UNIT - 5

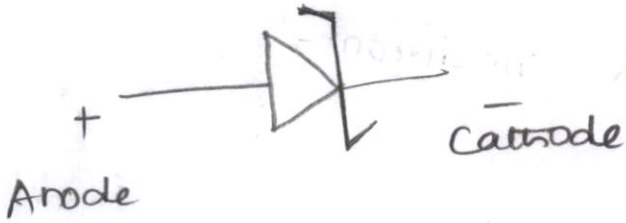
Special purpose Devices

Zener diode:-

A Zener diode is a type of PN junction diode that is designed to conduct in both forward and reverse directions. It has heavily doped regions and is mainly used to conduct current in the reverse direction. It starts conducting in the reverse direction when the reverse voltage exceeds a certain limit known as reverse breakdown (or) Zener breakdown voltage.

Symbol of Zener diode:

The symbol of Zener diode resembles an ordinary diode except for the change in a little bend at the edges of the vertical line to make a shape that resembles Z as shown below.

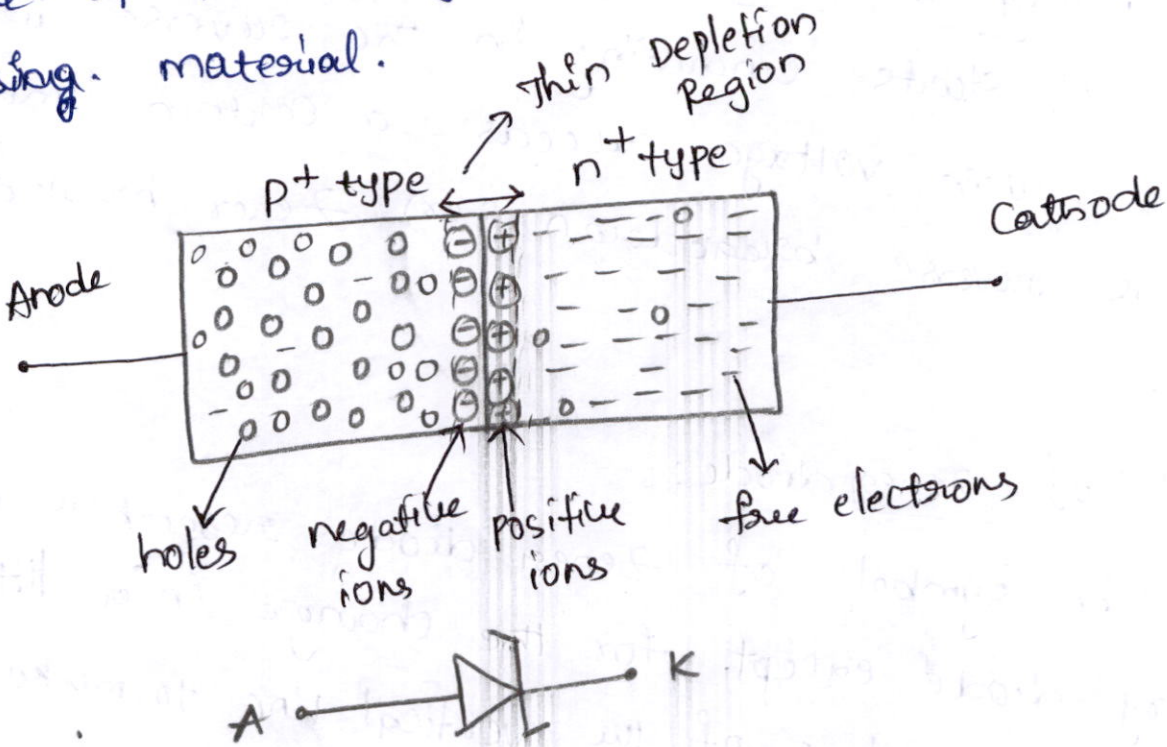


Construction of Zener diode: (Circuit diagram (or) layer Structure of Zener diode)

Zener diode is always connected in reverse direction because it is specifically designed to work in reverse direction.

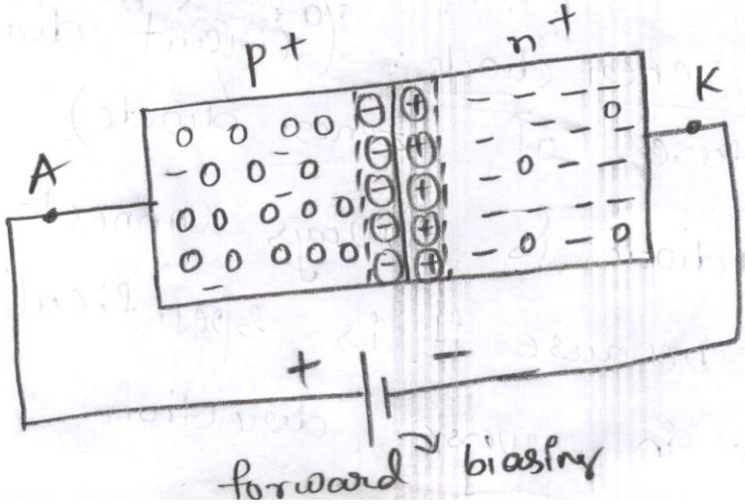
The reverse biasing means the anode of the diode is connected to the positive terminal of the supply & the cathode is connected to the -ve terminal of the diode supply.

→ The depletion region is very thin because it is made of the heavily doped P & n type semiconductor material.

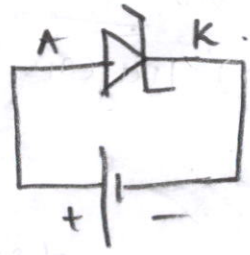


Working of zener diode and V-I characteristics of Zener diode :-

① under forward biased condition:-



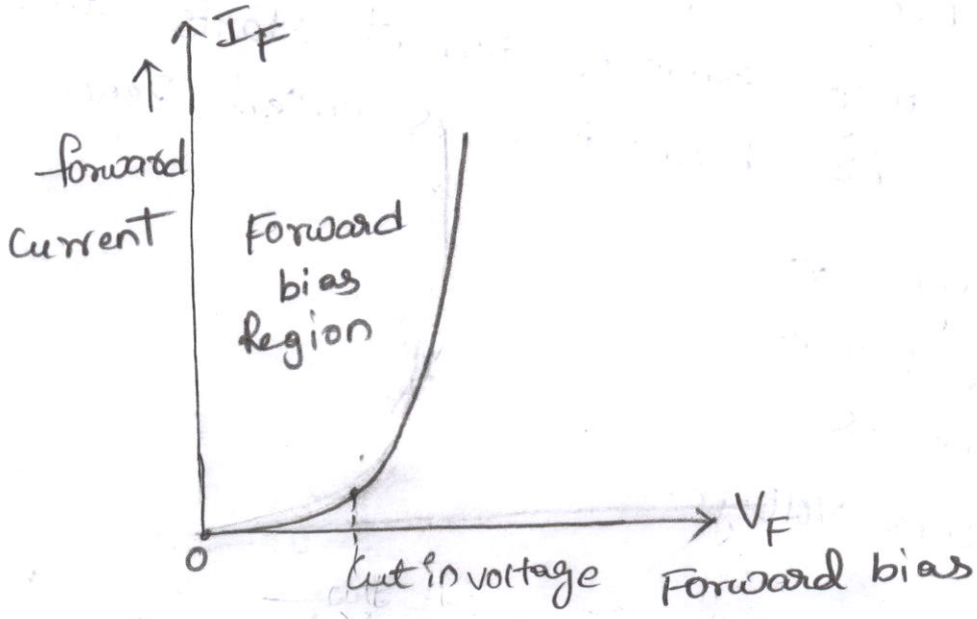
(or)



→ Zener diode is heavily doped than the normal pn junction diode. Hence it has very thin depletion region.

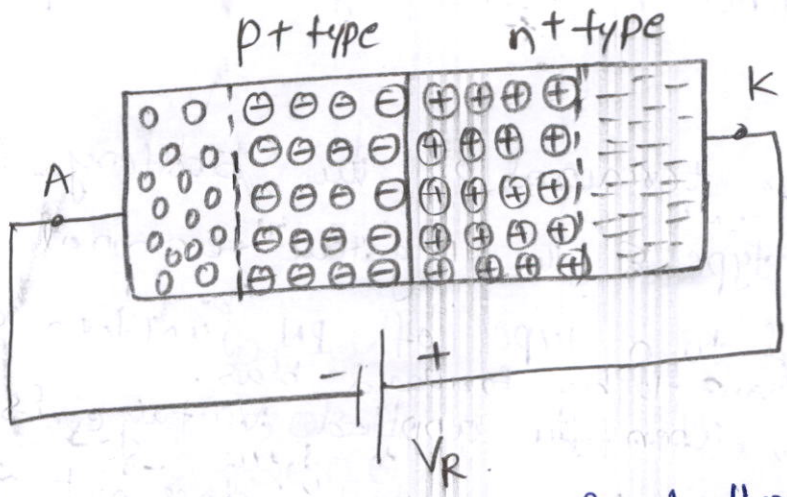
→ When the positive terminal of the battery is connected to the P type & the negative terminal of the battery is connected to n type of PN function diode. Then the bias is said to be forward bias.

→ In forward bias, when the applied voltage is lower than the barrier potential, the diode does not allow current through it but only the small leakage current. Once the applied voltage crosses the barrier voltage the current increases suddenly while the voltage remains constant. The forward bias operation in the Zener diode is the same as in any normal diode.



VI characteristics under forward bias.

(2) Under reverse biased condition:



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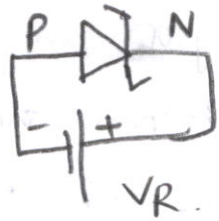


→ when negative terminal of battery is connected to p type and +ve terminal is connected to n type then the bias is said to be reverse bias.

→ If this reverse biased voltage across the diode is increased, high electric field develop across the junction. This strong electric field break all the covalent near the junction and the junction breaksdown and a large reverse current starts flowing through the diode. This breakdown is called Zener breakdown.

→ The voltage at which this break down occurs is called Zener voltage.

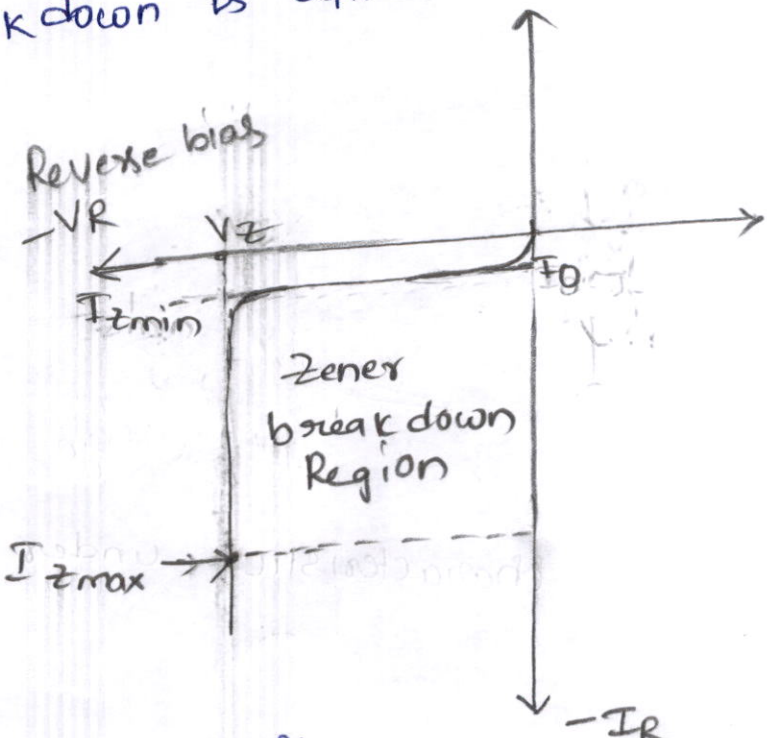
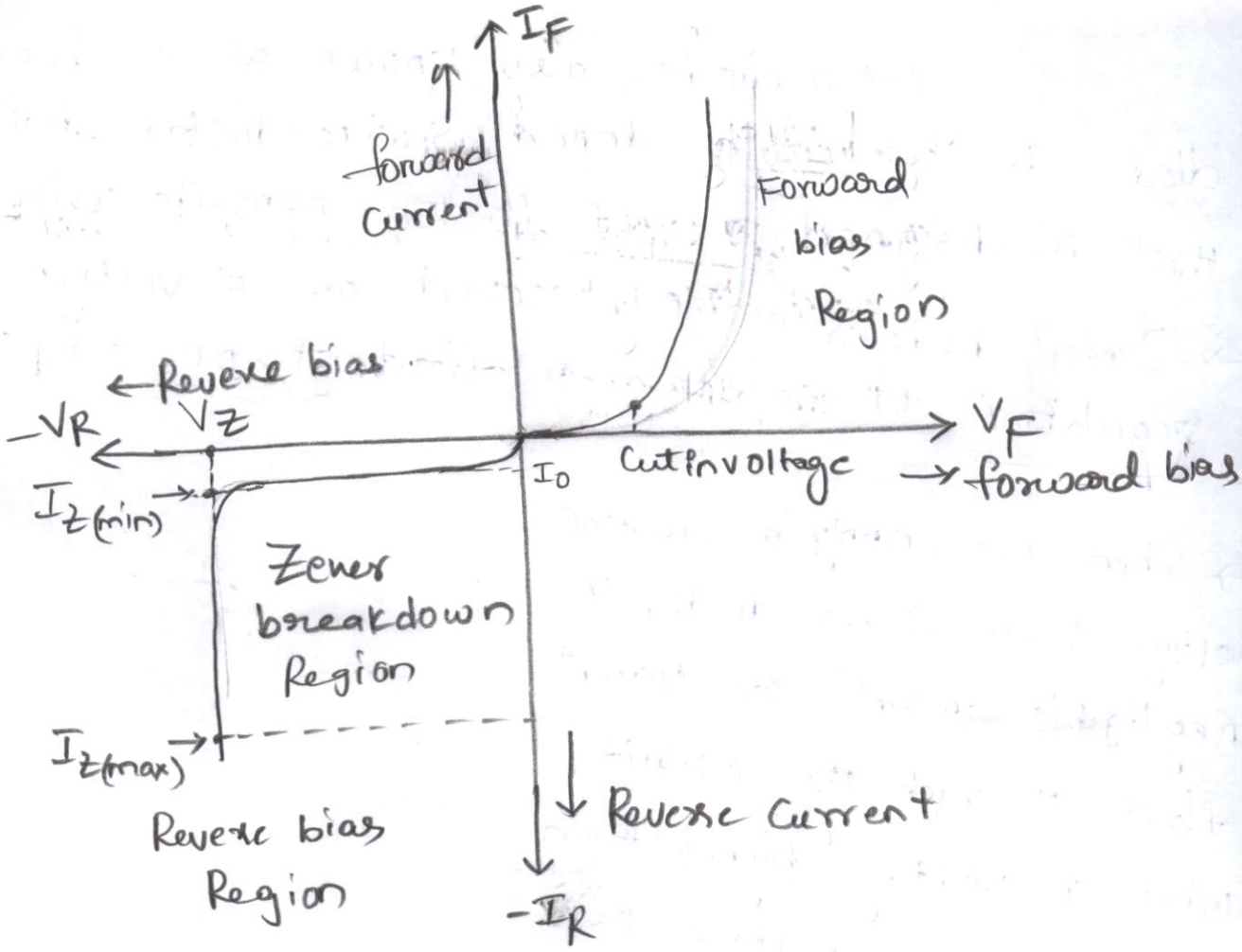


fig:
VI characteristics current under reverse bias

Complete VI Characteristics of Zener diode:



Equivalent circuit of Zener diode:-

fig ⓐ: Zener diode

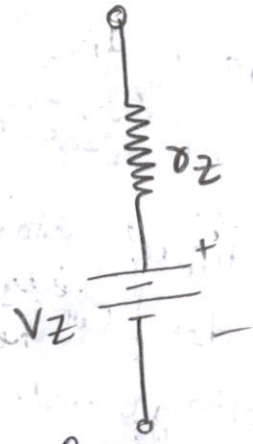


fig ⓑ practical diode

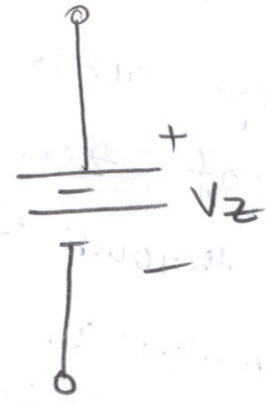


fig ⓒ Ideal Equivalent circuit.

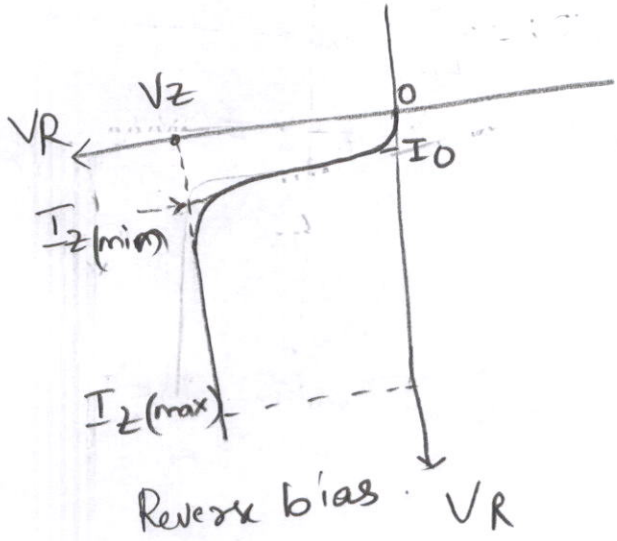
Zener diode as Voltage Regulator:-

Zener diode, also known as a breakdown diode, is a heavily doped semiconductor device that is designed to act in the opposite direction.

→ Zener diode is commonly used as a voltage regulator to maintain a constant DC output voltage

→ when we apply a reverse voltage to a zener diode, a negligible amount of current flows through the circuit.

→ when a voltage higher than zener breakdown voltage is applied, zener breakdown occurs.



→ when we increase the reverse voltage further, the voltage across the diode remains at the same value of zener breakdown (VZ) where as the current through it keeps on rising as seen in figure.

→ This makes the zener diode to act as a voltage Regulator, which provides constant output which is zener breakdown voltage.

→ A zener diode working in the breakdown region can serve as a voltage regulator. It maintains a constant output voltage even when

Input voltage V_i (or) load current i_L varies.

→ The circuit diagram of a zener diode as a voltage regulator is as shown below:

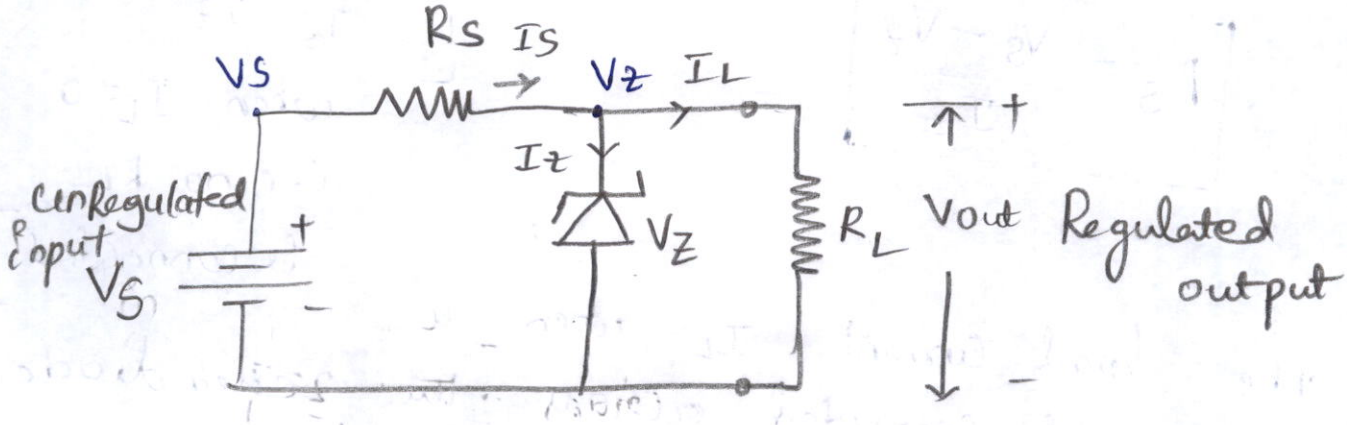


fig: voltage Regulator.

→ As shown in the above figure, by passing a small current through the diode from a voltage source Vs via a suitable current limiting resistor (R_s), the zener diode will conduct sufficient current to maintain a voltage drop of Vout.

→ Resistor Rs is connected in series with the zener diode to limit the current flow through the diode.

→ zener diode cathode is connected to the positive terminal of DC supply, so it is reverse biased & will be operating in its breakdown condition.

→ The load is connected in parallel with the zener diode, so the voltage across R_L is always the same as the zener diode,

$$V_{R_L} = V_Z$$

→ The minimum value of the series Resistor R_S to limit the flow of current through the diode, when no load is connected across it is,

$$R_S = \frac{V_S - V_Z}{I_Z}$$

[∵ $I_S = I_Z$ when $I_L = 0$ i.e no R_L is connected]

→ The load current I_L when a load R_L is connected across the zener diode is

$$I_L = \frac{V_Z}{R_L}$$

→ The zener current I_Z at full load is

$$I_S = I_Z + I_L$$

$$\Rightarrow \boxed{I_Z = I_S - I_L}$$

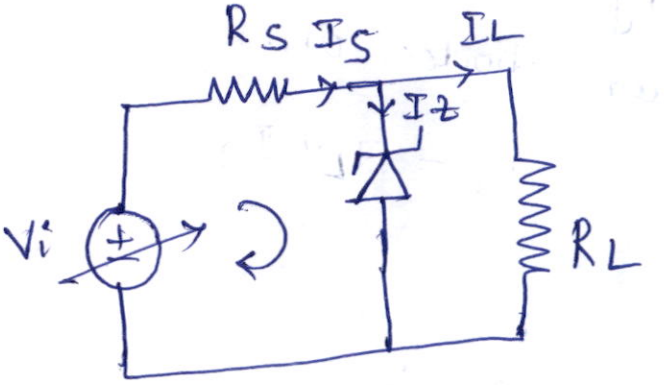
Basically there are two types of regulations such as

① Line Regulation: In this regulation, series resistance & load resistance are fixed, only i/p voltage is changing. output voltage Remains the same as long as the i/p voltage is maintained above a minimum value.

Load Regulation:

In this type of regulation, input voltage is fixed and the load resistance is varying. output voltage remains same as long as the load Resistance is maintained above a minimum value.

Line Regulation:-



In line Regulation, load resistance is Constant and i/p voltage varies. V_i must be sufficiently large to turn the zener diode ON.

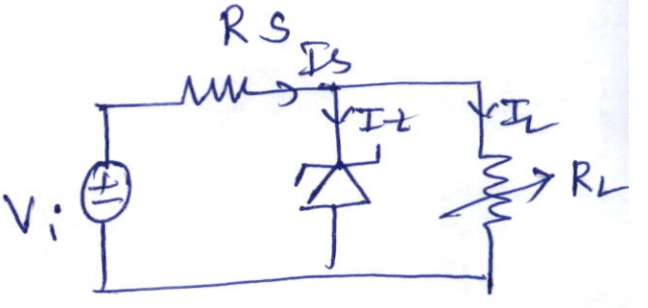
$$V_L = V_Z = \frac{V_{Imin} \times R_L}{(R_L + R_S)}$$

$$V_{Imin} = \frac{V_Z (R_L + R_S)}{R_L}$$

$$V_{Imax} = I_{Rmax} \times R + V_Z$$

$$V_o = V_i - I_S \times R_S$$

load Regulation:-



In load Regulation, o/p voltage is Constant & load resistance varies. Too small a load resistance R_L

$$V_L = V_Z = \frac{V_{Imin} \times R_L}{R_L + R_S}$$

So, the minimum load resistance R_L

$$R_{Lmin} = \frac{V_Z \times R_S}{V_I - V_Z}$$

Any load resistance > than R_{Lmin} will make Zener diode ON.

$$I_S = I_L + I_Z$$

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Silicon Controlled Rectifier (SCR):-

A silicon controlled Rectifier is a 3 terminal and 4 layer semiconductor current controlling device. It is some sometimes referred as SCR diode, 4 layer diode, 4 layer device (or) thyristor. It is made up of a silicon material which controls high power and converts high AC current into DC current. Hence it is named as silicon controlled rectifier.

Construction and Symbol of SCR:

A silicon controlled rectifier is made up of 4 semiconductor layers of alternating P and N type materials, which forms NPNP (or) PNPN structures.

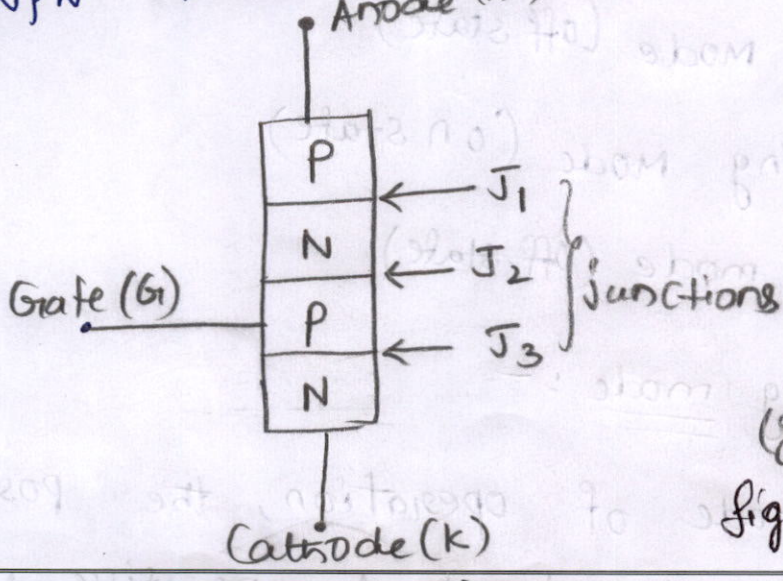


fig: SCR structure

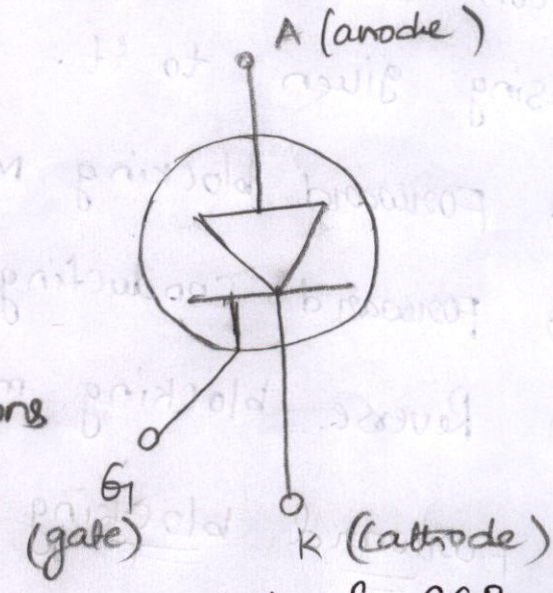


fig: Symbol of SCR

→ It has 3 PN junctions namely J_1, J_2, J_3 with 3 terminals attatched to the semiconductors materials namely Anode (A), Cathode (K), and gate(G)

→ Anode, is a positively charged electrode through which the current enters into an electrical device,

→ Cathode, is a negatively charged electrode through which the conventional current leaves the electrical device

→ Gate, is a terminal that controls the flow of current between anode and cathode.

→ Junction J_1 is formed between the first P-N layer the junction J_2 is formed between the N-P layer and the junction J_3 is formed between the last P-N layer.

Modes of operation in SCR:-

There are 3 modes of operation for a silicon controlled rectifier (SCR), depending upon the biasing given to it.

① Forward blocking mode (off state)

② Forward conducting mode (on state)

③ Reverse blocking mode (~~off state~~)

① Forward blocking mode:-

In this mode of operation, the positive voltage (+) is given to Anode A, negative voltage

is given to cathode (K) and gate G is open circuited as shown in below figure.

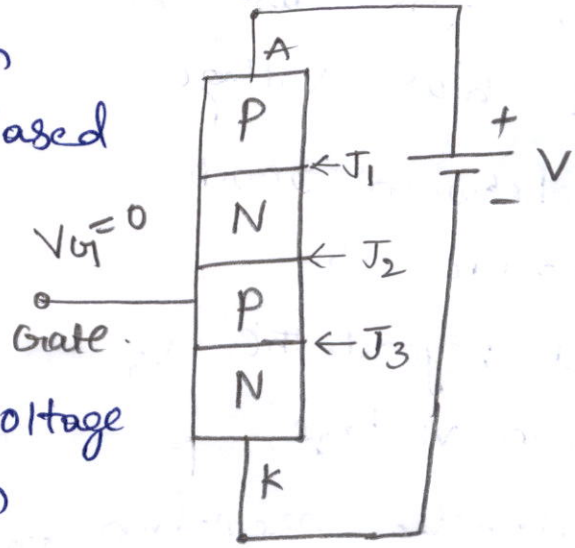


fig: Forward blocking mode of SCR

→ In this case, the junction J_1 and J_3 are forward biased where as the junction J_2 becomes reverse biased.

→ Due to the reverse bias voltage the width of depletion region increases at junction J_2. It blocks the current flowing between junction J_1 & J_3.

→ However a small amount of leakage current flows between J_1 & J_3 junctions.

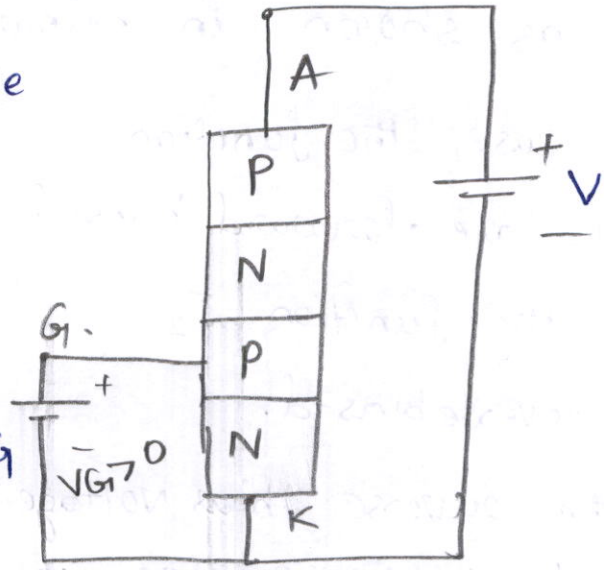
→ when the voltage applied to SCR reaches a breakdown value, the high energy minority carriers causes avalanche breakdown. At this breakdown voltage, current starts flowing through the SCR. But below this breakdown voltage, the SCR offers high resistance to current & so it will be in off state.

② Forward Conducting mode:-

The SCR can be made to conduct in two ways.

1. By increasing the forward bias voltage applied between anode and cathode beyond the breakdown voltage.

2) By applying positive voltage at gate terminal.



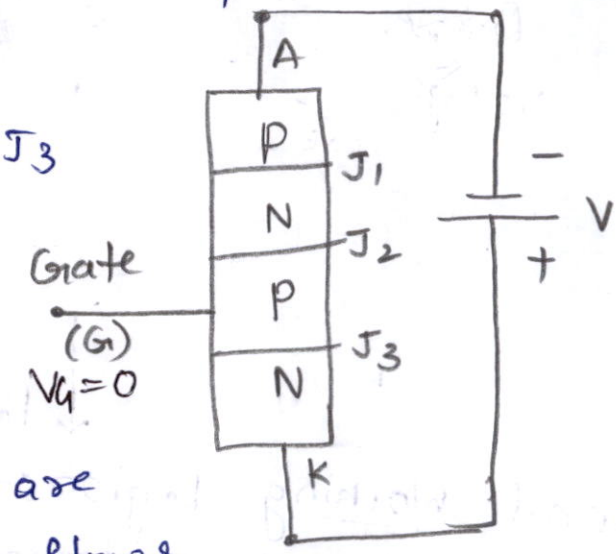
→ In the first case the forward bias voltage applied between anode and cathode is increased beyond the breakdown voltage, then avalanche breakdown occurs at function J_2 and current starts flowing through the SCR. So the SCR will be in ON state.

Forward conducting mode of SCR.

→ In the second case, a small positive voltage V_G is applied to the gate terminal, which makes function J_2 forward bias. So the depletion region width at function J_2 becomes very narrow. under this condition applying a small forward bias voltage between anode and cathode is enough for electric current to penetrate through this narrow depletion region. Therefore electric current starts flowing through the SCR circuit.

(3) Reverse blocking mode :-

In this mode of operation, the negative voltage is given to anode and positive voltage is given to cathode and gate is open circuited as shown below, In this case the function J_1 and function J_3 are reverse biased where as the function J_2 becomes forward biased.

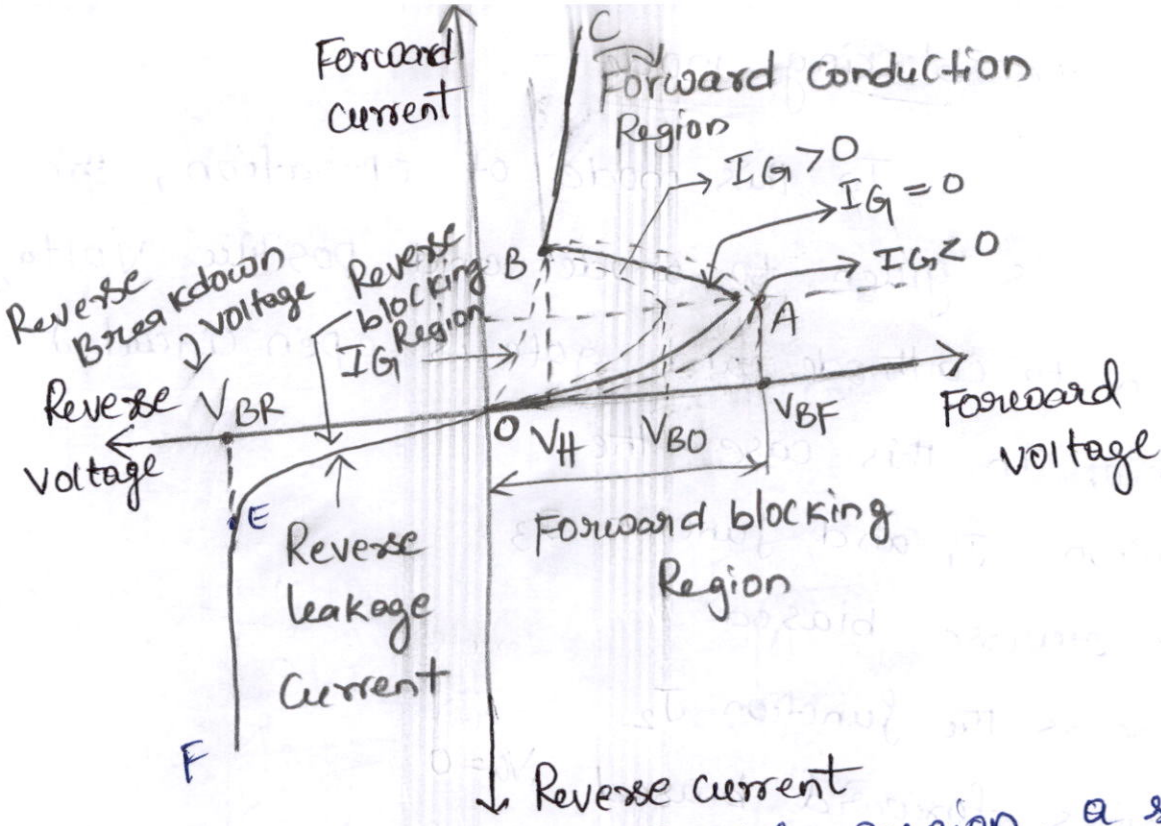


→ As functions J_1 and J_3 are reverse biased no current flows through the SCR circuit. But a small leakage current flows due to drift of charge carriers in the forward biased function J_2. This small leakage current is not enough to turn on SCR. so SCR will be in off state

VI characteristics of SCR :-

The V-I characteristics of SCR is divided into 3 Regions.

i) Forward blocking Region
ii) Forward conduction Region
iii) Reverse blocking Region.



i) Forward blocking Region:- In this region, a small leakage current flows from anode to cathode. This small leakage current is known as forward leakage current The region OA is known as forward blocking region.

ii) Forward Conduction Region:- In this region the current flow in the SCR increases rapidly after junction breakdown occurs. The voltage at which the junction J_2 gets broken when the gate is open is called forward breakdown voltage V_{BF}.

→ The Region AB indicates that as soon as the device becomes on, the voltage across the SCR drops to some volts.

→ The Region BC is called Conduction Region.

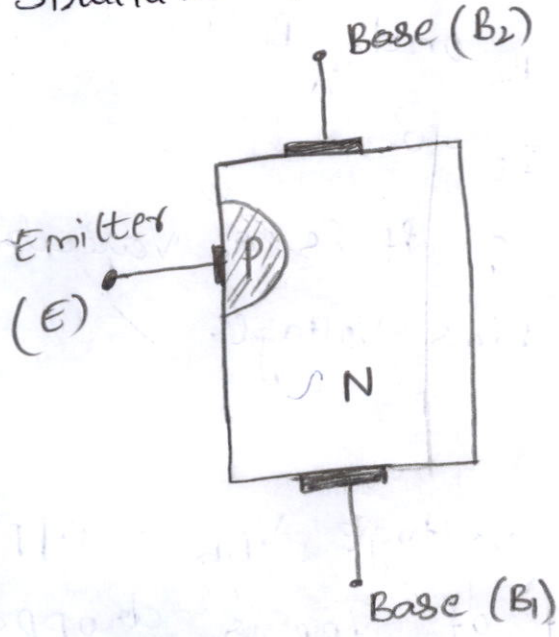
iii) Reverse Blocking Region:- In this region as J_1 and J_3 are reverse biased, no current flows through the SCR circuit. But a small leakage current flows

due to drift of charge carriers in the forward biased junction J_2. If the reverse bias voltage applied between anode and cathode is increased beyond the reverse breakdown voltage an avalanche breakdown occurs. As a result the current increases rapidly. The region EF shows the avalanche region. This current may damage the SCR.

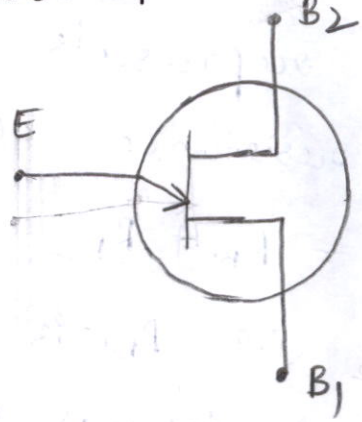
UJT (uni junction transistor):-

UJT is a three terminal semiconductor switching device. As it has only one pN function and three leads Emitter, Base1 and Base2. It is commonly called as unijunction transistor.

Structure of UJT:



Symbol of UJT:-

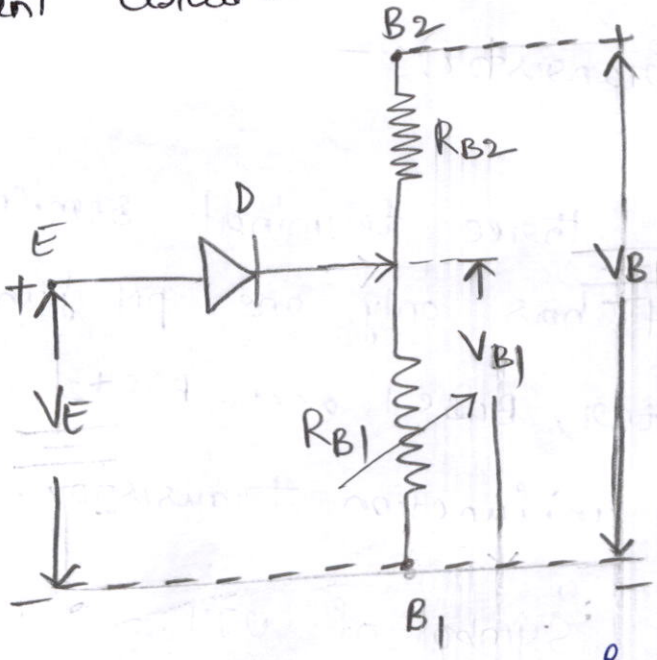


→ UJT consists of a lightly doped N type Si bar into which heavily doped P type material is diffused closer to base 2.

→ It forms a single PN junction.

→ The arrow in the emitter represents the direction of the conventional current.

Equivalent Circuit:-



→ Diode D represents PN junction

→ Internal resistance between B_2 and B_1 is

$$R_{BB} = R_{B1} + R_{B2} \quad \text{when } I_E = 0$$

→ $R_{B1} > R_{B2}$ i.e R_{B1} is greater & it is a variable resistor which depends on the bias voltage.

Intrinsic stand off ratio:

→ with emitter open, if voltage V_{BB} is applied between B_2 and B_1 then part of V_{BB} is dropped over R_{B1} and R_{B2}

The voltage drop across R_{B1} is $-V_{B1}$

$$V_{B1} = \frac{V_{BB} R_{B1}}{R_{B1} + R_{B2}}$$

$$V_{B1} = V_{BB}\left(\frac{R_{B1}}{R_{B1} + R_{B2}}\right)$$

$$\Rightarrow V_{B1} = V_{BB}\,\eta$$

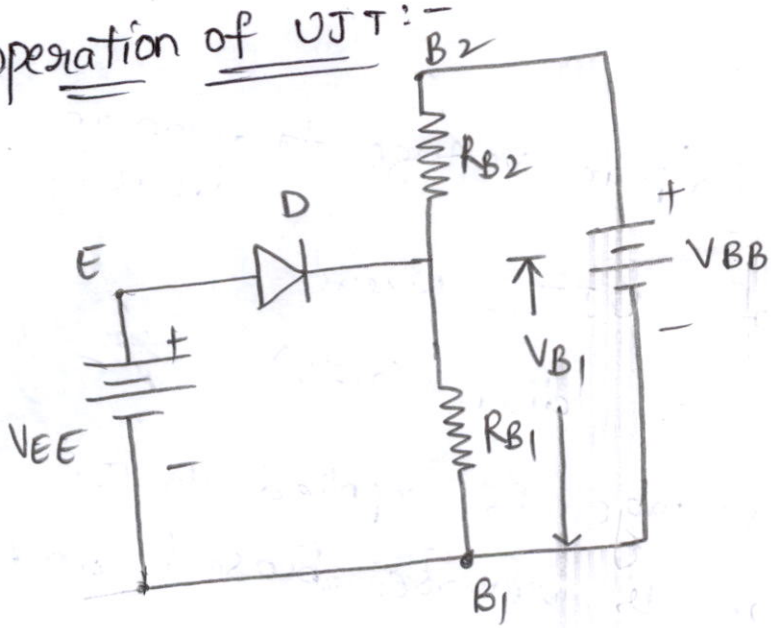
where $\boxed{\eta = \frac{R_{B1}}{R_{B1} + R_{B2}}}$ ⇒ Intrinsic stand off ratio

η ranges from 0.5 to 0.75

→ η will define the reverse bias condition for diode.

→ V_{B1} reverse biases the PN junction & I_E is in cutoff condition.

operation of UJT:-



(i) with emitter terminal open: when $V_E = 0$ and only V_{BB} is applied between B_1 & B_2.

→ V_{B1} reverse biases the PN junction, I_E is cutoff

→ Due to the minority carriers there is a small

leakage current flowing from B_2 to E.

(ii) When a positive voltage V_E is applied to Emitter:

→ If V_E exceeds V_{B1} by atleast 0.7V then the diode becomes forward biased.

→ Holes are injected from heavily doped p type material into N type bar.

→ These holes are repelled by B_2 and attracted by B_1 because B_2 is connected to '+' terminal & B_1 is connected to '−' terminal.

→ So more current I_E will flow into R_{B1} which reduces the value of R_{B1}

→ V_E increases the I_E which inturn reduces the R_{B1}. This causes further increase in I_E regeneratively. It is limited by V_E.

$$V_p = \eta V_{BB} + V_D$$

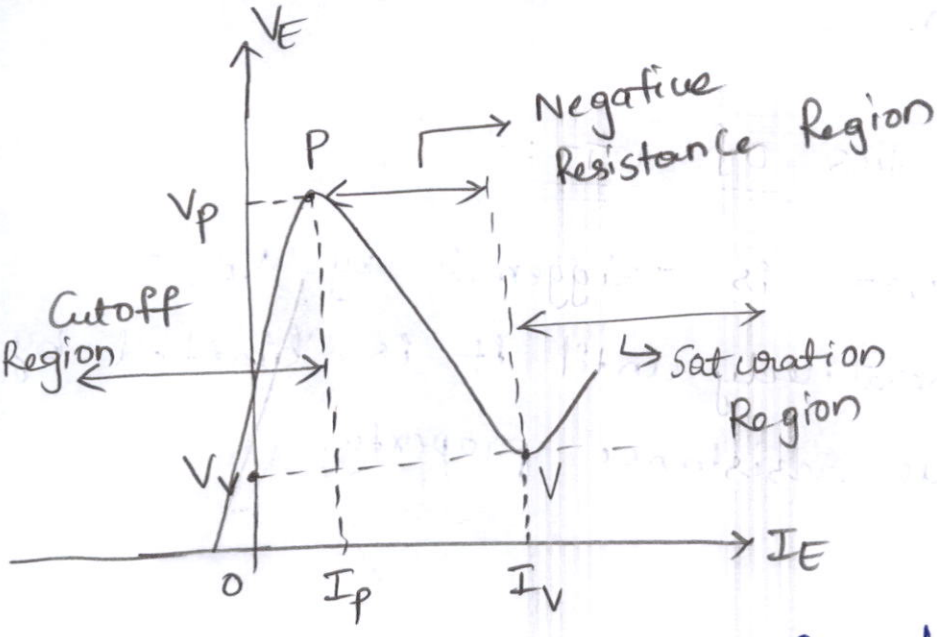
[⇒ peak voltage to turn on diode.]

V_p → peak voltage of UJT, where

V_D is cutin voltage of diode (0.7V)

(iii) When a negative voltage is applied to the Emitter :- PN junction is reverse biased and I_E is cutoff. UJT is in OFF condition.

VI characteristics of UJT :-



→ VI characteristics of UJT can be explained by

i) Cutoff Region
ii) Negative Resistance Region
iii) Saturation region.

→ If $V_E < V_p$ (Emitter voltage < Peak voltage) the Emitter is reverse biased there is a small leakage current.

UJT is in OFF condition, the region left of the peak point is Cutoff region.

→ If $V_E > V_p$, the diode is forward biased.

→ It increases the I_E and decreases R_{B1} thereby decreasing $V_E \Rightarrow I_E \propto \frac{1}{R_{B1}} \Rightarrow$ Negative Resistance.

→ I_E increases until it reaches the valley point.

→ The region between P and V is the negative resistance region.

→ After the valley point, the device is driven into saturation region.

Unique Characteristics of UJT :-

When UJT is triggered by V_E, I_E increases regeneratively until it is limited by V_E. i.e negative resistance property.

Applications :-

- → Switching Circuits
- → UJT Relaxation oscillator
- → Sawtooth generator
- → pulse generator
- → timing and trigger Control circuits.

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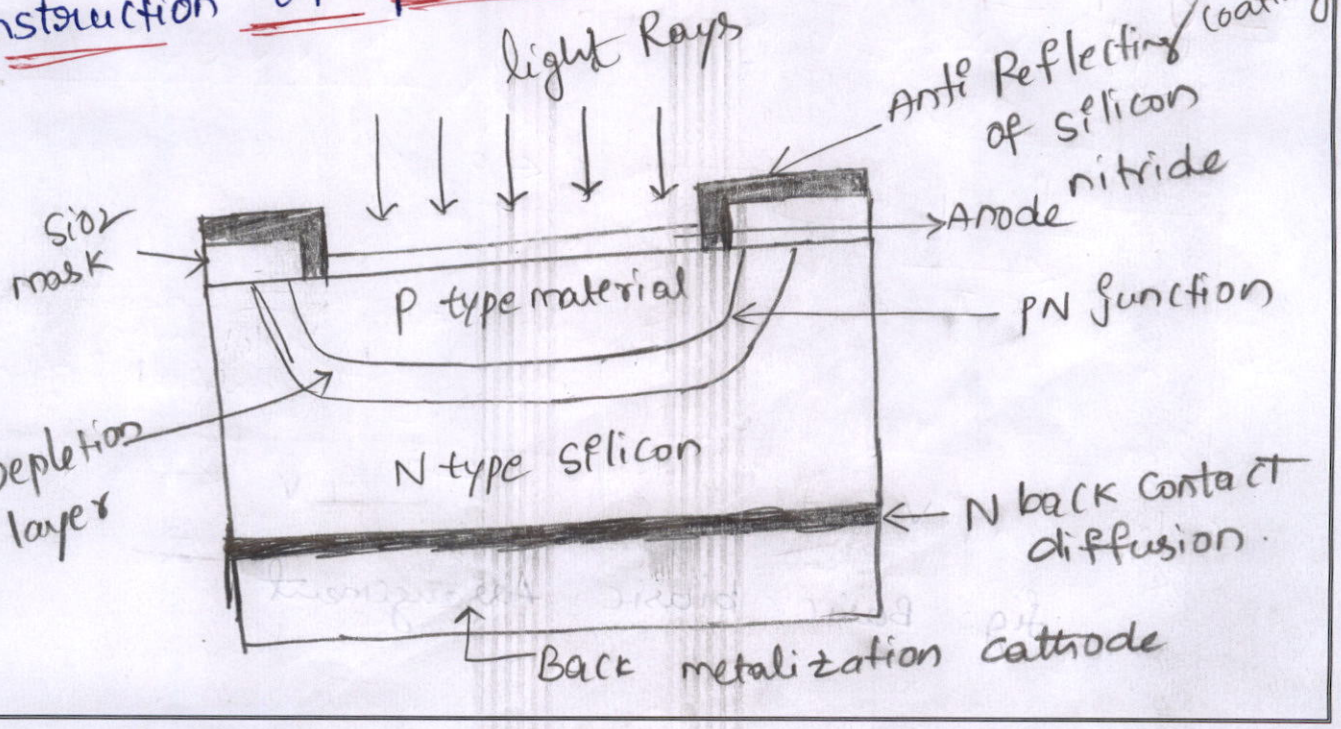
Photo diode:-

A photo diode is a PN function diode that consumes light energy to produce an electric current. It is also called as a photo detector, a light detector and photo sensor.

→ The photo diode is a semiconductor PN junction device whose region of operation is limited to the reverse biased region. The below figure shows the symbol of photo diode.

fig: symbol

Construction of photo diode:-



The photodiode is made up of two layers of p type and N type semiconductor. In this the p type material is formed from diffusion of the lightly doped p type substrate. Thus the layer of p+ ions is formed due to the diffusion process.

→ The p+ diffusion layer is developed on N type heavily doped epitaxial layer.

→ The contacts are made up of metals to form two terminal cathode and anode.

→ The front area of the diode is divided into two types that are active and non active surface.

→ The non active is made up of SiO_2 and active surface is coated with anti reflection material.

→ The active surface is called so because the light rays are incident on it.

Working principle of photodiode :-

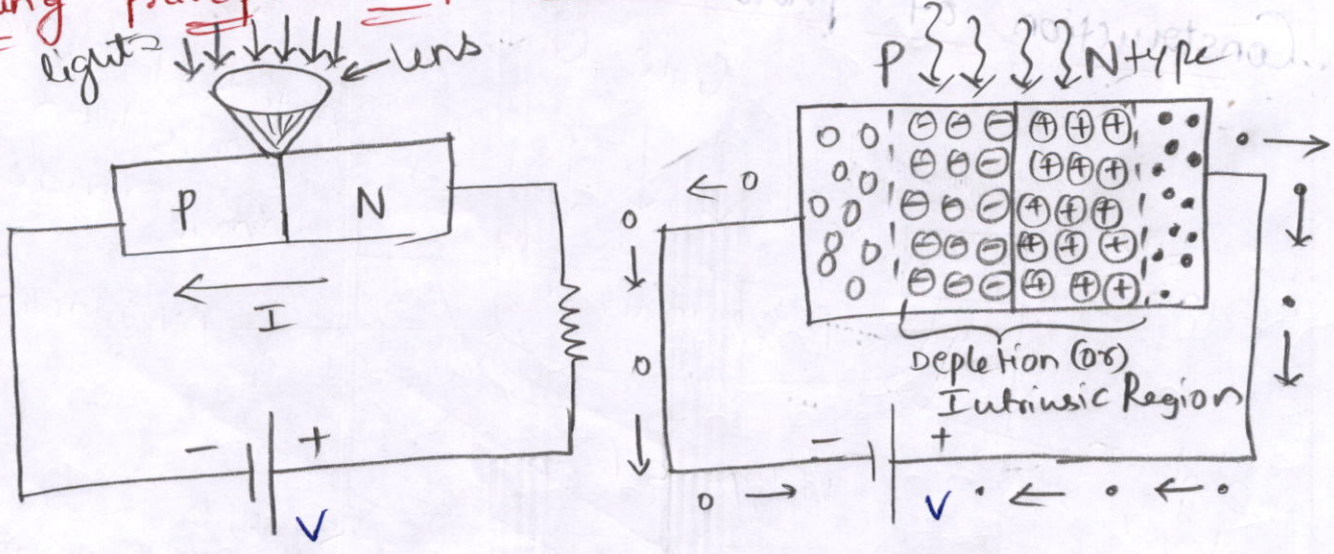


fig: Basic biasic Arrangement

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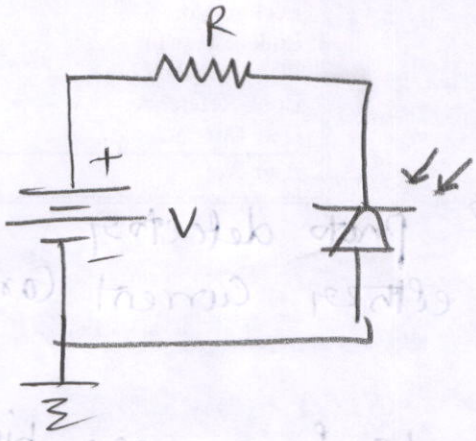
→ A photodiode is a type of photo detector capable of converting light into either current (or) voltage.

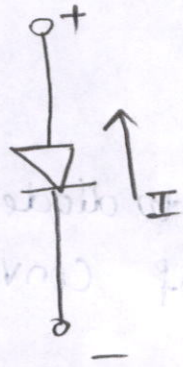
→ A photodiode is designed to operate in reverse bias. The depletion region width is large. under normal conditions it carries small reverse current due to minority charge carriers.

→ When light is incident through glass window on the PN function, photons in the light hits the pn junction and some energy is imparted to the valance electrons. So valance electrons break covalent bonds and become free electrons. That means electrons from valance band get the energy to jump into the conduction band and contribute to current. In this way, the photodiode converts light energy into electrical energy.

→ The current which flows in photodiode before light rays are incident on it is called dark current.

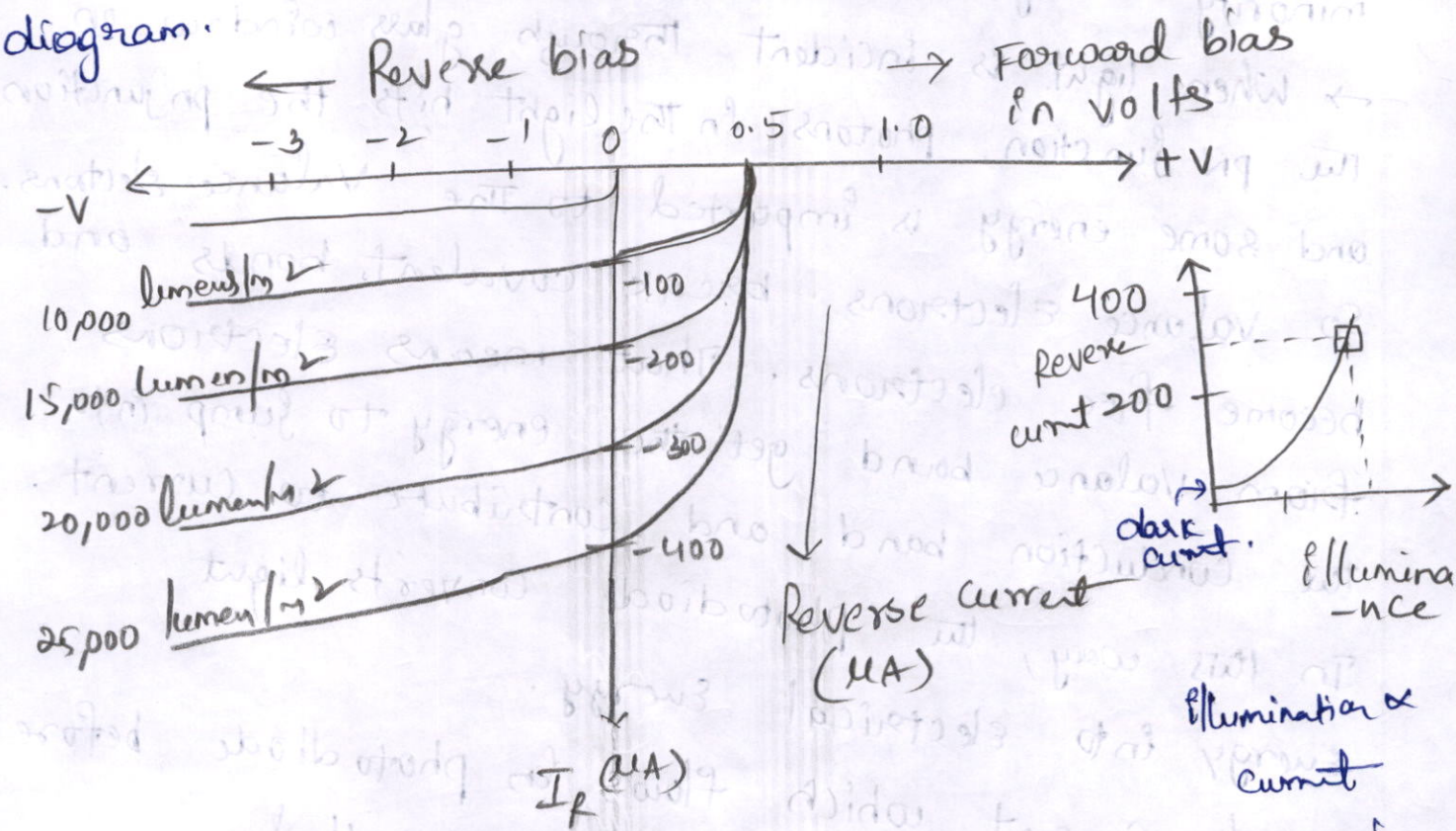
Equivalent circuit & symbol of photodiode





VI Characteristics of photodiode :-

The characteristics curve of the photodiode can be understood with the help of the below diagram.



→ The characteristics are shown in the negative region because the photodiode can be operated in reverse mode only.

→ The reverse saturation current in the photodiode is denoted by I_0.

It varies linearly with the intensity of photons striking the diode surface.

→ The Reverse saturation current,

$$I = I_{sc} + I_o \left(1 - e^{V/\eta V_t}\right)$$

→ I_{sc} → short circuit current

→ V is +ve for forward voltage & negative for reverse bias.

→ V_t → volt Equivalent

→ η = 1 for Ge $\eta = 2$ for Si

Advantages: The advantages of photo diode are

→ It Can be used as Variable resistance device
→ Highly sensitive to light
→ The speed of operation is very high.
→ Light weight & Compact size
→ wide spectral response
→ Relatively low cost

Disadvantages :-

→ Rapid increase in dark current and it depends on temperature.
→ Require amplification at low illumination level
→ photodiode characteristics are temperature dependent & have poor temperature stability.

Applications of photo diode:

→ photo diodes are used in safety electronics such as fire and smoke detectors.
→ used in numerous medical applications. They are used in ~~numerous~~ instruments that analyze samples, detectors for Computed tomography and also used in blood gas monitors.
→ photo diodes are used in solar cell panels.
→ used in logic circuits.
→ used in detection circuits
→ used in character recognition circuits.
→ These are used for the exact measurement of the intensity of light in science & industry.
→ photo diodes are faster and more complex than normal PN function diodes & hence are frequently used for lightning regulation & optical communication.

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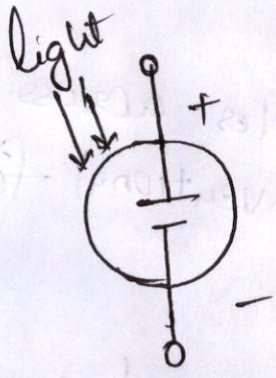
Solar Cell:-

A solar cell is also known as a photovoltaic cell (PV cell) is defined as an Electrical device that converts light energy into Electrical Energy through photovoltaic effect.

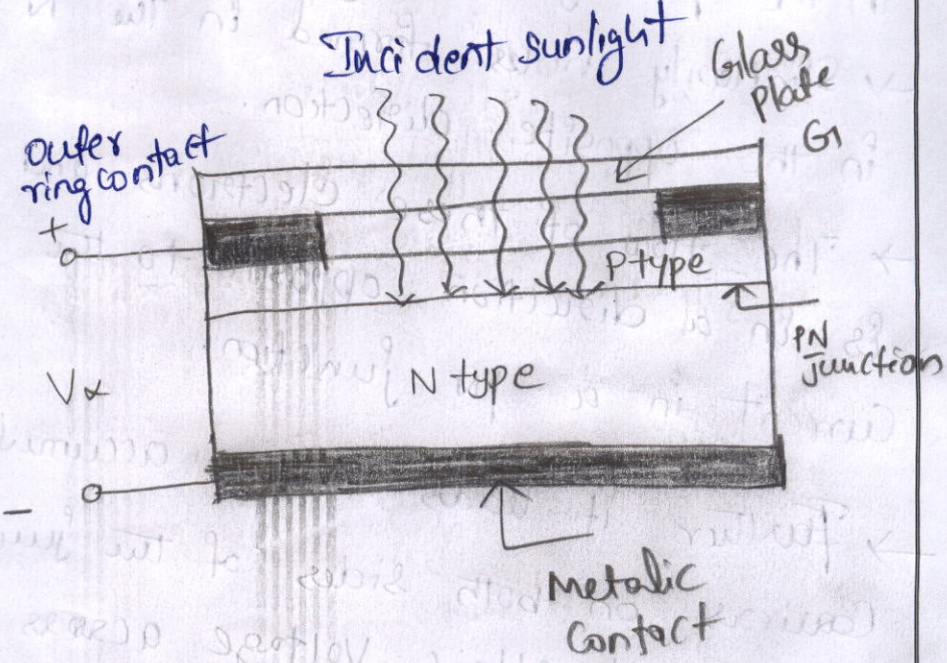
→ A solar cell is basically a pn junction diode.

→ solar cells are a form of photoelectric cell, defined as a device whose electrical characteristics such as current, voltage (or) resistance vary when exposed to light.

Symbol of solar cell



Construction of a PN junction solar cell



Construction and working of solar cell:

When sunlight is incident on a photovoltaic cell it is converted into electrical Energy. solar cell is used in satellites to provide the electrical power.

→ Solar cell consists of a single semiconductor crystal which has been doped with both p and N type impurities, thereby forming a PN junction. The basic construction of a PN junction solar cell is as shown in above figure.

→ Sunlight incident on the glass plate G passes through it and reaches the junction. An incident light photon at the junction may colide with a valance electron and impart sufficient energy to make a transition to conduction band.

→ As a result, an electron hole pair is formed.

→ The newly formed electrons are minority carriers in the p region. They move freely across the junction.

→ Similarly holes formed in the N region cross the junction in the opposite direction.

→ The flow of these electrons and holes across the junction is in a direction opposite to the conventional forward current in a PN junction.

→ Further it leads to the accumulation of a majority carriers on both sides of the junction. This gives rise to a photovoltaic voltage across the junction in the open circuit condition.

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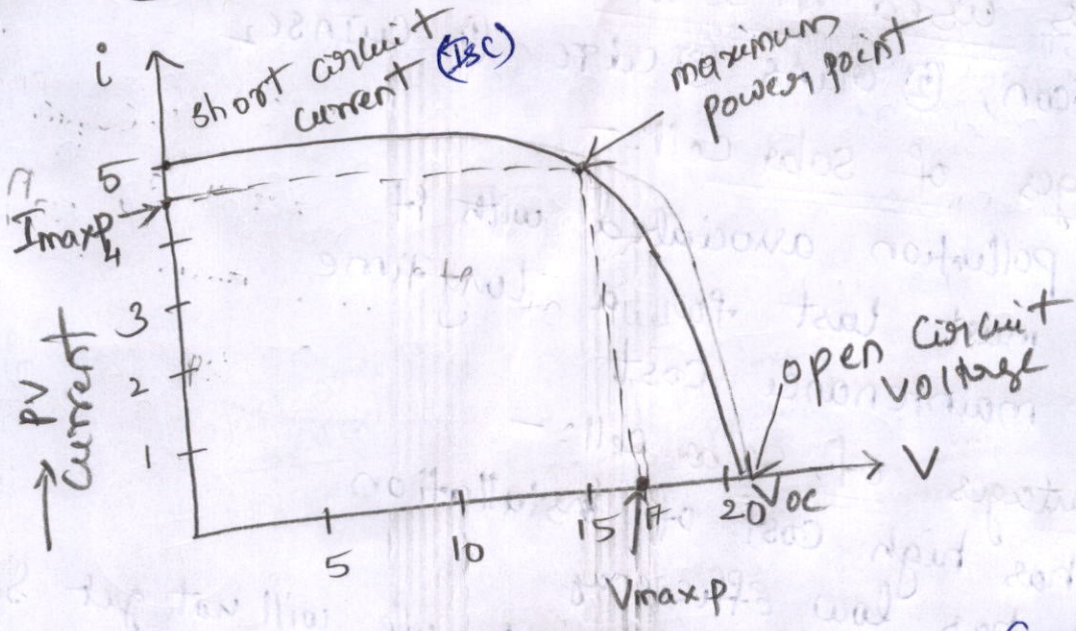
In bright sunlight, about 0.6V is developed by a single solar cell.

→ The efficiency of the solar cell is measured by the ratio of electrical energy o/p to the light energy input.

→ At present an efficiency in the range of 10 to 40% is obtained.

VI characteristics of Solar Cell:



Short circuit current: It is the maximum current that a solar cell can deliver without harming its own construction. It is measured by short circuiting the terminals of the cell..

Open circuit voltage of solar cell :- (Voc) It is measured by measuring voltage across the terminals of the cell when no load is connected to the cell.

Maximum power point of solar cell :- (Pm) The maximum electrical power one solar cell can deliver at its standard test condition. If we draw the VI characteristics maximum power will occur at the bend point of the characteristic curve denoted by Pm.

→ Current & voltage at maximum power point is denoted by Im & Vm

→ Efficiency = $\eta = \frac{P_m}{P_{in}}$

Materials used in solar cell :-

1. Silicon, ② GaAs ③ CdTe ④ CuInSe$_2$

Advantages of solar cell :-

→ No pollution associated with it
→ It must last for a long time
→ No maintenance cost

Disadvantages of solar cell :-

→ It has high cost of installation
→ It has low efficiency
→ During cloudy day & night we will not get solar energy

Uses of solar generation systems :

→ It may be used to charge batteries
→ used in light meters
→ It is used to power calculators & wrist watches
→ It can be used in space craft to provide Electrical Energy.

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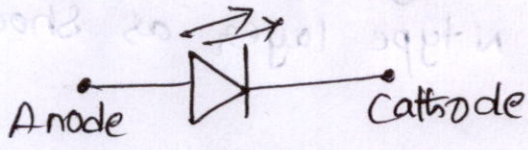
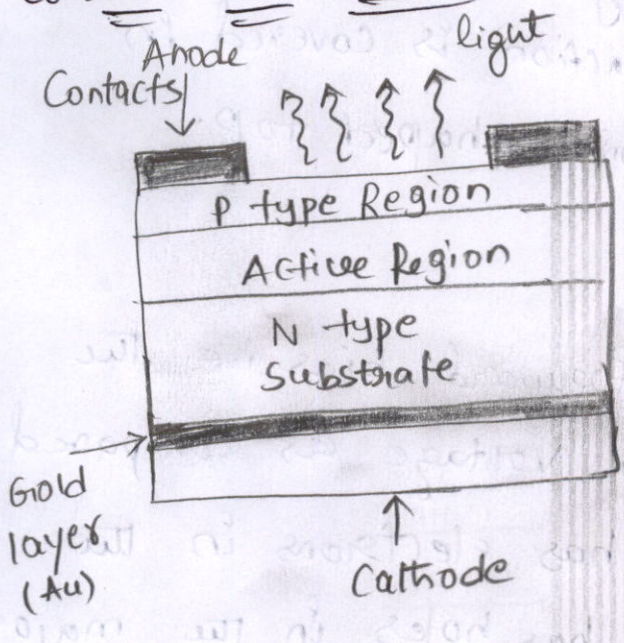
Light Emitting Diode:-

LED is a special type of diode that converts electrical energy into light energy. It is a simple PN junction diode that radiates light in forward bias.

Symbol of LED:- The symbol of LED resembles any conventional PN junction diode except it has arrows pointing outward representing the emission of light as shown in below figure



Construction of LED:-



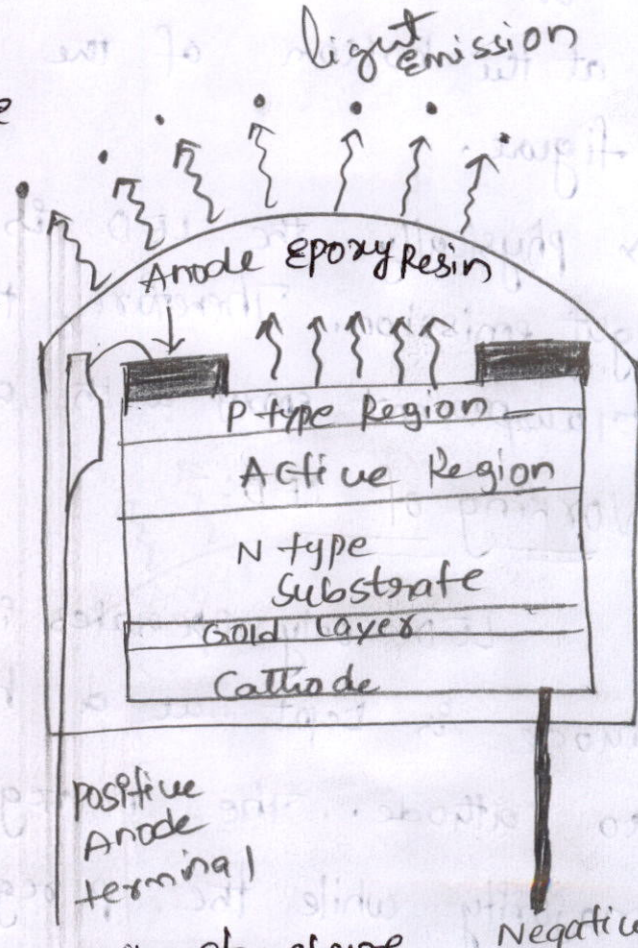


fig: Structure of LED

LED is made of 3 layers p type semiconductor layer, and N type semiconductor layer and active region.

→ The N layer had the majority of electrons & the p layer has a majority of holes. The active Region has Equal no. of holes & electrons in active Region.

→ The layer of p type material and N type material is combined together on top of each other with an active region between them. As the electron hole recombination occurs in p region, the p layer is kept at the top & the anode is deposited at the edge of the p layer to have maximum light emission.

→ While for the cathode, a gold film is deposited at the bottom of the N type layer as shown in the figure.

→ physically the LED is designed to have maximum light emission. Therefore, the function is covered in transparent epoxy with a dome shaped top.

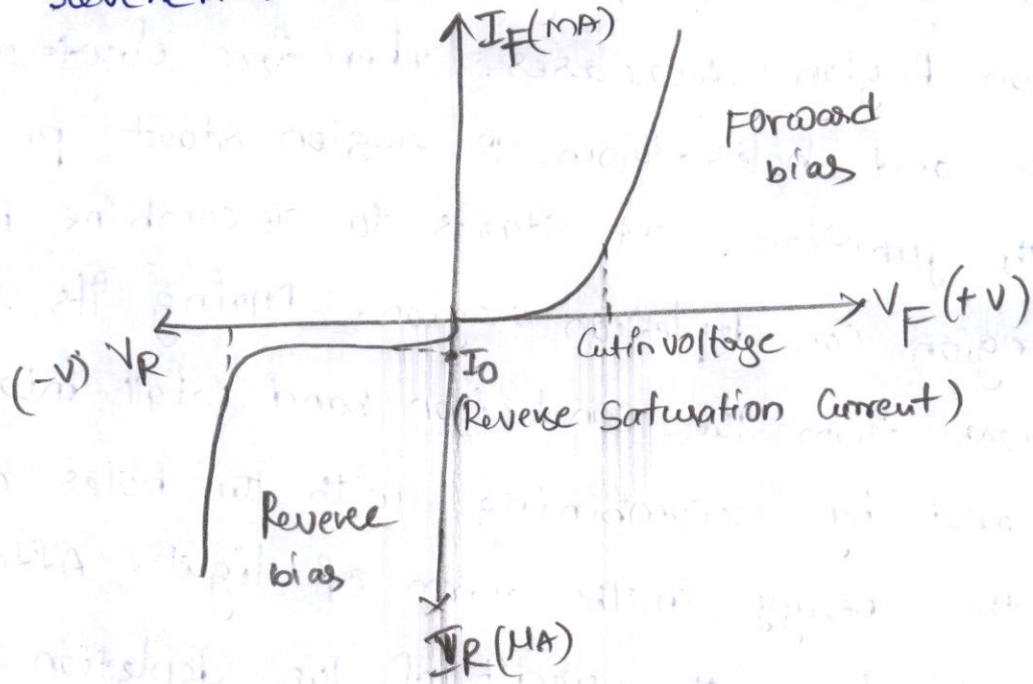
Working of LED:-

LED only operates in forward bias i.e the anode is kept at a higher voltage as compared to cathode. The n region has electrons in the majority while the p region has holes in the majority. Apart from that n type layer is heavily doped as compared to p type.

VI Characteristics of LED:-

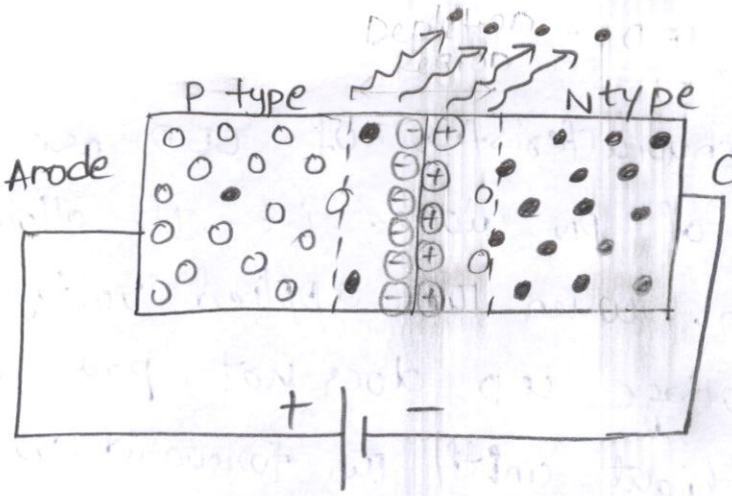
The VI characteristics of LED are same as VI characteristics of PN diode. i-e It allows current in forward direction. when the applied voltage is less than the cutin voltage LED does not pass current and does not produce light until the forward voltage exceeds the knee voltage

→ Under reverse bias LED acts as a normal diode.

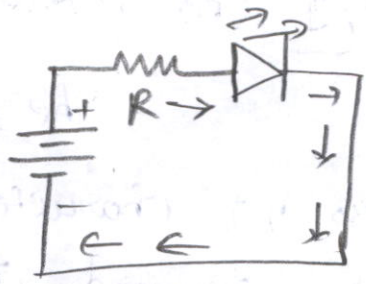


Advantages of LED:-

→ The operating temperature of LED ranges from 0° to 70°C
→ LED can withstand mechanical shock & vibrations.
→ It has longer life span.
→ It requires very small voltage & consumes very low power.
→ LEDs are cheaper & very reliable
→ The switching time of LED is very fast in the range of 1ns.



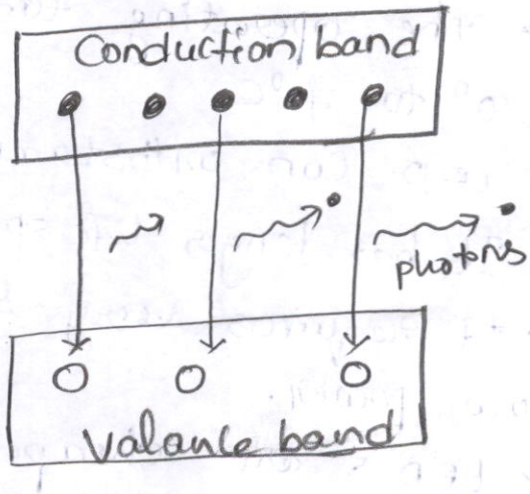
Working of LED



Equivalent circuit of LED

when LED is forward biased, the applied potential starts pushing on the P layer & the N layer. As a result the depletion Region decreases. Therefore electrons from n region and holes from p region start passing through the function. It starts to recombine in the active region (or) depletion region. During its recombination the electrons from the conduction band fall into the valance band by recombining with the holes and release the energy in the form of light. After a few recombination, the width of the depletion region further decreases & the intensity of light is increased.

→ The convertion of electricity into light energy is called Electro Luminance. The semi conductors exhibit such property are GaAs, GaAsp, GaP.



→ Intensity of LED is can be controlled by varying the current flowing through it.

Disadvantages:

→ LEDs are not as energy efficient as LCDs Therefore it cannot be made into a large display.
→ It is expensive as compared to a large LCD.
→ High initial price
→ Temperature dependence
→ It is liable to get damaged by over voltage (or) over current.

Applications of LEDs:—

→ LED's are used in traffic signs & signal lights at every intersection & in the street lights.
→ used as a display in digital clocks, calculators and digital multimeters, etc.,
→ Colourful LEDs are used for decorations & in toys
→ In automobiles, they are used for lighting as well as indicators.
→ Laser LED's of a single wavelengths are used in optical communication.
→ It is indeed in digital camera flashes & torch lights.
→ LEDs are used in medical equipment.