparrow \Rightarrow 5 = 2 + 3$

if $I_L \downarrow \Rightarrow 5 = 4 + 1$

→ if R_L increases then I_L decreases,

→ This increases I_Z, as a result the i/p current I_S remains constant, Thereby keeping Vout constant.

→ If R_L decreases then I_L increases,

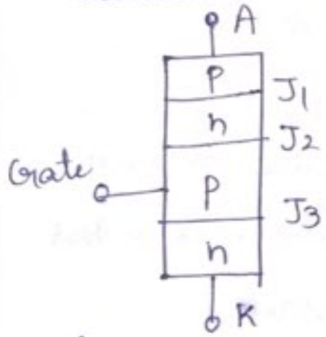
→ This decreases I_Z, as a result the i/p current I_S remains constant, Thereby keeping Vout constant.

SCR : (silicon Controlled Rectifier)

→ SCR belongs to Thyristor family.

Definition : A silicon semiconductor device with 3 junctions, which can convert AC signal into pulsating DC signal, and can controll the amount of signal to be ~~controlled~~ Converted is known as "SCR".

Construction & symbol :



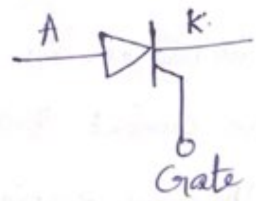


fig: Constructional structure

→ It is Constructed using two P-type & two n-type semiconductors, which are arranged as shown in above fig

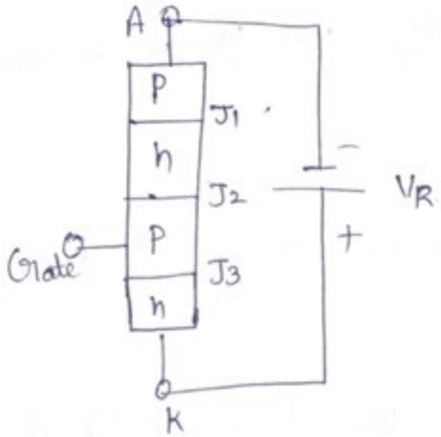
→ As there are 4 layers of semiconductors, 3 junctions named as J_1, J_2, J_3 are formed, and there exist 3 terminals named as Anode, cathode, Gate.

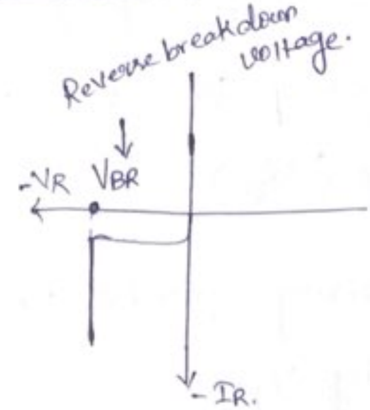
Working principle & V-I characteristics:

→ There are 3 modes of operations for SCR

1. Reverse blocking mode.
2. forward blocking mode
3. forward Conduction mode.

① **Reverse blocking mode :** SCR is operated in Reverse blocking mode by providing negative voltage across Anode & Cathode





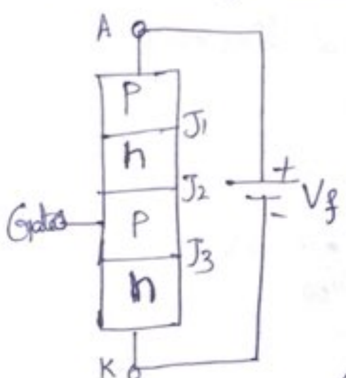
→ It is observed that, in this mode J_1 is Reverse based, J_2 is forward biased, J_3 is Reverse biased.

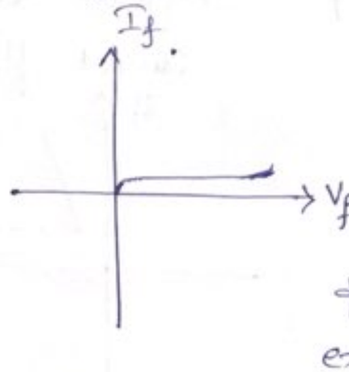
→ As J_1 & J_3 are reverse biased, there exist a small leakage current called " reverse leakage current."

→ If (-ve) voltage is further increased then J_1 & J_3 junctio breakdown and hence current increases rapidly.

→ The (-ve) voltage at which J_1 & J_3 junctions breakdown and current rises rapidly is known as " Reverse breakdow voltage (V_{BR})". → It is considered as OFF mode of SCR.

② **Forward blocking mode :-** SCR is operated in forward blocking mode by providing positive voltage across anode & cathode.





→ J_1, J_3 are forward biased and J_2 is reverse biased.

→ As J_1, J_3 are forward biased there exist a small amount of Current called "forward leakage current".

→ This mode is considered as OFF mode of SCR

③ Forward conduction mode: SCR can be operated in forward conduction mode by following any of these two ways

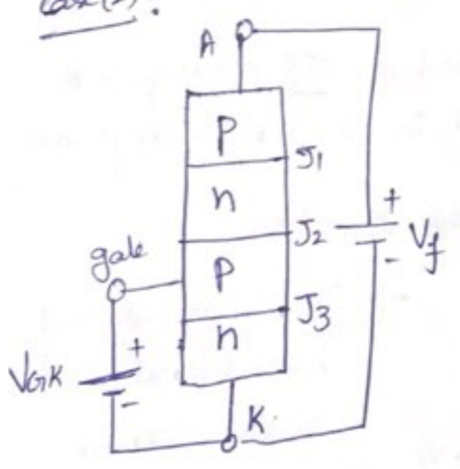
Case(1) ① By increasing forward voltage V_f till forward breakover voltage (V_{BO}).

Case(2) ② By proving positive voltage b/w gate & cathode by retaining V_f.

Case(1):
forward breakover voltage: The forward voltage V_f at which J_2 junction breaksdown and SCR changes its state from OFF to ON is called "forward breakover (V_{BO}) voltage".

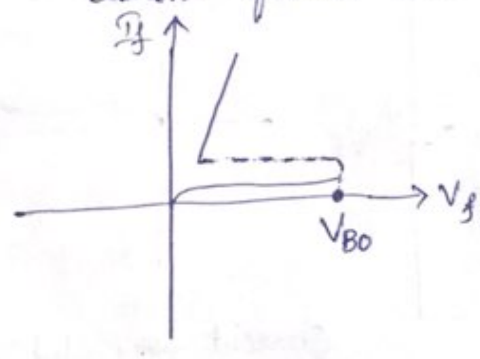
→ At forward breakover voltage SCR goes from forward blocking mode to forward conduction mode.

Case(2):



→ By applying (+ve) V_{GK} along with (+ve) V_f, all junctions J_1, J_2, J_3 are forward biased.

→ Hence SCR turns ON and current flows linearly.



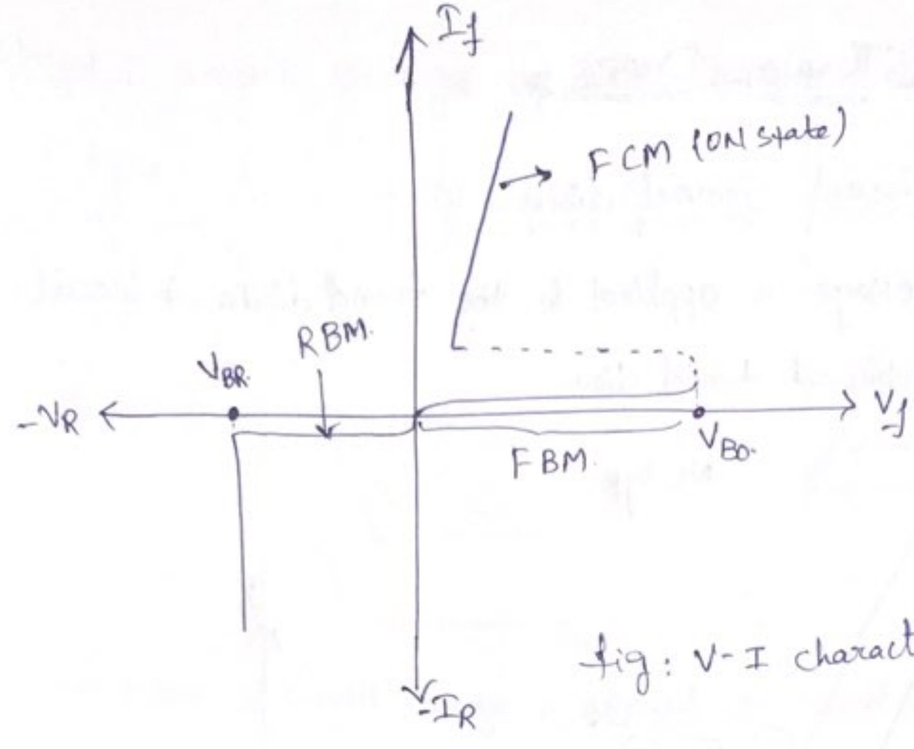
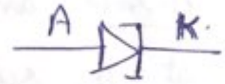


fig: V-I characteristics of SCR

Tunnel diode :- It is a heavily doped pn-junction diode in which electric current decreases as the voltage increases. i.e it exhibits "negative Resistance" in a certain Region when it is forward biased.

→ A tunnel diod is also known as "ESAKI DIODE"

→ ~~Tunnel diode has a PN junction~~ Symbol : 

→ The heavily doped PN junction is almost 1000 time greater than in normal diode.

→ Tunnel diode is used as a very fast switching device in

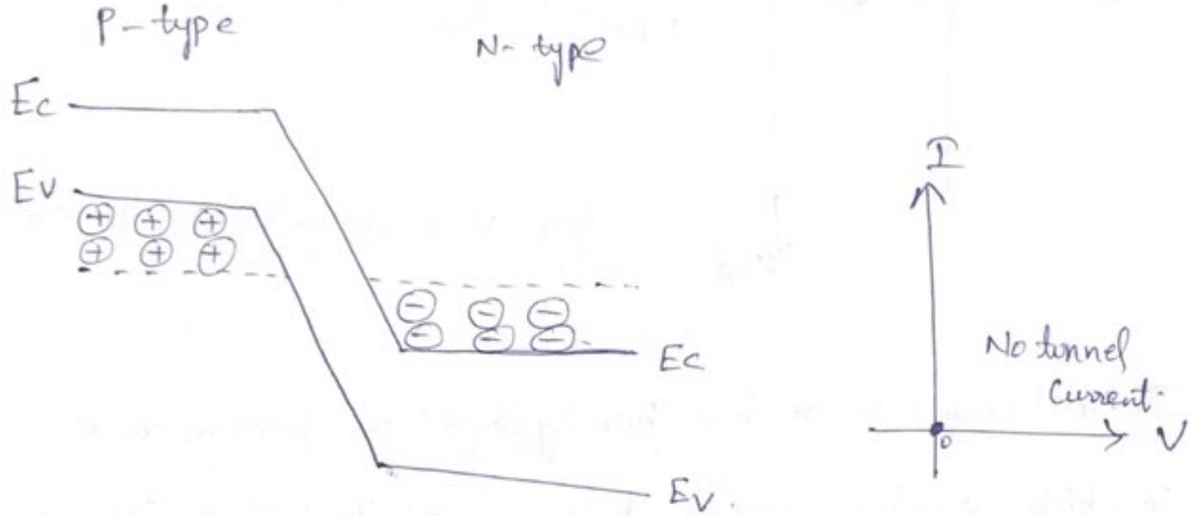
Tunneling effect(or) Tunneling:

→ As tunnel diode is heavily doped, depletion layer width is of very small. Thus conduction band of n-type & valence band of p-type overlaps. As a result for a small applied voltage es of n-type conduction band tunnel to p-type valence band. This is called "Tunneling".

WORKING OF TUNNEL DIODE:

Step 1: unbiased tunnel diode:

When no voltage is applied to the tunnel diode, it is said to be an unbiased tunnel diode.



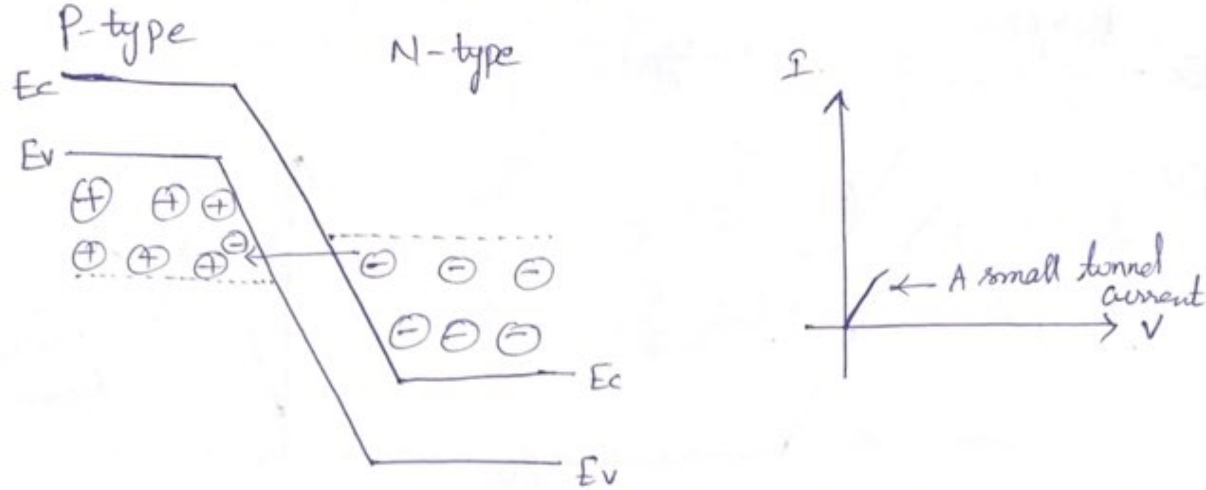
→ In tunnel diode, the conduction band of n-type sc overlaps with valence band of p-type sc due to heavy doping.

→ Because of this overlapping the conduction band electrons at n-side and valence band holes at p-side are nearly at the same energy level

→ So some $\bar{e}$s tunnel from conduction band of n-side to valence band of p-side. Illy holes tunnel from valence band of p-side to conduction band of n-side.

→ Hence the net current flow is zero, as equal no: of $\bar{e}$s & holes flow in opposite direction.

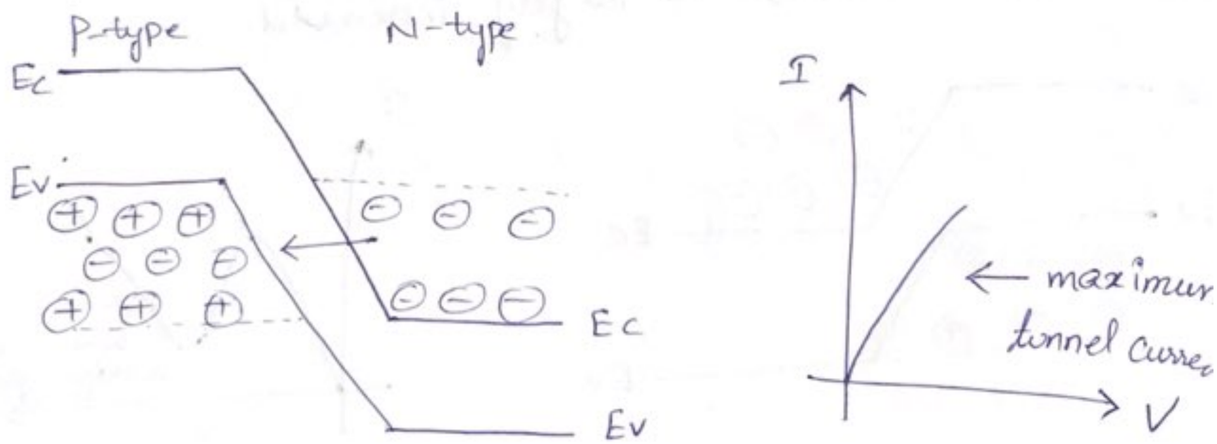
Step2: small voltage applied to tunnel diode.



→ When a small voltage is applied to tunnel diode, a sma
no: of ēs in conduction band of n-type will tunnel to valenc
band in p-type

→ Hence a small amount of tunnel current starts flowing

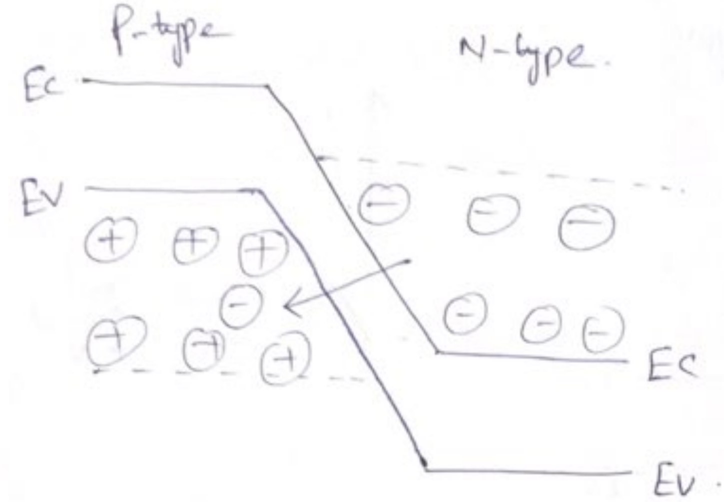
Step3: Applied voltage is slightly increased

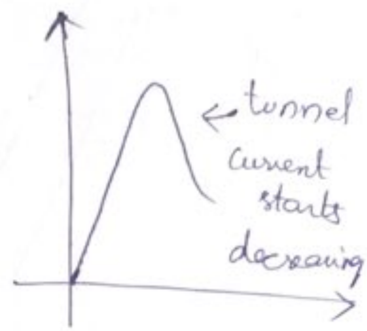


→ When applied voltage is increased, a large no: of
free electrons at n-side conduction band tunnel to vale
band in p-type. As a result maximum tunnel curre
flows.

→ energy level of n-side conduction band =
energy " " p-side valence band.

Step4: Applied voltage is further increased.

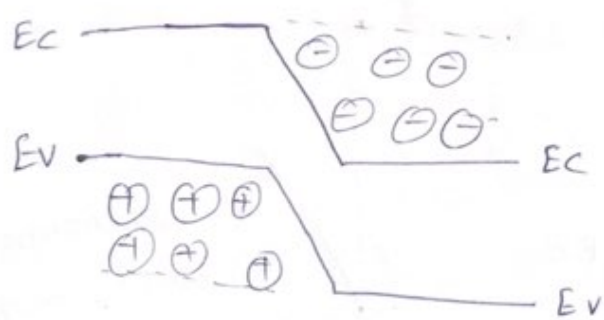


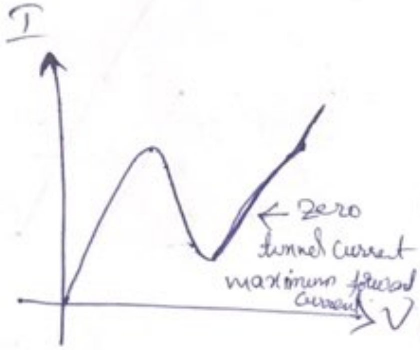


→ If the applied voltage is further increased, a slight misalignment of conduction band and valence band takes place.

→ Very few $\bar{e}$s tunnel from n-type conduction band to P-type valence band. Thus, the tunneling current starts decreasing.

Step5: Applied voltage is largely increased.

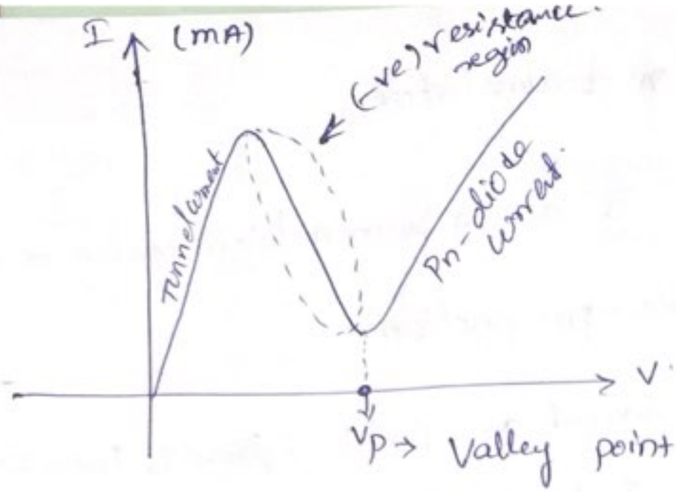




→ If applied voltage is largely increased then tunneling current drops to zero.

→ At this point, the conduction band & valence band no longer overlap and tunnel diode operates same as p-n diode.

V-I Characteristics



→ The region in which current decreases with increase in voltage is called "(-ve) resistance region".

→ The voltage at which tunnel current drops to zero is called " valley point " voltage.

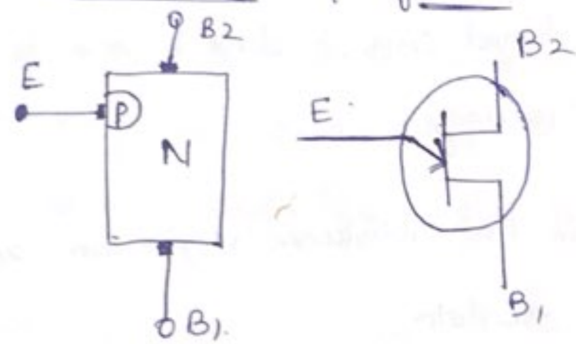
→ Tunnel diode operating in (-ve) resistance region can act as an amplifier (or) an oscillator.

UJT : uni junction transistor

Definition: It is a 3 terminal semiconductor device, which as only one pn-junction.

* 3 terminals are named as Emitter, base 1, base 2.
* As it has only 1 junction, it is called as "unijunction transistor".

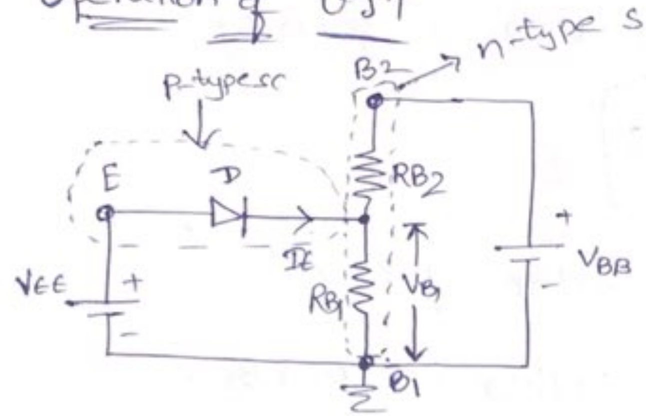
Construction & symbol



→ UJT is constructed with a bare substrate of n-type semiconductor, into which heavily doped p-type sc is diffused closed to base 2.

→ Arrow mark on Emitter terminal indicates that, maximum amount of Current flows from emitter towards base 1 terminal.

Operation of UJT



Case(1): with emitter terminal open.

→ if $V_{EE} = 0$ and if V_{B1} reverse bias the diode then $I_E = 0$.

→ But due to minority carriers, there is a small leaka[ge] current flowing from B_2 to E.

Case(2): When a (+ve) V_{EE} is applied to Emitter:-

→ If V_{EE} is applied in such away that, it should be more than cut-in voltage of diode as well as voltage across RB_1 (V_{B1}), then diode D is forward biased.

→ When diode is forward biased, emitter injects holes into n-type sc bar.

→ These holes are repelled by B_2 (as RB_2 is provided w[ith] (+ve) voltage) and are attracted by B_1. (as RB_1 is provided with (-ve) voltage).

→ Hence there exist large amount of Curren[t] flow from Emitter towards base 1 (B_1). As a result RB_1 reduces,

→ UJT is limited by V_E

→ peak voltage (V_P) of UJT is given by

$$\boxed{V_P = \eta V_{BB} + V_D}$$

V_D → cut-in voltage of diode.

V_{BB} → Applied voltage b/w B_1 & B_2.

** η → intrinsic stand-off ratio

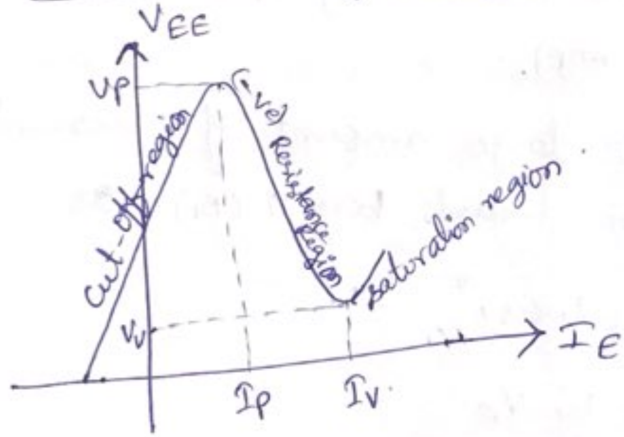
$$\eta = \frac{R_{B1}}{R_{B1}+R_{B2}} \simeq 0.5 \text{ to } 0.75$$

$$V_{BB} = \frac{V_{B1}}{\eta}$$

Case(3): When (-ve) voltage is applied to Emitter.

→ Diode is reverse biased and hence UJT is in off condition.

Characteristics of UJT:-



V_V → valley point.

Cut-off Region:

for $V_{EE} < V_P$,

Emitter is reverse biased and hence there will be small leakage current.

→ practically UJT is in OFF state.

→ This region is known as Cut-off region.

(−ve) Resistance Region :-

if $V_{EE} > V_P$, then diode is forward biased.

→ It increases I_E and decreases R_{B1} there by decreasing V_{EE}.

$$I_E \propto \frac{1}{R_{B1}} \Rightarrow \text{Negative resistance.}$$

[from $V = IR$, if $R\downarrow$, then $V\downarrow$,
Rough so $V_E \downarrow$ es with $\downarrow$ in R_{B1}].

→ The Region in which I_E increases with decrease in V_{EE} is called (−ve) Resistance Region

saturation Region

→ The region after valley point is called saturation region.

Varactor diode :

→ Varactor diode is originated from Variable capacitor

→ The pn-junction diode which operates only in reverse bias, and whose capacitance can varied w.r.t reverse bias voltage is called as "Varactor diode".

→ It is also called as Varicap diode, Tuning diode, Variable reactance diode, Variable Capacitance diode.

→ symbol : 

→ junction capacitance $C_j = C_0\left[1+\frac{V_R}{V_B}\right]^{-n} = \frac{C_0}{\left[1+\frac{V_R}{V_B}\right]^{n}}$

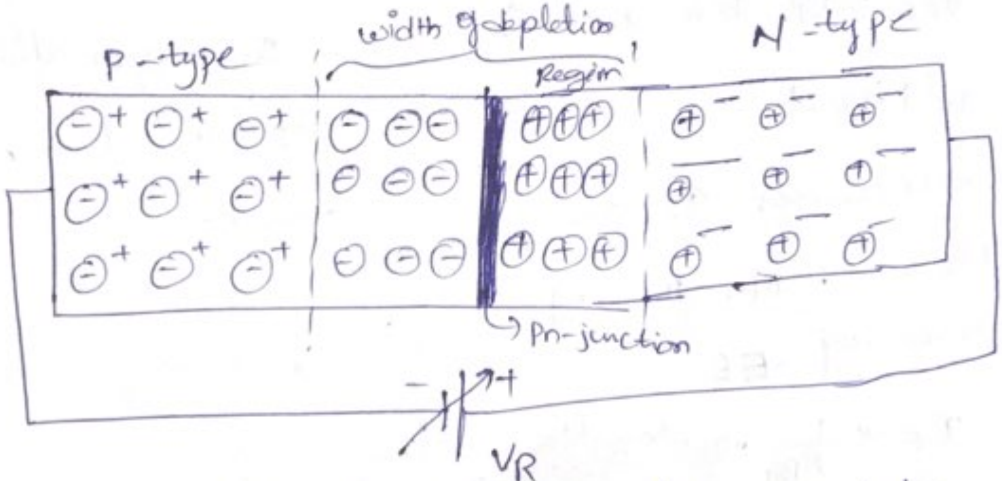
C_0 → capacitance at zero biasing.

V_R → Reverse bias voltage

V_B → barrier voltage

$$C_j \propto \frac{1}{V_R}$$

Working principle (or) principle of operation:



→ When reverse bias is applied to a diode, then holes from p-side & electrons from n-side move away from the junction

→ This process increases the width of the depletion region.

→ Depletion region acts as an insulator (or) dielectric material.

→ Width of depletion region is controlled by reverse bias voltage.

→ Thus the diode is used as a ~~variab~~ voltage variable capacitor.

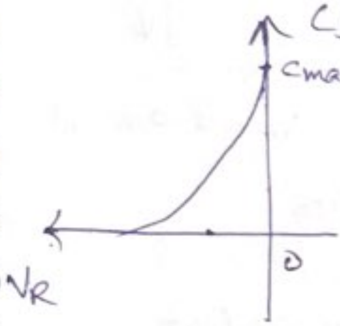
→ WKT, junction capacitance

$$C_j = \frac{C_0}{\left[1 + \frac{V_R}{V_B}\right]^n}$$

$$C_j \propto \frac{1}{V_R}$$

→ If reverse voltage increases then depletion region width increases which reduces the capacitance

→ Thus reverse voltage must be maintained at minimum value to have maximum capacitance.



→ Graph depicts that if reverse voltage increases then junction capacitance decreases.

Photo diode :- A pn junction semiconductor device that consumes light energy to generate electric current is termed as "Photo diode".

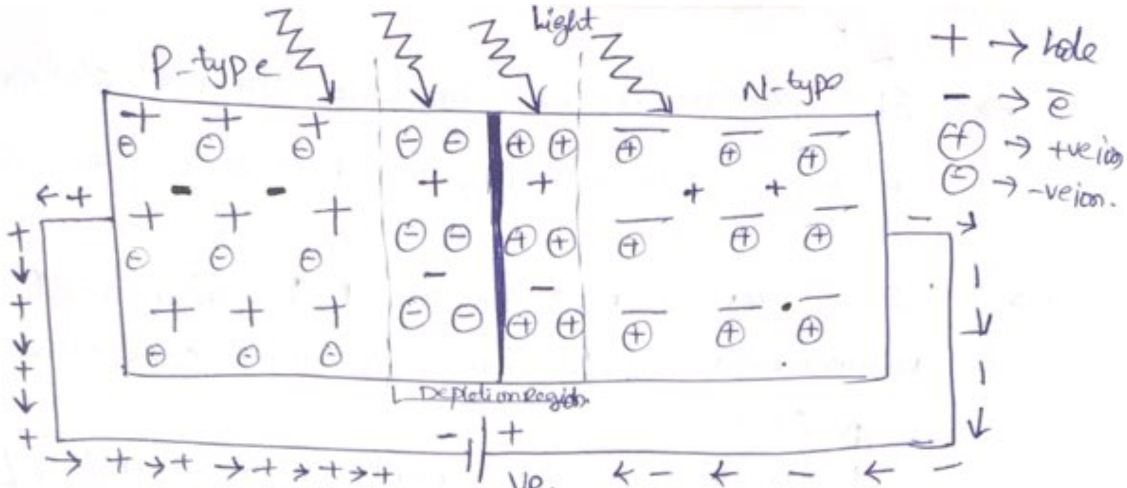
→ It is also called as photo detector, photo-sensor, light detector.

→ Symbol : 

→ Arrow marks represent light (or) photons.

Working principle (or) principle of operation :-

→ Photodiodes are specially designed to operate in reverse bias condition.



→ A normal pn-junction diode allows small amount of current under reverse bias condition.

→ To increase current in reverse bias condition, we need to generate more minority carriers.

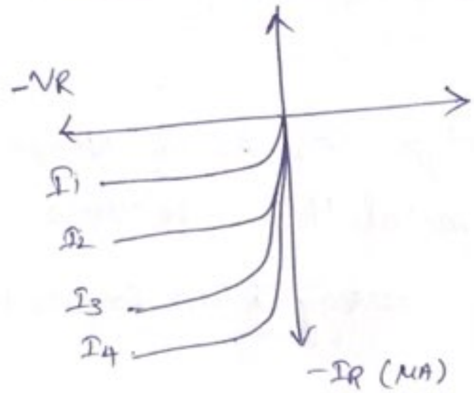
→ Applied reverse voltage supply energy to minority charge carriers but not increase the no: of minority charge carriers.

** → To overcome this problem, we need to apply external energy directly to depletion region to generate more charge carriers

** → Photo diode is designed to generate more no: of charge carriers in depletion region.

** → In photo diodes, we use light (or) photons as external energy to generate charge carriers in depletion region

V-I characteristics



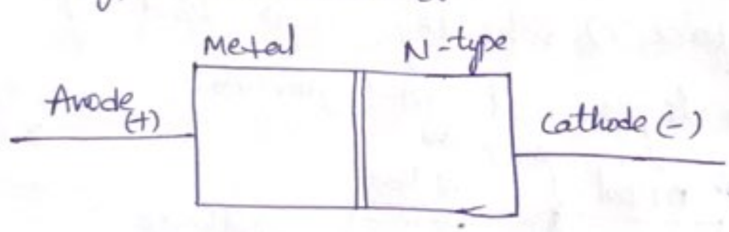
$I_4 > I_3 > I_2 > I_1$.

Schottkey Diode :- It is a metal-semiconductor junction diode that has less forward voltage drop than P-N junction diode and can be used in high-speed-switching applications

→ It is also called as surface barrier diode, hot-electron diode, hot carrier diode.

Symbol :

Construction & operation :- In the construction of schottkey a Metal-Semiconductor (m-s) junction is formed b/w a metal & an n-type semiconductor.



Case(1): No biasing.

→ Both in metal & N-type sc the majority charge carriers are electrons

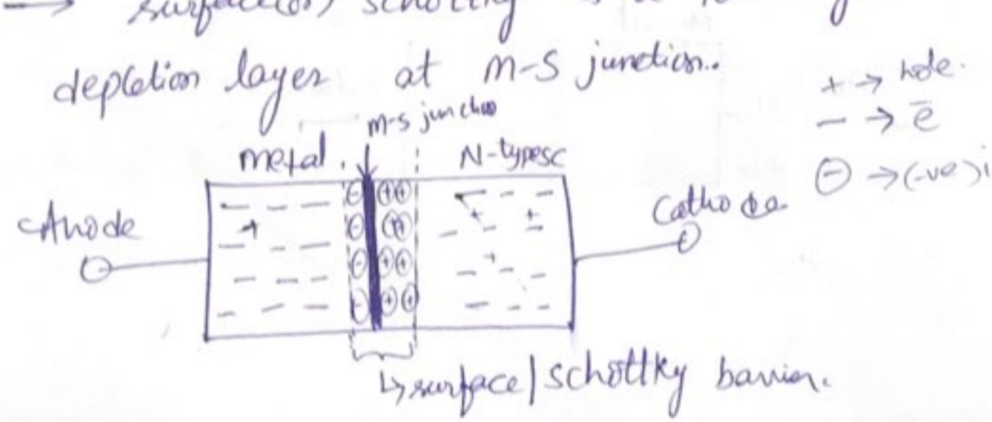
→ When metal is joined with N-type sc, $\bar{e}$s of N-type sc start moving towards the metal, this is because $\bar{e}$s of N-type sc have more energy when compared with $\bar{e}$s of metal.

→ Thus these injected $\bar{e}$s are called as hot carriers and hence it is also called as hot carrier diode (or) hot $\bar{e}$s diode

→ In schottky diode the flow of current is due to majority carriers ($\bar{e}$s) hence schottky diode is a unipolar device.

→ Heavy flow of $\bar{e}$s into metal creates a region near the M-S junction. And this region contains -ve ions on metal side & more (+ve) ions on N-type sc. And it is called as surface barrier (or) schottky barrier.

→ surface (or) schottky is a kind of depletion layer at M-S junction.



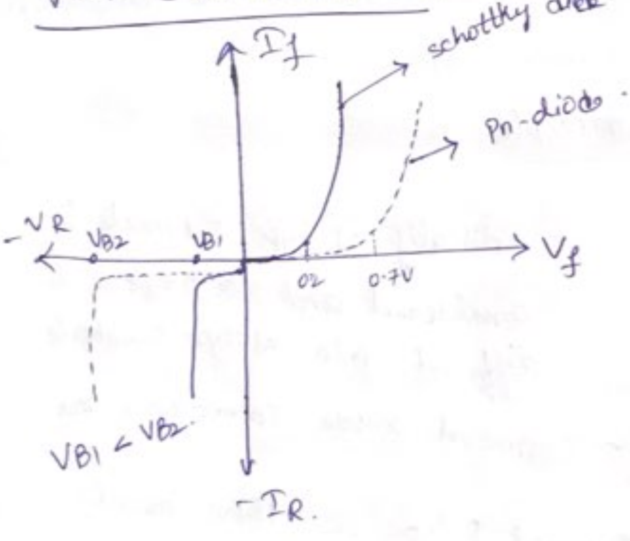
→ schottky/surface barrier opposes the flow of ēs from N-type to metal.

→ so. we need to provide biasing.

Case (2): with biasing.

→ When forward biasing is applied by connecting metal to (+ve) terminal & N-type sc to (-ve) terminal of battery then due to force of repulsion ēs of N-type sc cross the schottky barrier and move into metal side. There by resulting large amount of current flow.

V-I characteristics:



→ V-I characteristics of schottky diode is almost similar to P-N junction diode.

→ The forward voltage drop (cut-in-voltage) of schottky diode is of the order of 0.2V.

→ In schottky diode, the reverse saturation current occurs at very low voltage as compared to pn junction diode

LED : Light Emitting Diode

It is a PN-junction diode which emits light when an electric current passes through it in forward direction

→ Amount of light emitted $\propto$ forward current

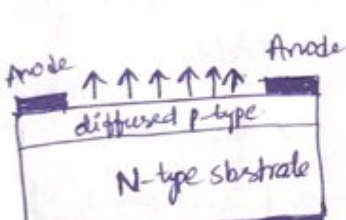
→ LED is made of semiconductor compound material, and the light is emitted (or) radiated through the junction of the diode.

→ semiconductor compound materials can be Gallium Arsenide (GaAS) Gallium phosphide (GaP).. etc

→ symbol : Anode  cathode.

* → silicon & Geremanium are not used in the construction of LED.

Construction & WORKING principle

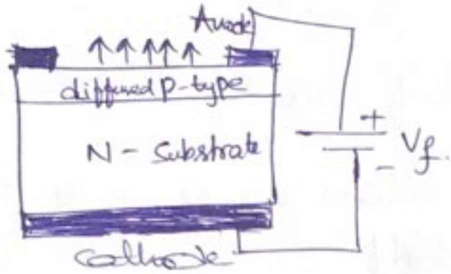


→ Initially N-type substrate is considered and a p-type sc is diffused onto N-type substrate.

→ metal anode connections are made at the outside of diffused P-type SC. These metal anode connections are made in such away that more control surface is made available for the light to escape.

→ Gold film to applied at bottom of substrate to act as Cathode.

WORKING: LED must be forward biased to understand the working principle.



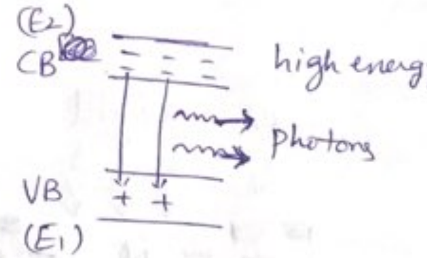
→ The process of obtaining light energy by providing an electrical voltage is called "electro-luminisence"

→ When forward voltage is applied, then forward current is produced.

→ This forward current is due to electrons.

→ In LED, electrons of N-type are in higher conduction band & holes of p-type are in lower Valence band.

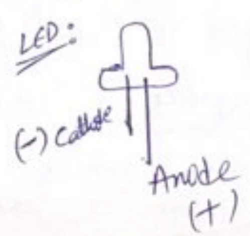
**→ When current flows through diode, then recombination of electrons & holes takes place i.e.,) electrons move from higher energy level to lower energy level and releases the photons.

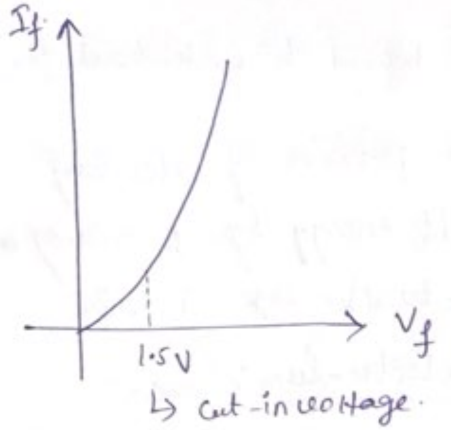


**→ These photons will have a wave length of energy difference [$E_2 - E_1$]

**→ The energy difference can be either in the form of heat (or) in the form of light

LED:





V-I characteristics

→ cut-in voltage of LED is 1.5V

→ if $V_f > 1.5V$ then LED release energy in the form of light.

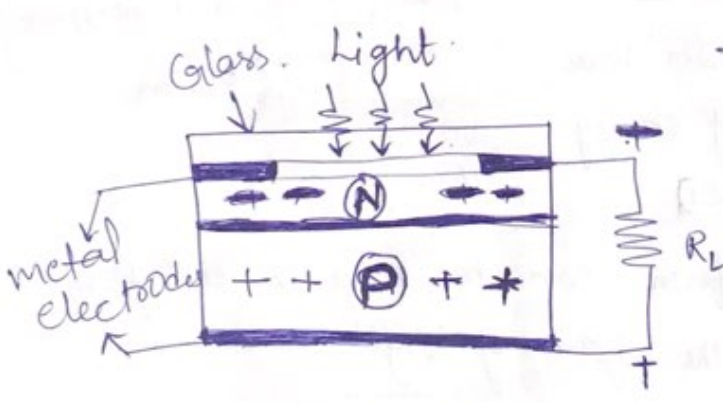
→

Solar cell: It is a p-n junction device which converts ~~solar~~ light energy into electrical energy.

→ it is also called Photo-voltaic cell

→ It works on the principle called "photo-voltaic effect".

Construction:



→ Initially P-type SC is considered.

→ A thin layer of N-type SC is diffused into P-type SC.

→ on top of N-type SC, metal layer is developed in such a way that; more central space is made available for light to inject. → Glass avoids mechanical shock.

→ Another metal layer is developed at bottom of p-type sc.

→ metal layer at N-type sc acts as ~~Anode~~ Cathode &
" " " p-type " " " ~~Cathode~~ Anode.

Working : When light is incident on pn-junction then electron-hole pairs are generated.

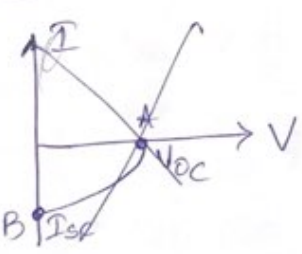
→ due to junction field (or) electric field at juncti[on] holes move towards P-type & $\bar{e}$s move toward N-type sc.

→ These electrons & holes are collected at two side of junction.

→ These photogenerated $\bar{e}$s & holes develope photo voltage at both the metal layers of P-type & N-type sc.

→ When external load is connected across metal layers then photo current flows through load.

V-I characteristics



→ ~~V-I characteristics lies in 4th quadrant.~~

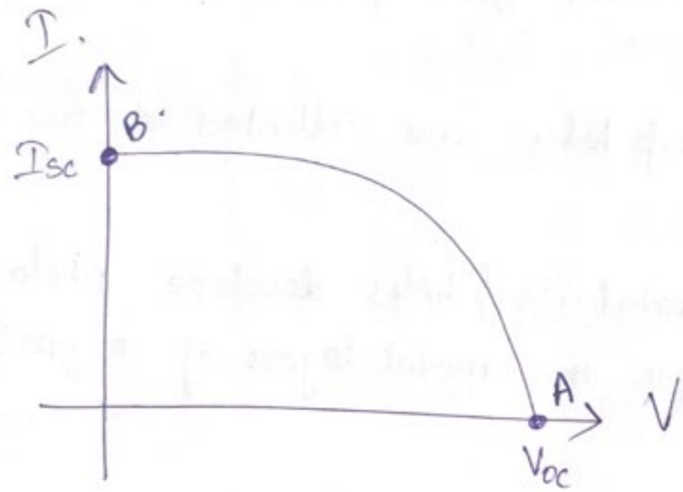
→ ~~This is because~~ ** solar cell doesn't draw current but supplies current.

→ 'A' represents open circuit voltage

→ 'B' represents short ckt current.

Photo-voltaic effect: The effect, in which current/voltage is generated when exposed to light. Through This effect solar cells convert sunlight into electrical energy.

* each solar cell generaly 0.5V of voltage.
* Solar pannel is the combination of many solar cells.

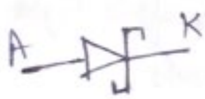
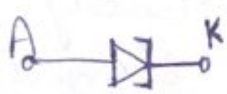


→ V_{oc}, voltage when no load is connected (Current is minimum)

→ I_{sc}, short ckt current when load is connected (Current is maximum).

ADV

Device	Advantages	Disadvantages	Applications
Zener diode A K	→ High accuracy → small size → low cost	→ lower regulation ratio → can't handle high-power	→ Voltage Regulators → clipping & clamping ckts → switching applications
LED A K	→ long life → Reliability → high intensity & brightness.	→ Temperature dependence → Light quality → voltage sensitivity	→ motorcycles & cars → home appliances → traffic light signals.
Photo diode. A K	→ less resistance → long life → less noise	→ less sensitivity → Temperature dependence → Active area is small	→ Consumer electronics → medical applications → optical Communi-cations
UJT B_2 E B_1	→ low cost → (-ve) resistance Characteristics → low power absorbing device	→ Inability to provide appropriate amplification	→ timing ckts → relaxation oscillator → voltage detector
SCR A K gate	→ easy to turn on → low cost → can handle large voltages, currents & power	→ can't be easily turn off → low switching speed → can't be used at high frequencies	→ choppers. → inverters → Battery chargers.

Device	Advantages	Disadvantages	Applications
Varactor diode 	→ less noise → light weight → Reliability	→ can't operate in forward bias mode.	→ Voltage controlled oscillators → RF filters → Frequency & Phase modulators
schottky diode 	→ low-turn on voltage → low-junction capacitance → Low-voltage drop.	→ Reverse leakage current → low reverse voltage rating	→ Switched-mode power supplies → reverse current protection → RF mixers detector.
solar cell 	→ No pollution associated with it → No maintenance cost → long life	→ high cost of installation → low efficiency.	→ Provides electricity for → waterpumps → laptop → computers
Tunnel diode 	→ low cost → Durable → suitable for high-frequency, speed applications	→ Not possible to fabricate tunnel diodes on large scale → Swing in o/p. → low-power device.	→ In digital ckts → frequency converter

① Draw energy band diagram of tunnel diode & explain tunneling phenomenon. Draw V-I characteristics. [OR]
(1) What is tunneling phenomena? Explain principle of operation of tunnel diode with its characteristics [or] with the help of energy band diagram explain tunnelling phenomena in tunnel diode.

② Define varactor diode ? Explain operation of varactor diode with its circuit and mention applications

③ How and under what conditions Zener breakdown take place in diode ? Draw V-I characteristics of zener diode and show the breakdown region.

④ Explain in detail about principle of operation of SCR.

⑤ Explain the construction & characteristics of UJT.

⑥ prove the statement "A zener diode can act as voltage regulator".

⑦ Draw the symbols of all special purpose devices along with their definitions.

EDC- ASSIGNMENT-5