5.10 LIGHT EMITTING DIODE (LED)

Light Emitting Diode (LED) works only in forward bias condition. When Light Emitting Diode (LED) is forward biased, the free electrons from n-side and the holes from p-side are pushed towards the junction.

When free electrons reach the junction or depletion region, some of the free electrons recombine with the holes in the positive ions. We know that positive ions have less number of electrons than protons. Therefore, they are ready to accept electrons. Thus, free electrons recombine with holes in the depletion region. In the similar way, holes from p-side recombine with electrons in the depletion region.

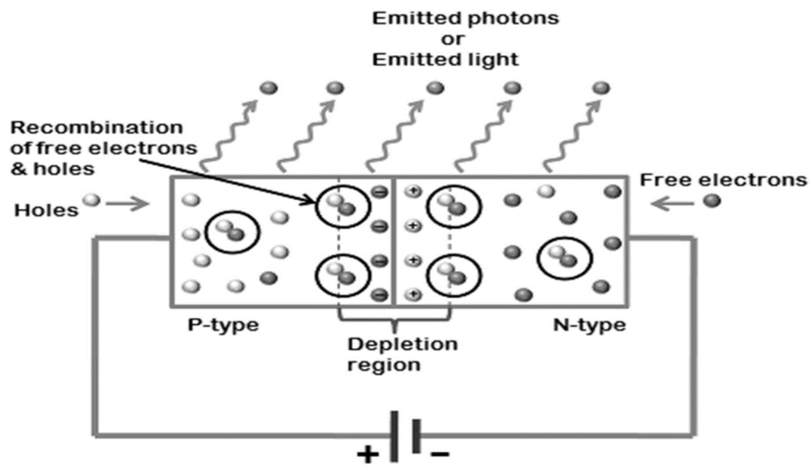

Fig:5.10.1 Working of Light Emitting Diode

Because of the recombination of free electrons and holes in the depletion region, the width of depletion region decreases. As a result, more charge carriers will cross the p-n junction.

Some of the charge carriers from p-side and n-side will cross the p-n junction before they recombine in the depletion region. For example, some free electrons from n-type semiconductor cross the p-n junction and recombines with holes in p-type semiconductor. In the similar way, holes from p-type semiconductor cross the p-n junction and recombines with free electrons in the n-type semiconductor.

Thus, recombination takes place in depletion region as well as in p-type and n-type semiconductor.

The free electrons in the conduction band releases energy in the form of light before they recombine with holes in the valence band.

In silicon and germanium diodes, most of the energy is released in the form of heat and emitted light is too small.

However, in materials like gallium arsenide and gallium phosphide the emitted photons have sufficient energy to produce intense visible light.

When external voltage is applied to the valence electrons, they gain sufficient energy and breaks the bonding with the parent atom. The valence electrons which breaks bonding with the parent atom are called free electrons.

When the valence electron left the parent atom, they leave an empty space in the valence shell at which valence electron left. This empty space in the valence shell is called a hole.

The energy level of all the valence electrons is almost same. Grouping the range of energy levels of all the valence electrons is called valence band.

In the similar way, energy level of all the free electrons is almost same. Grouping the range of energy levels of all the free electrons is called conduction band.

The energy level of free electrons in the conduction band is high compared to the energy level of valence electrons or holes in the valence band. Therefore, free electrons in the conduction band need to lose energy in order to recombine with the holes in the valence band.

The free electrons in the conduction band do not stay for long period. After a short period, the free electrons lose energy in the form of light and recombine with the holes in the valence band. Each recombination of charge carrier will emit some light energy.

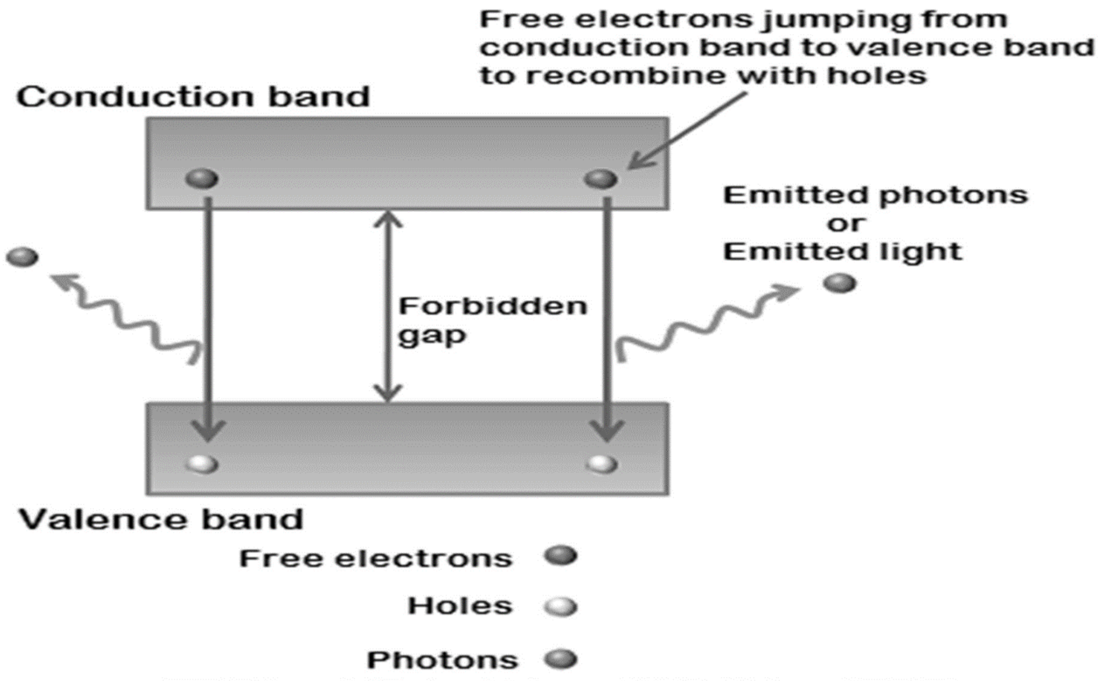

Fig:5.10.2 Process of Light Emission in LED

The energy lose of free electrons or the intensity of emitted light is depends on the forbidden gap or energy gap between conduction band and valence band.

The semiconductor device with large forbidden gap emits high intensity light whereas the semiconductor device with small forbidden gap emits low intensity light.

In other words, the brightness of the emitted light is depends on the material used for constructing LED and forward current flow through the LED.

In normal silicon diodes, the energy gap between conduction band and valence band is less. Hence, the electrons fall only a short distance. As a result, low energy photons are released. These low energy photons have low frequency which is invisible to human eye.

In LEDs, the energy gap between conduction band and valence band is very large so the free electrons in LEDs have greater energy than the free electrons in silicon diodes. Hence, the free electrons fall to a large distance. As a result, high energy photons are released. These high energy photons have high frequency which is visible to human eye.

The efficiency of generation of light in LED increases with increase in injected current and with a decrease in temperature.

In light emitting diodes, light is produced due to recombination process. Recombination of charge carriers takes place only under forward bias condition. Hence, LEDs operate only in forward bias condition.

When light emitting diode is reverse biased, the free electrons (majority carriers) from n-side and holes (majority carriers) from p-side moves away from the junction. As a result, the width of depletion region increases and no recombination of charge carriers occur. Thus, no light is produced.

If the reverse bias voltage applied to the LED is highly increased, the device may also be damaged.

All diodes emit photons or light but not all diodes emit visible light. The material in an LED is selected in such a way that the wavelength of the released photons falls within the visible portion of the light spectrum.

Light emitting diodes can be switched ON and OFF at a very fast speed of 1 ns.

Light emitting diode (LED) symbol

The symbol of LED is similar to the normal p-n junction diode except that it contains arrows pointing away from the diode indicating that light is being emitted by the diode.

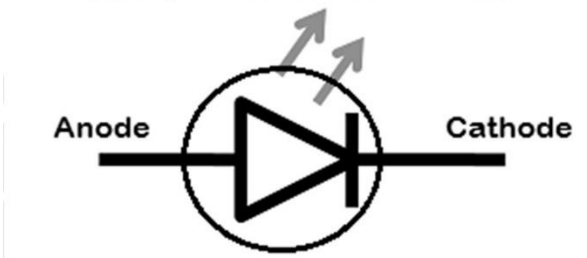

Fig:5.10.3 Symbol of Light Emitting Diode

LEDs are available in different colors. The most common colors of LEDs are orange, yellow, green and red.

The schematic symbol of LED does not represent the color of light. The schematic symbol is same for all colors of LEDs. Hence, it is not possible to identify the color of LED by seeing its symbol.

LED construction

One of the methods used to construct LED is to deposit three semiconductor layers on the substrate. The three semiconductor layers deposited on the substrate are n-type semiconductor, p-type semiconductor and active region. Active region is present in between the n-type and p-type semiconductor layers.

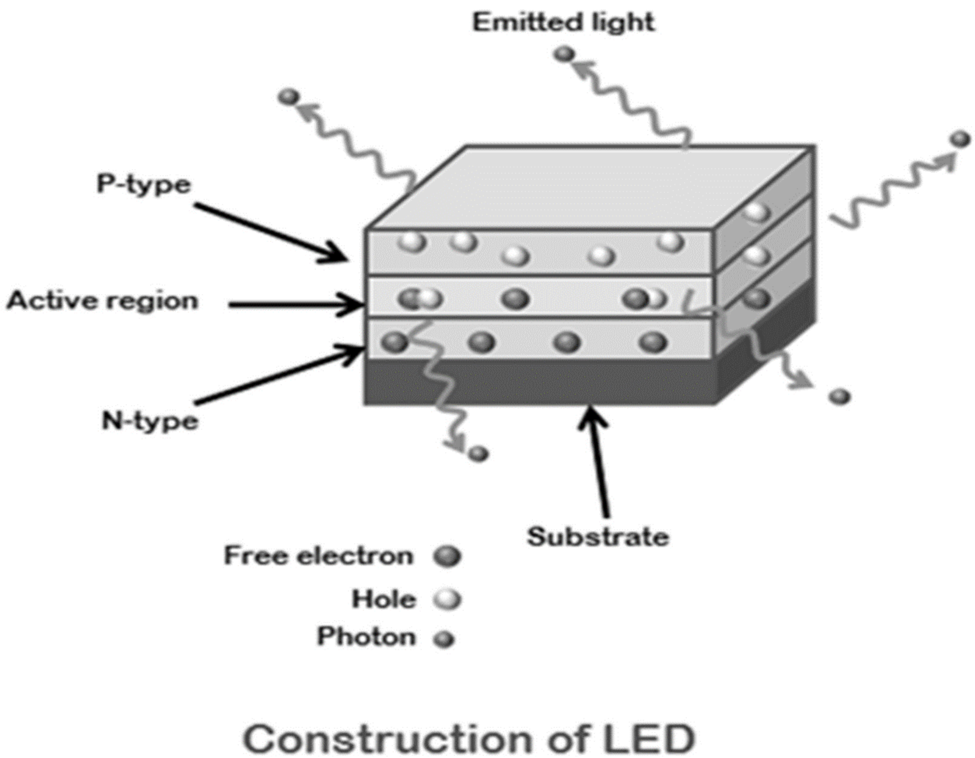

Fig:5.10.4 Construction of Light Emitting Diode

When LED is forward biased, free electrons from n-type semiconductor and holes from p-type semiconductor are pushed towards the active region.

When free electrons from n-side and holes from p-side recombine with the opposite charge carriers (free electrons with holes or holes with free electrons) in active region, an invisible or visible light is emitted.

In LED, most of the charge carriers recombine at active region. Therefore, most of the light is emitted by the active region. The active region is also called as depletion region.

Biasing of LED

The safe forward voltage ratings of most LEDs is from 1V to 3 V and forward current ratings is from 200 mA to 100 mA.

If the voltage applied to LED is in between 1V to 3V, LED works perfectly because the current flow for the applied voltage is in the operating range. However, if the voltage applied to LED is increased to a value greater than 3 volts. The depletion region in the LED breaks down and the electric current suddenly rises. This sudden rise in current may destroy the device.

To avoid this we need to place a resistor (Rs) in series with the LED. The resistor (Rs) must be placed in between voltage source (Vs) and LED.

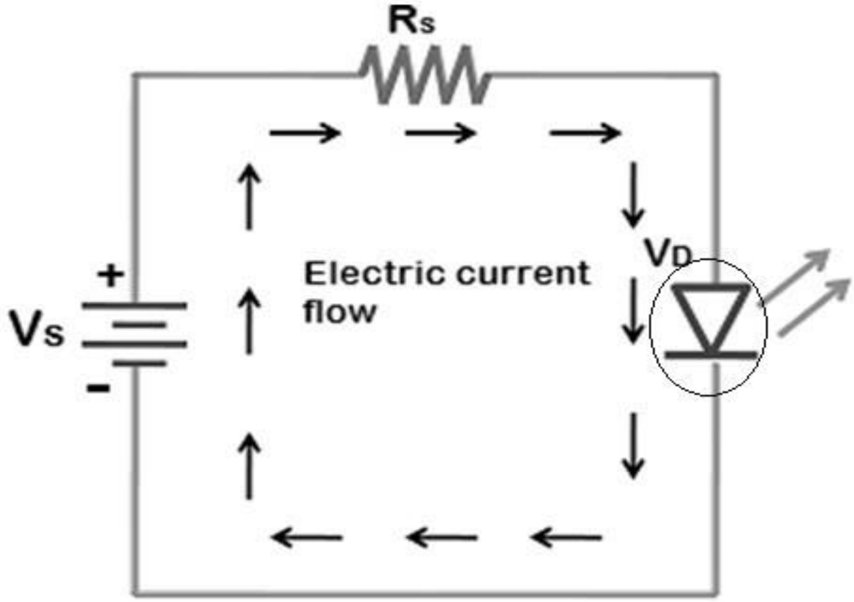

Fig:5.10.5 Biasing of Light Emitting Diode

The resistor placed between LED and voltage source is called current limiting resistor. This resistor restricts extra current which may destroy the LED. Thus, current limiting resistor protects LED from damage.

The current flowing through the LED is mathematically written as

$$I_F = \frac{V_s - V_D}{R_s}$$

Where,

IF = Forward current

VS = Source voltage or supply voltage

VD = Voltage drop across LED

RS = Resistor or current limiting resistor

Voltage drop is the amount of voltage wasted to overcome the depletion region barrier (which leads to electric current flow).

The voltage drop of LED is 2 to 3V whereas silicon or germanium diode is 0.3 or 0.7 V. Therefore, to operate LED we need to apply greater voltage than silicon or germanium diodes.

Light emitting diodes consume more energy than silicon or germanium diodes to operate.

Output characteristics of LED

The amount of output light emitted by the LED is directly proportional to the amount of forward current flowing through the LED. More the forward current, the greater is the emitted output light. The graph of forward current vs output light is shown in the figure.

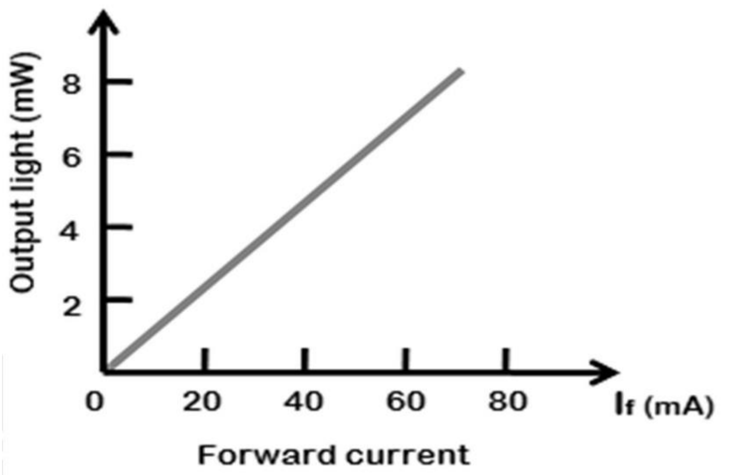

Fig:5.10.6 Characteristics of Light Emitting Diode

Visible LEDs and invisible LEDs

LEDs are mainly classified into two types: visible LEDs and invisible LEDs.

Visible LED is a type of LED that emits visible light. These LEDs are mainly used for display or illumination where LEDs are used individually without photosensors.

Invisible LED is a type of LED that emits invisible light (infrared light). These LEDs are mainly used with photosensors such as photodiodes.

Determines the color of an LED

The material used for constructing LED determines its color. In other words, the wavelength or color of the emitted light depends on the forbidden gap or energy gap of the material.

Different materials emit different colors of light.

Gallium arsenide LEDs emit red and infrared light.

Gallium nitride LEDs emit bright blue light.

Yttrium aluminium garnet LEDs emit white light.

Gallium phosphide LEDs emit red, yellow and green light.

Aluminium gallium nitride LEDs emit ultraviolet light.

Aluminum gallium phosphide LEDs emit green light.

Advantages of LED

1. The brightness of light emitted by LED is depends on the current flowing through the LED. Hence, the brightness of LED can be easily controlled by varying the current. This makes possible to operate LED displays under different ambient lighting conditions.
2. Light emitting diodes consume low energy.
3. LEDs are very cheap and readily available.
4. LEDs are light in weight.
5. Smaller size.
6. LEDs have longer lifetime.
7. LEDs operates very fast. They can be turned on and off in very less time.
8. LEDs do not contain toxic material like mercury which is used in fluorescent lamps.
9. LEDs can emit different colors of light.

Disadvantages of LED

1. LEDs need more power to operate than normal p-n junction diodes.
2. Luminous efficiency of LEDs is low.

Applications of LED

The various applications of LEDs are as follows

1. Burglar alarms systems
2. Calculators
3. Picture phones
4. Traffic signals
5. Digital computers
6. Multimeters
7. Microprocessors
8. Digital watches
9. Automotive heat lamps
10. Camera flashes
11. Aviation lighting

5.2 SILICON CONTROLLED RECTIFIER (SCR)

Silicon Controlled Rectifier (SCR) is a unidirectional semiconductor device made of silicon which can be used to provide a selected power to the load by switching it ON for variable amount of time. These devices are solid-state equivalent of thyratrons and are hence referred to as thyristors or thyrode transistors. In fact, SCR is a trade name of General Electric (GE) to the thyristor. Basically SCR is a three terminal, four-layer (hence of three junctions J1, J2 and J3) semiconductor device consisting of alternate layers of p- and n-type material doping. Figure 1a shows the SCR with the layers pnpn which has the terminals Anode (A), Cathode (K) and the Gate (G). Further it is to be noted that the Gate terminal will generally be the p-layer nearer to the Cathode terminal.

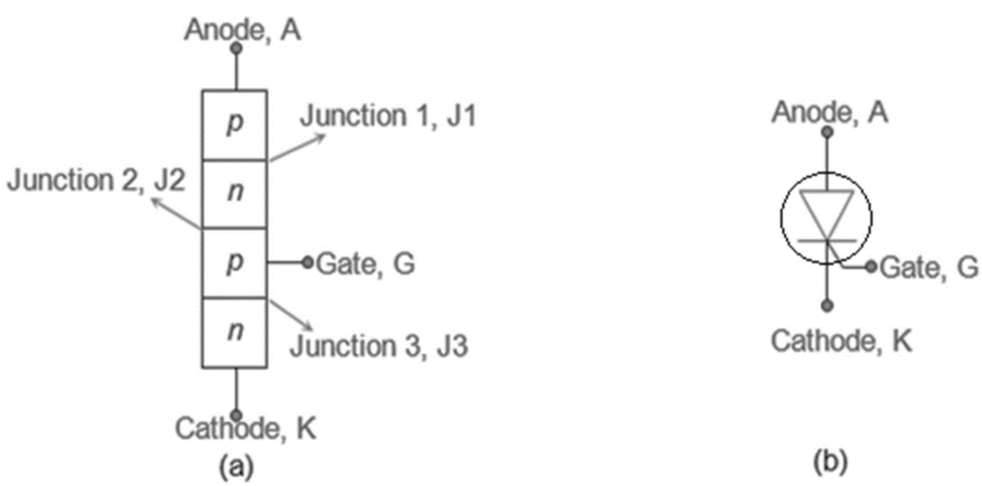

Fig:5.2.1 (a) SCR Construction (b) SCR Symbol

These SCRs can be considered equivalent to two inter-connected transistors

Here it is seen that a single SCR is equal to a combination of pnp (Q1) and npn (Q2) transistors where the emitter of Q1 will act as the anode terminal of the SCR while the emitter of Q2 will be its cathode. Further, the base of Q1 is connected to the collector of Q2 and the collector of Q1 is shorted with the base of Q2 to result in the gate terminal of the SCR.

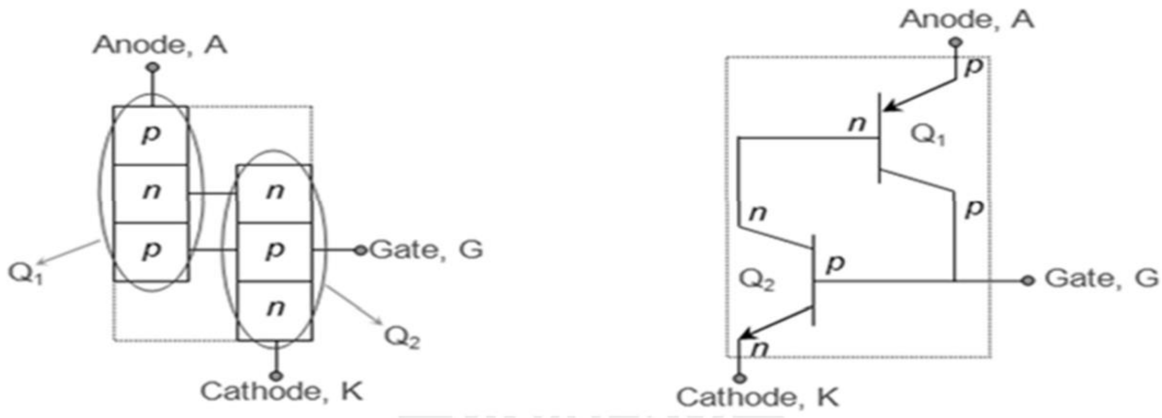

Fig:5.2.2 SCR Realization interms of BJT

The working of SCR can be understood by analyzing its behaviour in the following modes:

1. **Reverse Blocking Mode:** In this mode, the SCR is reverse biased by connecting its Anode terminal to negative end of the battery and by providing its Cathode terminal with a positive voltage. This leads to the reverse biasing of the junctions J1 and J3, which inturn prohibits the flow of current through the device, inspite of the fact that the junction J2 will be forward biased. Further, in this state, the SCR behaviour will be identical to that of a typical diode as it exhibits both the flow of reverse saturation current as well as the reverse break-down phenomenon.

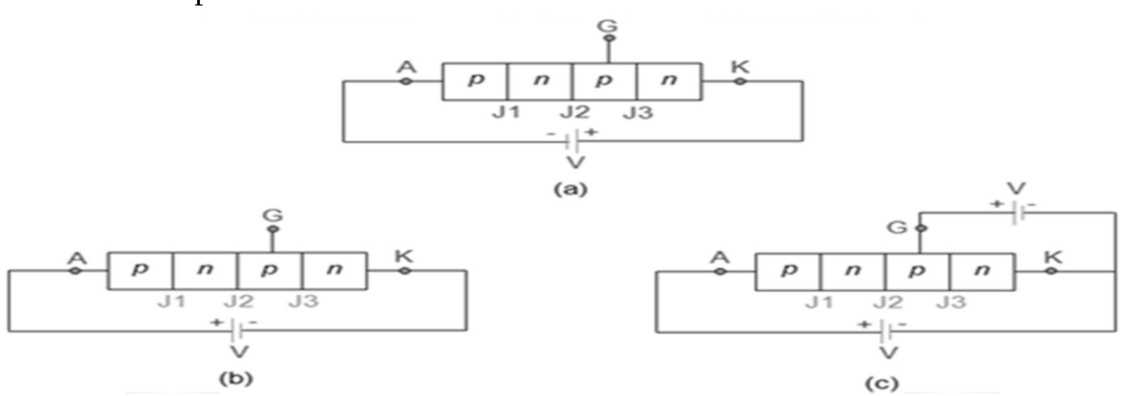

Fig:5.2.3 Biasing of Silicon Controlled Rectifier

2. **Forward Blocking Mode:** Here a positive bias is applied to the SCR by connecting its Anode to the positive of the battery and by shorting the SCR cathode to the battery's negative terminal, as shown by Figure 3b. Under this condition, the junctions J1 and J3 gets forward biased while J2 will be reverse biased which allows only a minute amount of current flow through the device.

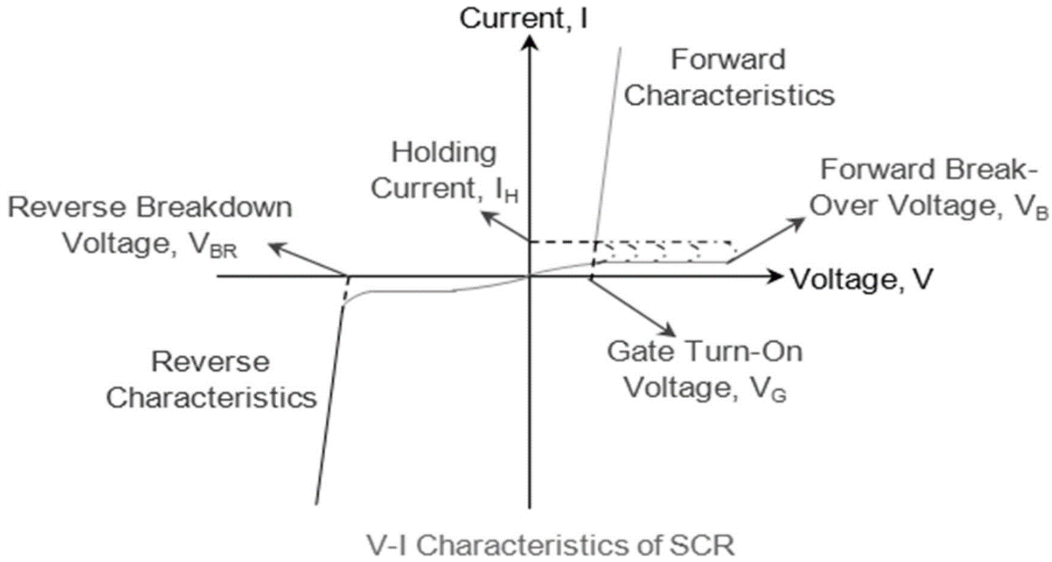

Fig:5.2.4 (a) SCR Construction (b) SCR Symbol

3. **Forward Conduction Mode:** SCR can be made to conduct either (i) By Increasing the positive voltage applied between the Anode and Cathode terminals beyond the Break-Over Voltage, VB or (ii) By applying positive voltage at its gate terminal as shown by Figure 3c. In the first case, the increase in the applied bias causes the initially reverse biased junction J2 to break-down at the point corresponding to Forward Break-Over Voltage, VB. This results in the sudden increase in the current flowing through the SCR as shown by the pink curve in Figure 4, although the gate terminal of the SCR remains unbiased.

However SCRs can be made to turn-on at a much smaller voltage level by proving small positive voltage between the gate and the cathode terminals. The reason behind this can be better understood by considering the transistor equivalent circuit of the SCR. Here it is seen that on applying positive voltage at the gate terminal, transistor Q2 switches ON and its collector current flows into the base of transistor Q1. This causes Q1 to switch ON which in turn results in the flow of its collector current into the base of Q2. This causes either transistor to get saturated at a very rapid rate and the action cannot be stopped even by removing the bias applied at the gate terminal, provided the current through the SCR is greater than that of the Latching current. Here the latching current is defined as the minimum current required to maintain the SCR in conducting state even after the gate pulse is removed.

In such state, the SCR is said to be latched and there will be no means to limit the current through the device, unless byusing an external impedance in the circuit. This necessitates one to resort for different techniques like Natural Commutation, Forced Commutation or Reverse Bias Turn-Off and Gate Turn-Off to switch OFF the SCR. Basically all of these techniques aim at reducing the Anode Current below the Holding Current, the minimum current which is to be maintained through the SCR to keep it in its conducting mode. Similar to turn-off techniques, there also exist different turn-on techniques for the SCR like Triggering by DC Gate Signal, Triggering by AC Gate Signal and Triggering by Pulsed Gate Signal, Forward-Voltage Triggering, Gate Triggering, dv/dt Triggering, Temperature Triggering and Light Triggering.

There are many variations of SCR devices viz., Reverse Conducting Thyristor (RCT), Gate Turn-Off Thyristor (GTO), Gate Assisted Turn-Off Thyristor (GATT), Asymmetric Thyristor, Static Induction Thyristors (SITH), MOS Controlled Thyristors (MCT), Light Activated Thyristors (LASCR) etc. Normally SCRs have high switching speed and can handle heavy current flow.

Application of SCR

1. Power switching circuits (for both AC and DC)
2. Zero-voltage switching circuits
3. Over voltage protection circuits
4. Controlled Rectifiers
5. Inverters
6. Battery Charging Regulator
7. Latching Relays
8. Computer Logic Circuits
9. Remote Switching Units
10. Phase Angle Triggered Controllers
11. Timing Circuits
12. IC Triggering Circuits
13. Welding Machine Control
14. Temperature Control Systems

5.3 DIODE AC SWITCH (DIAC)

Diac is a device which has two electrodes. It is a member of the thyristor family. It is mainly used in triggering of thyristor. The advantage of using this device is that it can be turned on or off simply by reducing the voltage level below its avalanche breakdown voltage. Also, it can be either turned on or off for both the polarity of voltages. This device works when avalanche breakdown occurs.

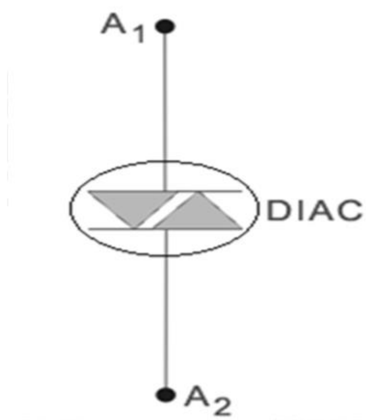

Fig:5.3.1 DIAC Symbol

The figure shows a symbol of diac which resembles the connection of two diodes in series. Also it can be called as a transistor without base.

Construction of Diac

It is a device which consists of four layers and two terminals. The construction is almost same as that of the transistor. But there are certain points which deviate from the construction from the transistor. The differentiating points are-

1. There is no base terminal in the diac.
2. The three regions have almost the same level of doping.
3. It gives symmetrical switching characteristics for either polarity of voltages.

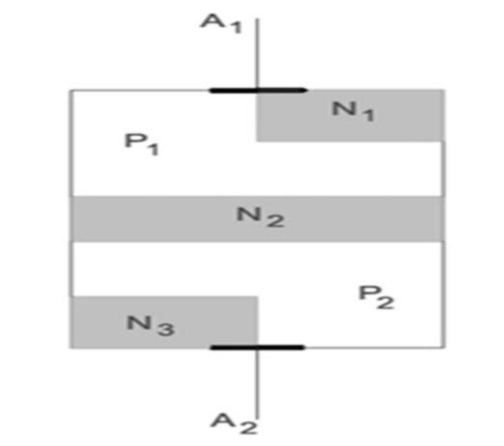

Fig:5.3.2 Construction of DIAC

Operation of Diac

From the figure, we see that it has two p-type material and three n-type materials. Also it does not have any gate terminal in it. The diac can be turned on for both the polarity of voltages. When A2 is more positive with respect to A1 then the current does not flows through the corresponding N-layer but flows from P2-N2-P1-N1. When A1 is more positive A2 then the current flows through P1-N2-P2-N3. The construction resembles the diode connected in series.

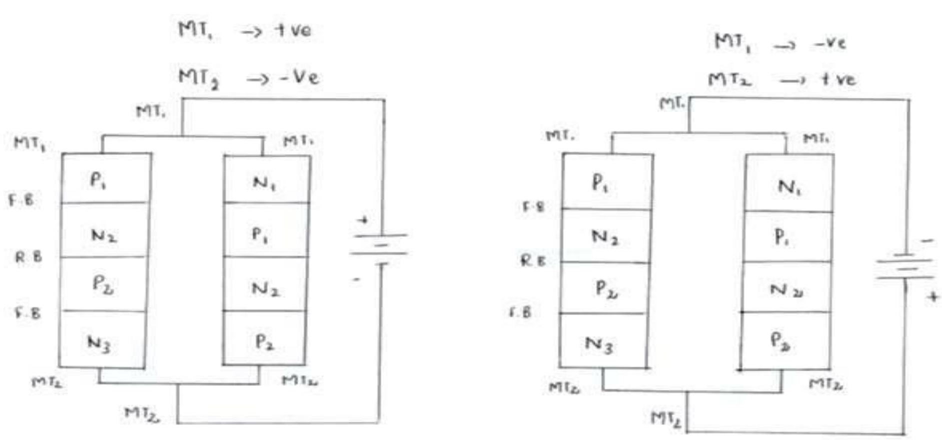

Fig:5.3.3 Biasing of DIAC

When applied voltage is small in either polarity, a very small current flows which is known as leakage current because of drift of electrons and holes in the depletion region. Although a small current flows, but it is not sufficient enough to produce avalanche breakdown so the device remains in the non conducting state. When the applied voltage in either polarity exceeds the breakdown voltage, diac current rises and the device conducts in accordance with its V-I characteristics.

The V-I characteristics resembles the english word Z. The diac acts as open circuit when the voltage is less than its avalanche breakdown voltage. When the device has to be turned off, the voltage must be reduced below its avalanche breakdown voltage.

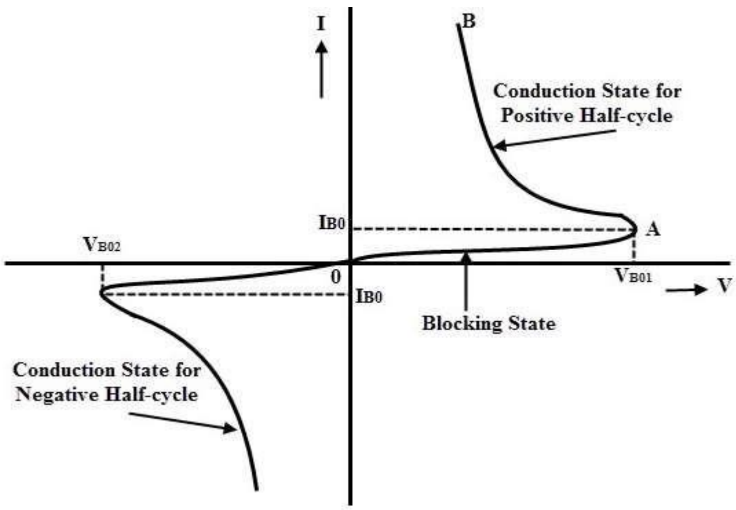

Fig:5.3.4 V-I Characteristics of DIAC

Application of Diac

It can be used mainly in the triac triggering circuit. The diac is connected in the gate terminal of the triac. When the voltage across the gate decreases below a predetermined value, the gate voltage will be zero and hence the triac will be turned off. The main applications are-

1. It can be used in the lamp dimmer circuit.
2. It is used in the heat control circuit.
3. It is used in the speed control of a universal motor.

5.8 OPTOCOUPLER or OPTO-ISOLATOR

An optocoupler or opto-isolator consists of a light emitter, the LED and a light sensitive receiver which can be a single photo-diode, photo-transistor, photo-resistor, photo-SCR, or a photo-TRIAC with the basic operation of an optocoupler being very simple to understand.

Phototransistor Optocoupler

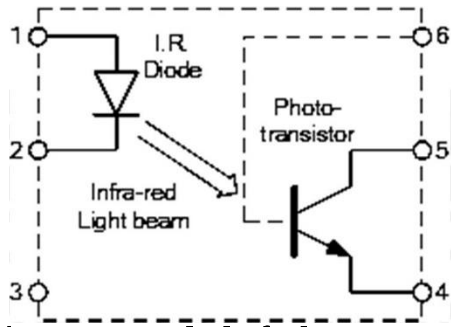

Fig:5.8.1 Symbol of Photo Transistor

Assume a photo-transistor device as shown. Current from the source signal passes through the input LED which emits an infra-red light whose intensity is proportional to the electrical signal.

This emitted light falls upon the base of the photo-transistor, causing it to switch-ON and conduct in a similar way to a normal bipolar transistor.

The base connection of the photo-transistor can be left open (unconnected) for maximum sensitivity to the LEDs infra-red light energy or connected to ground via a suitable external high value resistor to control the switching sensitivity making it more stable and resistant to false triggering by external electrical noise or voltage transients.

When the current flowing through the LED is interrupted, the infra-red emitted light is cut-off, causing the photo-transistor to cease conducting. The photo-transistor can be used to switch current in the output circuit. The spectral response of the LED and the photo-sensitive device are closely matched being separated by a transparent medium such as glass, plastic or air. Since there is no direct electrical connection between the input and output of an optocoupler, electrical isolation up to 10kV is achieved.

Optocouplers are available in four general types, each one having an infra-red LED source but with different photo-sensitive devices. The four optocouplers are called the: Photo-transistor, Photo-darlington, Photo-SCR and Photo-triac as shown below.

Optocoupler Types

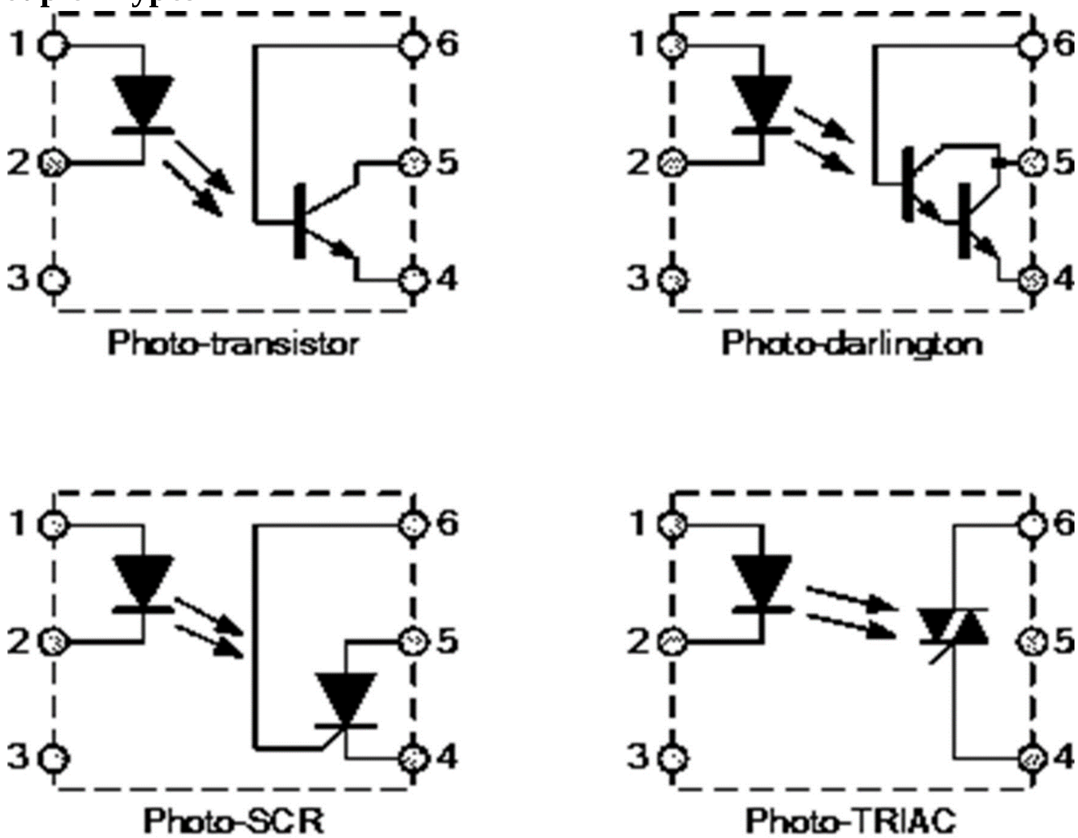

Fig:5.8.2 Symbol of Various Opto Coupler

The photo-transistor and photo-darlington devices are mainly for use in DC circuits while the photo-SCR and photo-triac allow AC powered circuits to be controlled. There are many other kinds of source-sensor combinations, such as LED-photodiode, LED-LASER, lamp-photoresistor pairs, reflective and slotted optocouplers.

Simple home made opto-couplers can be constructed by using individual components. An Led and a photo-transistor are inserted into a rigid plastic tube or encased in heat-shrinkable tubing as shown. The advantage of this home-made optocoupler is that tubing can be cut to any length you want and even bent around corners. Obviously, tubing with a reflective inner would be more efficient than dark black tubing.

Home-made Optocoupler

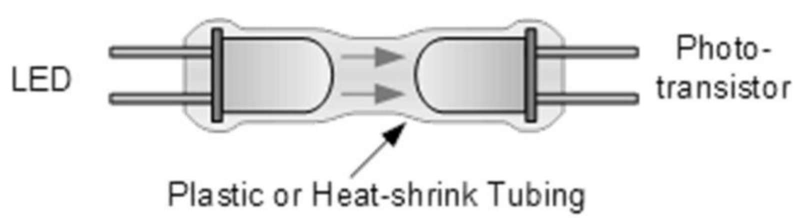

Fig:5.8.3 Homemade Optocoupler

Optocoupler Applications

Optocouplers and opto-isolators can be used on their own, or to switch a range of other larger electronic devices such as transistors and triacs providing the required electrical isolation between a lower voltage control signal, for example one from an Arduino or micro-controller, and a much higher voltage or mains current output signal.

Common applications for opto-couplers include microprocessor input/output switching, DC and AC power control, PC communications, signal isolation and power supply regulation which suffer from current ground loops, etc. The electrical signal being transmitted can be either analogue (linear) or digital (pulses).

In this application, the optocoupler is used to detect the operation of the switch or another type of digital input signal. This is useful if the switch or signal being detected is within an electrically noisy environment. The output can be used to operate an external circuit, light or as an input to a PC or microprocessor.

5.9 PHOTO TRANSISTOR

Phototransistors are either tri-terminal (emitter, base and collector) or bi-terminal (emitter and collector) semiconductor devices which have a light-sensitive base region. Although all transistors exhibit light-sensitive nature, these are specially designed and optimized for photo applications. These are made of diffusion or ion-implantation and have much larger collector and base regions in comparison with the ordinary transistors. These devices can be either homojunction structured or heterojunction structured, as shown by Figure respectively.

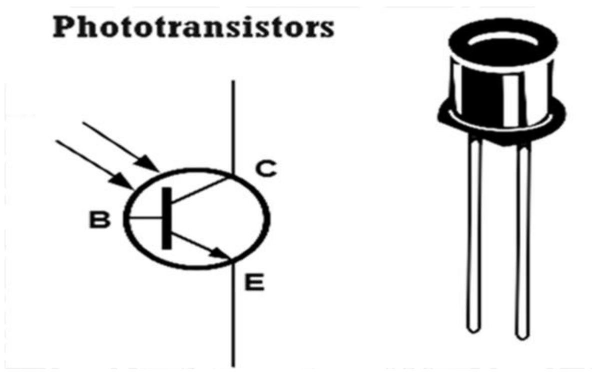

Fig:5.9.1 Symbol of Photo Transistor

In the case of homojunction phototransistors, the entire device will be made of a single material-type; either silicon or germanium. However to increase their efficiency, the phototransistors can be made of non-identical materials (Group III-V materials like GaAs) on either side of the pn junction leading to heterojunction devices. Nevertheless, homojunction devices are more often used in comparison with the hetero junction devices as they are economical.

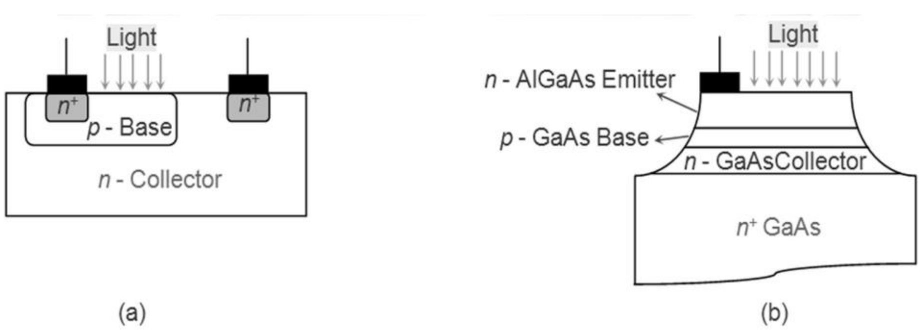

Fig:5.9.2 Photo Transistor (a) Homo Junction (b) Hetero Junction

The circuit symbol for npn phototransistors is shown by Figure 2 which is nothing but a transistor (with or without base lead) with two arrows pointing towards the base indicating its sensitivity to light. Similar symbolic representation holds well even in the case of pnp phototransistors with the only change being the arrow at emitter pointing in, instead of out.

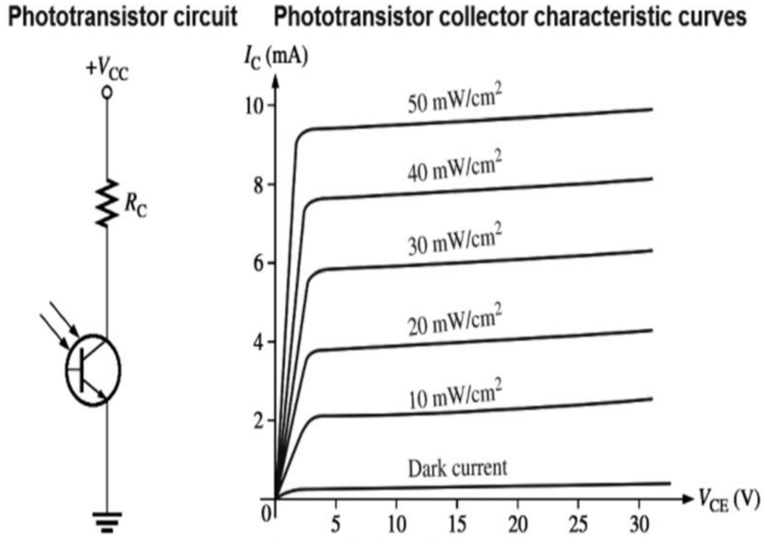

Fig:5.9.3 Characteristics of Photo Transistor

The behavior of phototransistors is identical to that of normal transistors except the fact that here the effect brought-about by the base voltage will be experienced due to the incident light. This can be made clearer by analyzing the following points

1. The characteristics of phototransistors are similar to those of normal transistors except that they have base current replaced by light intensity. This means that even these devices have three operating regions viz., cut-off, active and saturation. This further implies that the phototransistors can be used for either switching (cut-off and saturation mode dependent) applications or for amplification (active mode operation), just like ordinary transistors.
2. The phototransistors can be configured in two different configurations viz., common collector and common emitter, depending on the terminal which is common between the input and output terminals, similar to normal transistors.

3. A small reverse saturation current, called dark current, flows through the phototransistor even in the absence of light whose value increases with an increase in the value of temperature, a property identical to that exhibited by the ordinary transistors.
4. Phototransistors are prone to permanent damage due to breakdown if the voltage applied across the collector-emitter junction increases beyond its breakdown voltage, just as in the case of normal transistors.

Generally, in the case of phototransistor circuits, the collector terminal will be connected to the supply voltage and the output is obtained at the emitter terminal while the base terminal, if present, will be left unconnected. Under this condition, if light is made to fall on the base region of the phototransistor, then it results in the generation of electron-hole pairs which give rise to base current, nothing but the photo-current, under the influence of applied electric field. This further results in the flow of emitter current through the device, resulting in the process of amplification. This is because, here, the magnitude of the photo-current developed will be proportional to the luminance and will be amplified by the gain of the transistor leading to a larger collector current. The output of the phototransistor depends on varies factors like

- Wavelength of the incident light
- Area of the light-exposed collector-base junction
- DC current gain of the transistor.

Further, the characteristics of a particular phototransistor can be expressed interms of its

- Luminous sensitivity defined as the ratio of photoelectric current to the incident luminous flux
- Spectral response which decides the longest wavelength which can be used as the sensitivity of the phototransistors is a function of wavelength
- Photoelectric gain which indicates its efficiency of converting light into an amplified electrical signal
- Time constant which influences its response time.

However, it is important to note that the speed of response and the phototransistor gain are inversely proportional to each other, meaning which one decreases if the other increases.

Advantages of Phototransistor

1. Simple, compact and less expensive.
2. Higher current, higher gain and faster response times in comparison with photodiodes.
3. Results in output voltage unlike photo resistors.
4. Sensitive to a wide range of wavelengths ranging from ultraviolet (UV) to infrared (IR) through visible radiation.
5. Sensitive to large number of sources including incandescent bulbs, fluorescent bulbs, neon bulbs, lasers, flames and sunlight.
6. Highly reliable and temporally stable.
7. Less noisy when compared to avalanche photodiodes.
8. Available in wide variety of package types including epoxy-coated, transfer-molded and surface mounted.

Disadvantages of Phototransistor

1. Cannot handle high voltages if made of silicon.
2. Prone to electric spikes and surges.
3. Affected by electromagnetic energy.
4. Do not permit the easy flow of electrons unlike electron tubes.
5. Poor high frequency response due to a large base-collector capacitance.
6. Cannot detect low levels of light better than photodiodes.

Applications of Phototransistor

1. Object detection
2. Encoder sensing
3. Automatic electric control systems such as in light detectors
4. Security systems
5. Punch-card readers
6. Relays
7. Computer logic circuitry
8. Counting systems
9. Smoke detectors
10. Laser-ranging finding devices

11. Optical remote controls
12. CD players
13. Astronomy
14. Night vision systems
15. Infrared receivers
16. Printers and copiers
17. Cameras as shutter controllers
18. Level comparators

5.6 POWER MOSFET

Power MOSFET is a type of MOSFET which is specially meant to handle high levels of power. These exhibit high switching speed and can work much better in comparison with other normal MOSFETs in the case of low voltage levels. However its operating principle is similar to that of any other general MOSFET.

Power MOSFETs which are most widely used are n-channel Enhancement-mode or p-channel Enhancement-mode or n-channel Depletion-mode in nature.

Further, there are a wide variety of power MOSFET structures like Vertical Diffused MOS (VDMOS) or Double-Diffused MOS or DMOS, UMOS or Trench-MOS, VMOS, etc. An n-substrate VDMOS made of n-substrate and an n- epitaxial layer into which p and n+ regions are embedded into using double diffusion process.

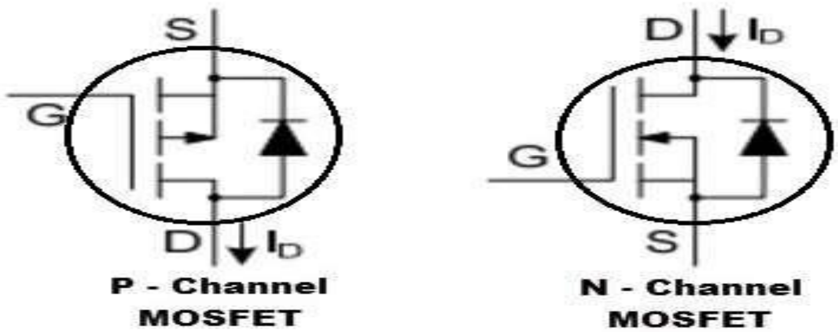

Fig:5.6.1 Symbol of Power MOSFET P and N Channel

Here the channel is formed in a p-type region when the gate-to-source voltage is made positive. Most importantly, here, the Source (S) terminal is placed over the Drain (D) terminal forming a vertical structure. As a result, in VDMOS the current flows beneath the gate area vertically between the source and the drain terminals through numerous n+ sources conducting in-parallel. As a result, the resistance offered by the device during its ON state RDS(ON) is much lower than that in the case of normal MOSFETs which enable them to handle high currents. This resistance of the device is seen to double as the current increments by about 6%. On the other hand RDS(ON) is highly influenced by the junction temperature TJ and is seen to be positive in nature.

Similar to this we can even have a p-substrate power MOSFET provided we replace n-type materials with p-type and then reverse the polarities of the voltages applied.

However they exhibit a much higher RDS(ON) in comparison with n-substrate devices as they employ holes as their majority charge carriers instead of electrons. Nevertheless, these are preferred to be used as buck converters.

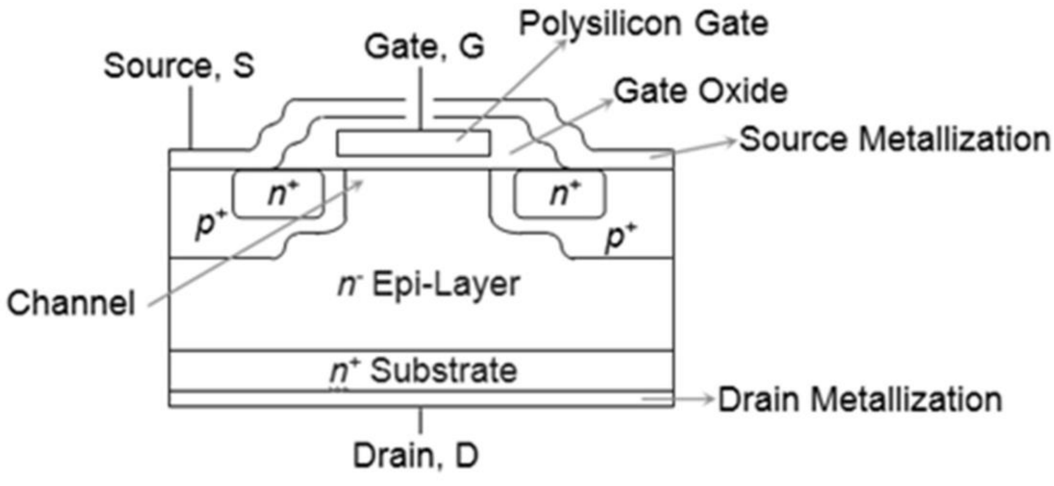

Fig:5.6.2 Construction of N Substrate Power MOSFET

Although the structures of the normal MOSFETs and the power MOSFETs are seen to be different, the basic principle behind their working remains unaltered. That is, in both of them the formation of conduction channel is the same which is nothing but the suitable bias applied at the gate terminal resulting in an inversion layer. As a result, the nature of transfer characteristics and the output characteristics exhibited by either of them are almost identical to each other.

Further, it is to be noted that in the case of power MOSFETs which are based on vertical structure, the doping and the thickness of the epitaxial layer decide the voltage rating while the channel width decides its current rating. This is the reason because of which they can sustain high blocking voltage and high current, making them suitable for low power switching applications. However even lateral-structure based MOSFETs exist which behaves better in comparison with vertical-structure based designs especially in saturated operating region, enabling their use in high-end audio amplifiers. Another advantage of power MOSFET is the fact that they can be paralleled as their forward voltage drop increases with an increase in the temperature which in turn assures equal current distribution amongst all of its components.

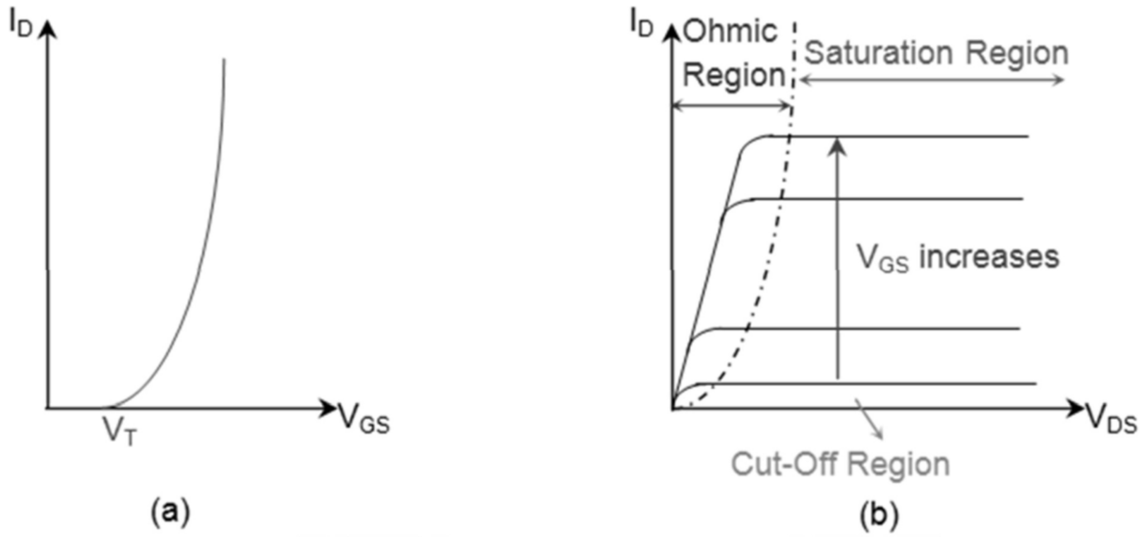

Fig:5.6.3 Power MOSFET (a) Transfer Characteristics (b) Output Characteristics

Applications of Power MOSFET

- DC to DC converters
- Low voltage motor controllers
- These are widely used in the low voltage switches which are less than the 200V

5.5 POWER TRANSISTOR

The symbol of the Power BJT is same as signal level transistor.

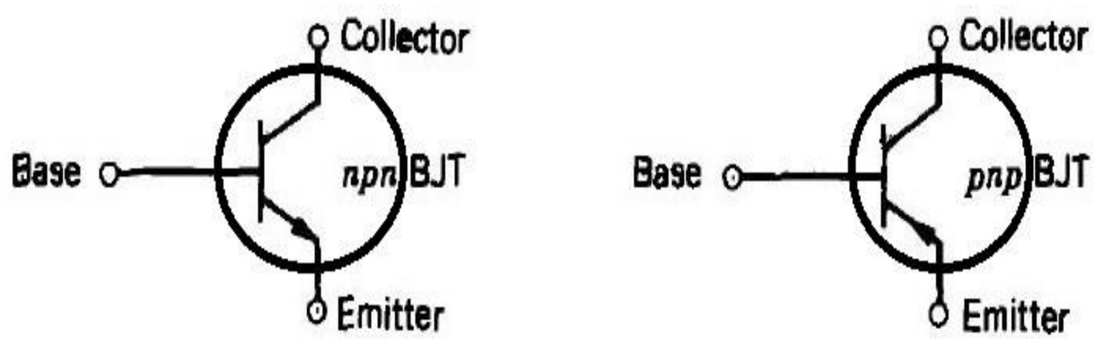

Fig:5.5.1 Symbol of Power Transistor NPN and PNP

Power BJT Structure:

The construction of the Power Transistor is different from the signal transistor as shown in the following figure.

The n- layer is added in the power BJT which is known as drift region.

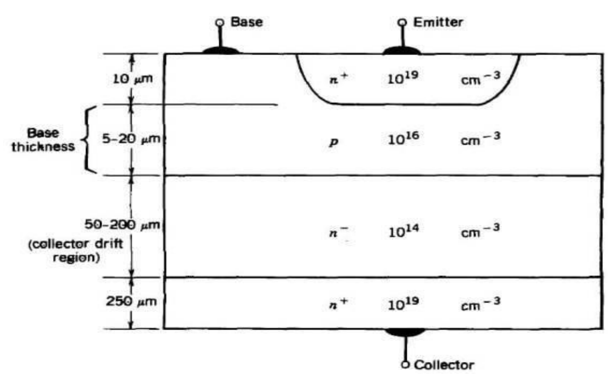

Fig:5.5.2 Construction of Power Transistor

- A Power BJT has a four layer structure of alternating P and N type doping as shown in above NPN transistor.
- It has three terminals labeled as Collector, Base, Emitter.
- In most of Power Electronic applications, the Power Transistor works in Common Emitter configuration.

- ie, Base is the input terminal, the Collector is the output terminal and the Emitter is common between input and output.
- In power switches NPN transistors are most widely used than PNP transistors.
- The characteristics of the device is determined by the doping level in each of the layers and the thickness of the layers.
- The thickness of the dirft region determines the breakdown voltage of the Power transistor.

Power BJT - VI Characteristics:

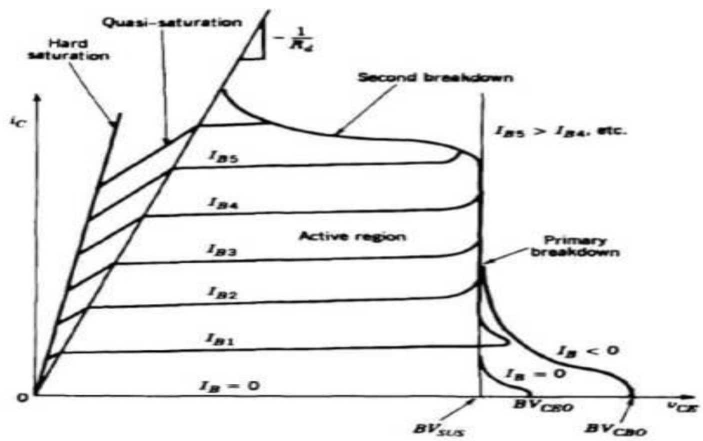

Fig:5.5.3 Characteristics of Power Transistor

- The VI characteristics of the Power BJT is different from signal level transistor.
- The major differences are Quasi saturation region & secondary breakdown region.
- The Quasi saturation region is available only in Power transistor characteristic not in signal transistors.
- It is because of the lightly doped collector drift region present in Power BJT.
- The primary breakdown is similar to the signal transistor's avalanche breakdown.
- Operation of device at primary and secondary breakdown regions should be avoided as it will lead to the catastrophic failure of the device.

5.7 SOLAR CELL

Solar Cell converts light energy into the electrical energy. A solar cell is basically a p-n junction diode. It utilizes photovoltaic effect to convert light energy into electrical energy.

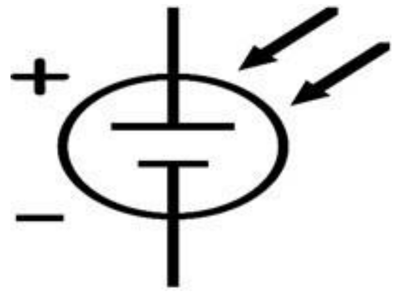

Fig:5.7.1 Symbol of Solar Cell

Construction of Solar Cell

Although this is basically a junction diode, but constructionally it is littlebit different form conventyional p-n junction diode. A very thin layer of p-type semiconductor is grown on a relatively thicker n-type semiconductor. We provide few finer electrodes on the top of the p-type semiconductor layer. These electrodes do not obstruct light to reach the thin p-type layer. Just below the p-type layer there is a p-n junction. We also provide a current collecting electrode at the bottom of the n-type layer. We encapsulate the entire assembly by thin glass to protect the solar cell from any mechanical shock.

Working Principle of Solar Cell

When light reaches the p-n junction, the light photons can easily enter in the junction, through very thin p-type layer. The light energy, in the form of photons, supplies sufficient energy to the junction to create a number of electron-hole pairs. The incident light, breaks the thermal equilibrium condition of the junction. The free electrons in the depletion region can quickly come to the n-type side of the junction. Similarly, the holes in the depletion can quickly come to the p-type side of the junction. Once, the newly created free electrons come to the n-type side, cannot further cross the junction because of barrier potential of the junction.

Similarly, the newly created holes once come to the p-type side cannot further cross the junction became of same barrier potential of the junction. As the concentration of electrons becomes higher in one side i.e. n-type side of the junction and concentration of holes becomes more in another side i.e. the p-type side of the junction, the p-n junction will behave like a small battery cell.

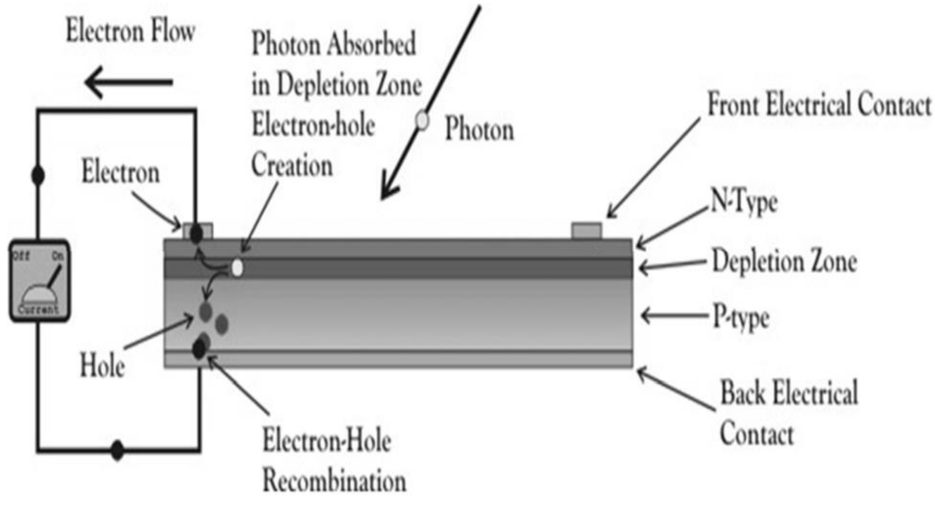

Fig:5.7.2 Working of Solar Cell

A voltage is set up which is known as photo voltage. If we connect a small load across the junction, there will be a tiny current flowing throgh it.

V-I Characteristics of a Photovoltaic Cell

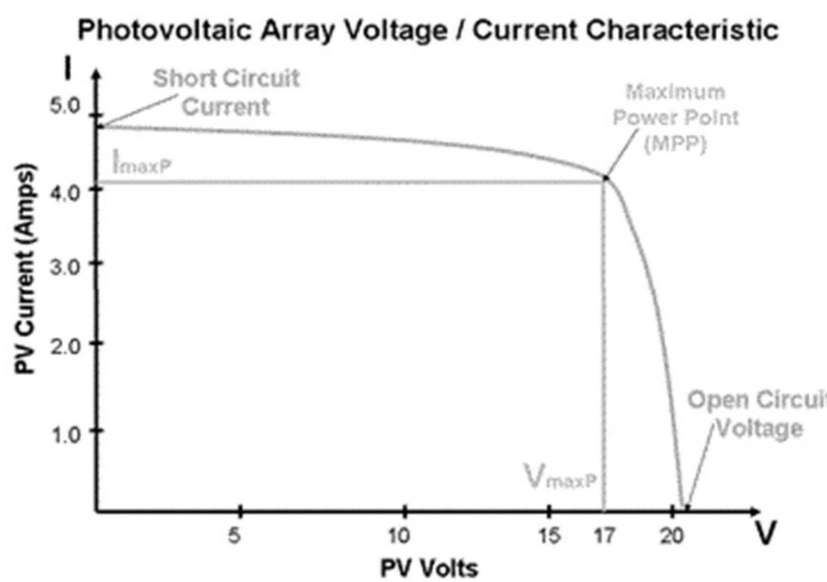

Fig:5.7.3 Characteristics of Solar Cell

Materials Used in Solar Cell

The materials which are used for this purpose must have band gap close to 1.5ev. Commonly used materials are-

1. Silicon.

2. GaAs.
3. CdTe.
4. CuInSe2

Materials to be Used in Solar Cell

1. Must have band gap from 1ev to 1.8ev.
2. It must have high optical absorption.
3. It must have high electrical conductivity.
4. The raw material must be available in abundance and the cost of the material must be low.

Advantages of Solar Cell

1. No pollution associated with it.
2. It must last for a long time.
3. No maintenance cost.

Disadvantages of Solar Cell

1. It has high cost of installation.
2. It has low efficiency.
3. During cloudy day, the energy cannot be produced and also at night we will not get solar energy.

Uses of Solar Generation Systems

1. It may be used to charge batteries.
2. Used in light meters.
3. It is used to power calculators and wrist watches.
4. It can be used in spacecraft to provide electrical energy.

5.4 THREE TERMINAL AC SWITCH (TRIAC)

Triac is a three terminal AC switch which is different from the other silicon controlled rectifiers in the sense that it can conduct in both the directions that is whether the applied gate signal is positive or negative, it will conduct. Thus, this device can be used for AC systems as a switch.This is a three terminal, four layer, bi-directional semiconductor device that controls AC power. The triac of maximum rating of 16 kw is available in the market.

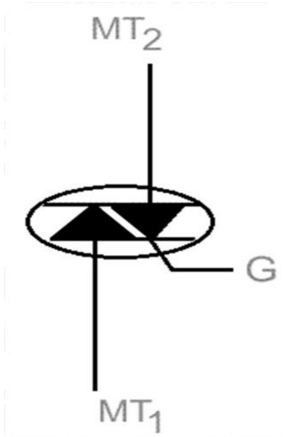

Fig:5.4.1 Symbol of TRIAC

Figure shows the symbol of triac, which has two main terminals MT1 and MT2 connected in inverse parallel and a gate terminal.

Construction of Triac

Two SCRs are connected in inverse parallel with gate terminal as common. Gate terminals is connected to both the N and P regions due to which gate signal may be applied which is irrespective of the polarity of the signal. Here, we do not have anode and cathode since it works for both the polarities which means that device is bilateral. It consists of three terminals namely, main terminal 1(MT1), main terminal 2(MT2), and gate terminal G.

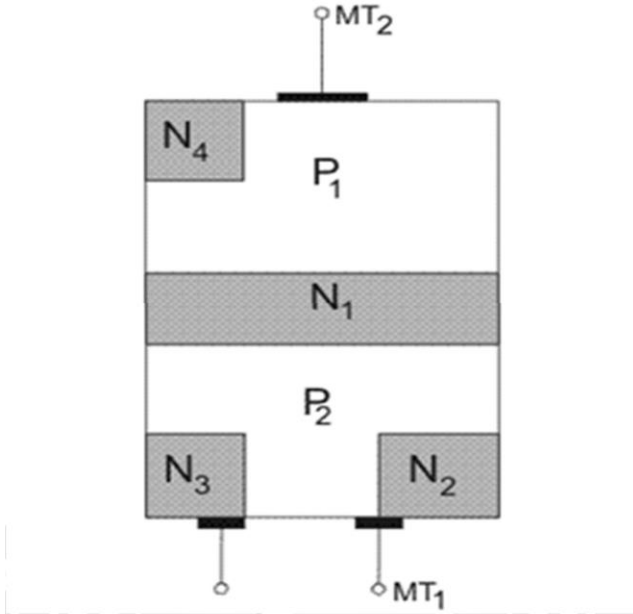

Fig:5.4.2 Construction of TRIAC

Figure shows the construction of a triac. There are two main terminals namely MT1 and MT2 and the remaining terminal is gate terminal.

Operation of Triac

The triac can be turned on by applying the gate voltage higher than break over voltage. However, without making the voltage high, it can be turned on by applying the gate pulse of 35 micro seconds to turn it on. When the voltage applied is less than the break over voltage, we use gate triggering method to turn it on. There are four different modes of operations, they are-

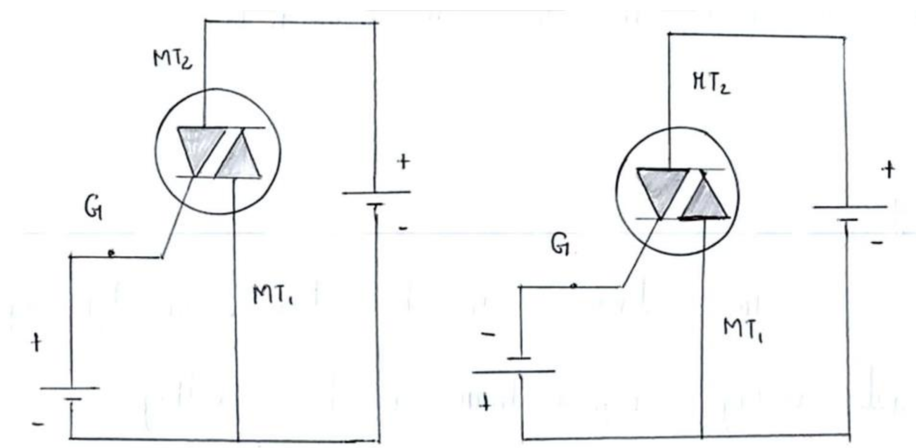

Fig:5.4.3 MT2 Positive and Gate Being Positive or Negative

1. **When MT2 and Gate being Positive with Respect to MT1** When this happens, current flows through the path P1-N1-P2-N2. Here, P1-N1 and P2-N2 are forward

biased but N1-P2 is reverse biased. The triac is said to be operated in positively biased region. Positive gate with respect to MT1 forward biases P2-N2 and breakdown occurs.

2. **When MT2 is Positive but Gate is Negative with Respect to MT1** The current flows through the path P1-N1-P2-N2. But P2-N3 is forward biased and current carriers injected into P2 on the triac.

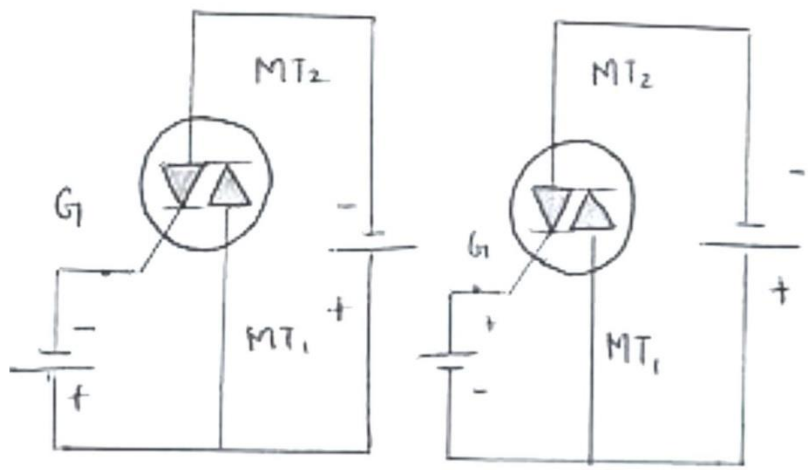

Fig:5.4.4 MT2 Negative and Gate Being Positive or Negative

3. **When MT2 and Gate are Negative with Respect to MT1** Current flows through the path P2-N1-P1-N4. Two junctions P2-N1 and P1-N4 are forward biased but the junction N1-P1 is reverse biased. The triac is said to be in thenegatively biased region.

4. **When MT2 is Negative but Gate is Positive with Respect to MT1** P2-N2 is forward biased at that condition. Current carriers are injected so the triac turns on. This mode of operation has a disadvantage that it should not be used for high (di/dt) circuits. Sensitivity of triggering in mode 2 and 3 is high and if marginal triggering capability is required, negative gate pulses should be used. Triggering in mode 1 is more sensitive than mode 2 and mode 3.

Characteristics of a Triac

The triac characteristics is similar to SCR but it is applicable to both positive and negative triac voltages. The operation can be summarized as follows-

First Quadrant Operation of Triac

Voltage at terminal MT2 is positive with respect to terminal MT1 and gate voltage is also positive with respect to first terminal.

Second Quadrant Operation of Triac

Voltage at terminal 2 is positive with respect to terminal 1 and gate voltage is negative with respect to terminal 1.

Third Quadrant Operation of Triac

Voltage of terminal 1 is positive with respect to terminal 2 and the gate voltage is negative.

Fourth Quadrant Operation of Triac

Voltage of terminal 2 is negative with respect to terminal 1 and gate voltage is positive.

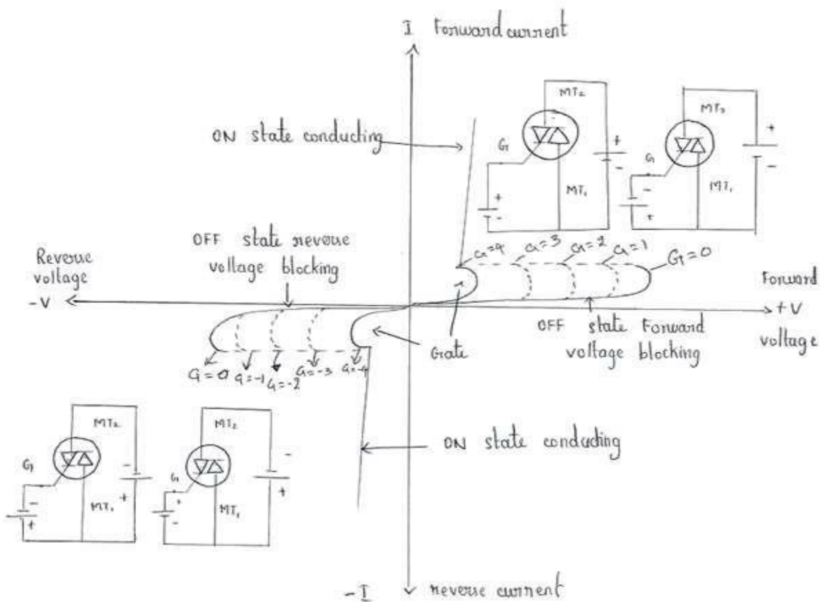

Fig:5.4.5 V-I Characteristics of TRIAC

When the device gets turned on, a heavy current flows through it which may damage the device, hence in order to limit the current a current limiting resistor should be connected externally to it. By applying proper gate signal, firing angle of the device may be controlled. The gate triggering circuits should be used for proper gate triggering. We can use diac for triggering the gate pulse. For firing of the device with proper firing angle, a gate pulse may be applied up to a duration of 35 micro seconds.

Advantages of Triac

1. It can be triggered with positive or negative polarity of gate pulses.
2. It requires only a single heat sink of slightly larger size, whereas for SCR, two heat sinks should be required of smaller size.
3. It requires single fuse for protection.
4. A safe breakdown in either direction is possible but for SCR protection should be given with parallel diode.

Disadvantages of Triac

1. They are not much reliable compared to SCR.
2. It has (dv/dt) rating lower than SCR.
3. Lower ratings are available compared to SCR.

Uses of Triac

1. They are used in control circuits.
2. It is used in High power lamp switching.
3. It is used in AC power control.

UNIT V POWER DEVICES AND DISPLAY DEVICES

5.1 UNIJUNCTION TRANSISTOR (UJT)

A typical UJT structure, pictured in figure, consists of a lightly doped, N-type silicon bar provided with ohmic contacts at each end. The two end connections are called base-l , designated B, and base-2, B2. A small, heavily doped P-region is alloyed into one side of the bar closer to 82. This P-region is the UJT emitter E, and forms a P-N junction with the bar.

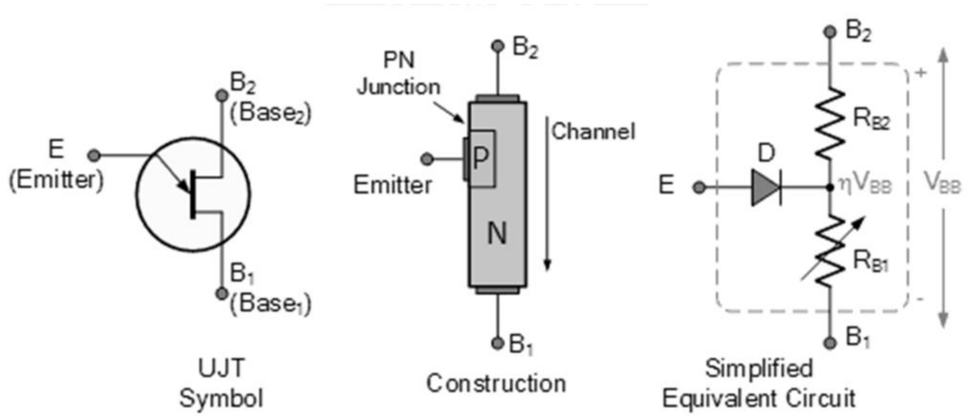

Fig:5.1.1 (a) UJT Symbol, (b) UJT Construction, (c) Equivalent Circuit

An interbase resistance, RBB, exists between B1 and B2. It is typically between 4 kΩ and 10kΩ, and can easily be measured with an ohmeter with the emitter open. RBB is essentially the resistance of the N-type bar. This interbase resistance can be broken up into two resistances, the resistance from B1 to emitter, called RB1 and resistance from B2 to emitter, called RB2. Since the emitter is closer to B2, the value of RB1 is greater than RB2 (typically 4.2 kΩ versus 2.8 kΩ).

The operation of the UJT can better be explained with the aid of an equivalent circuit.The UJT's circuit symbol and its equivalent circuit are shown in below. The diode represents the P-N junction between the emitter and the base-bar (point x). The arrow through RB1, indicates that it is variable since during nonnal operation it may typically range from 4 kΩ down to 10 Ω.

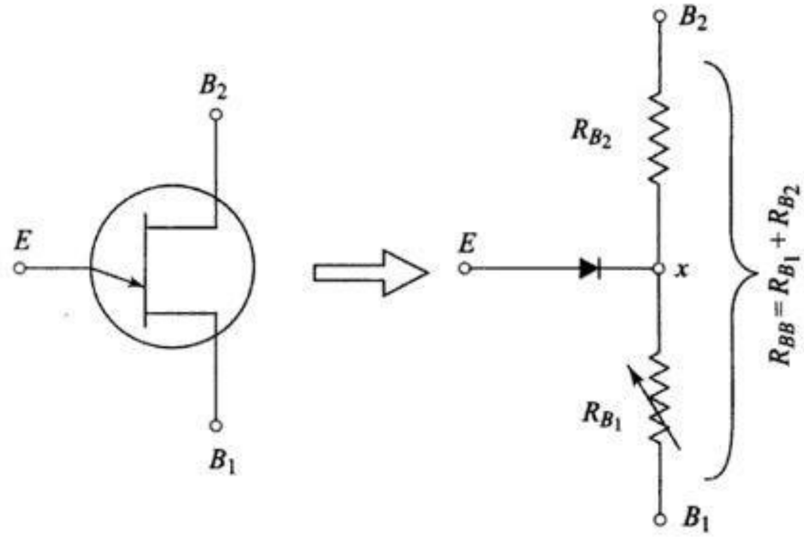

Fig:5.1.2 UJT Equivalent Circuit

UJT operation

(a) When the emitter diode is reverse biased, only a very small emitter current flows. Under this condition, RB1 is at its normal high-value (typically 4 kΩ). This is the UJT's "off" state.

(b) When the emitter diode becomes forward biased, RB1 drops to a very low value (reason to be explained later) so that the total resistance between E and BI becomes very low, allowing emitter current to flow readily. This is the "on" state.

Circuit Operation of Uni junction Transistor (UJT)

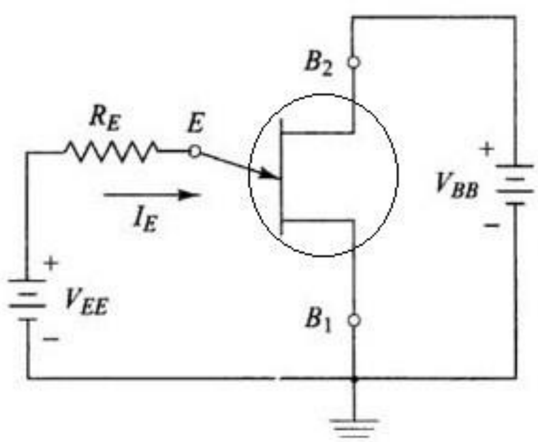

Fig:5.1.3 (a) Working of UJT

The UJT is normally operated with both B2 and E biased positive relative to B1 as shown in below figure. B1 is always the UJT reference terminal and all voltages are measured relative to B1. The VBB source is generally fixed and provides a constant voltage from B2 to B1. The VEE source is generally a variable voltage and is considered the input to the circuit. Very often, VEE is not a source but a voltage across a capacitor. The UJT circuit operation with the aid of the UJT equivalent circuit, shown inside the dotted lines in Fig.(a). We will also utilize the UJT emitter-base-1 VE-IE curve shown in Fig.(b). The curve represents the variation of emitter current IE, with emitter-base-1 voltage, VE, at a constant B2-B1 voltage. The important points on the curve are labelled, and typical values are given in parentheses.

The "Off " state If we neglect the diode fora moment, we can see in Fig.(a) that RB1 and RB2 form a voltage divider that produces a voltage Vx, from point x relative to ground.

$$V_x = \frac{R_{B_1}}{R_{B_1} + R_{B_2}} \times V_{BB} = \underbrace{\frac{R_{B_1}}{R_{BB}}}_{\eta} \times V_{BB}$$

Simply,

$$V_x = \eta\, V_{BB}$$

Where η (the greek letter "eta") is the internal UJT voltage divider ratio RB1/RBB and is called the intrinsic stand of ratio.

Values of η typically range from 0.5 to 0.8 but are relatively constant for a given UJT.

The voltage at point x is the voltage on the N-side of the P-N junction. The VEE source is applied to the emitter which is the P-side. Thus, the emitter diode will be reverse-biased as long as VEE is less than Vx This is the "off" state and is shown on the VE-IE curve as being a very low current region. In the "off" state, then, we can say that the UJT has a very high resistance between E and B1, and IE is usually a negligible reverse leakage current. With no IE, the drop across RE is zero and the emitter voltage, VE, equals the source-voltage.

The UJT "off " state, as shown on the VE-IE curve, actually extends to the point where the emitter voltage exceeds Vx by the diode threshold voltage, VD, which is needed to produce forward current through the diode. The emitter voltage and this point, P, is called the peak-point voltage, VP, and is given by

VP= Vx + VD= ηVBB+ VD

where VD is typically 0.5 V. For example, if η = 0.65 and VBB= 20V, then VP=13.5 V. Clearly, VP will vary as VBB varies.

The "On " state As VEE increases, the UJT stays "off" until VE approaches the peak-point value VP,then things begin to happen. As VE approaches Vp, the P-N junction becomes forward biased and begins to conduct in the opposite direction.

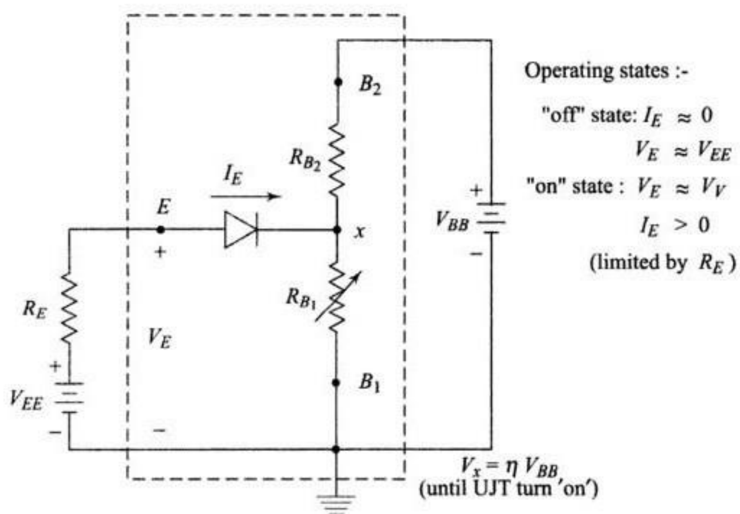

Fig:5.1.4 Equivalent Circuit for Analysis

Note on the VE-IE curve that IE becomes positive near the peak point P. When VE exactly equals VP, the emitter current equals IP, the peak-point current. At this point, holes from the heavily doped emitter are injected into the N-type bar, specially into the B1 region. The bar, which is lightly doped, offers very little chance for these holes to recombine. As such, the lower half of the bar becomes replete with additional current carriers (holes) and its resistance RB1, is drastically reduced. The decrease in RB1 causes Vx to drop. This drop in turn causes the diode to become more forward biased, and IE increases even further. The larger IE injects more holes into B1further reducing RB1, and so on. When this regenerative or snowballing process ends, RB1. has dropped to a very small value (2-25 Ω) and IE can become very large, limited mainly by external resistance RE.

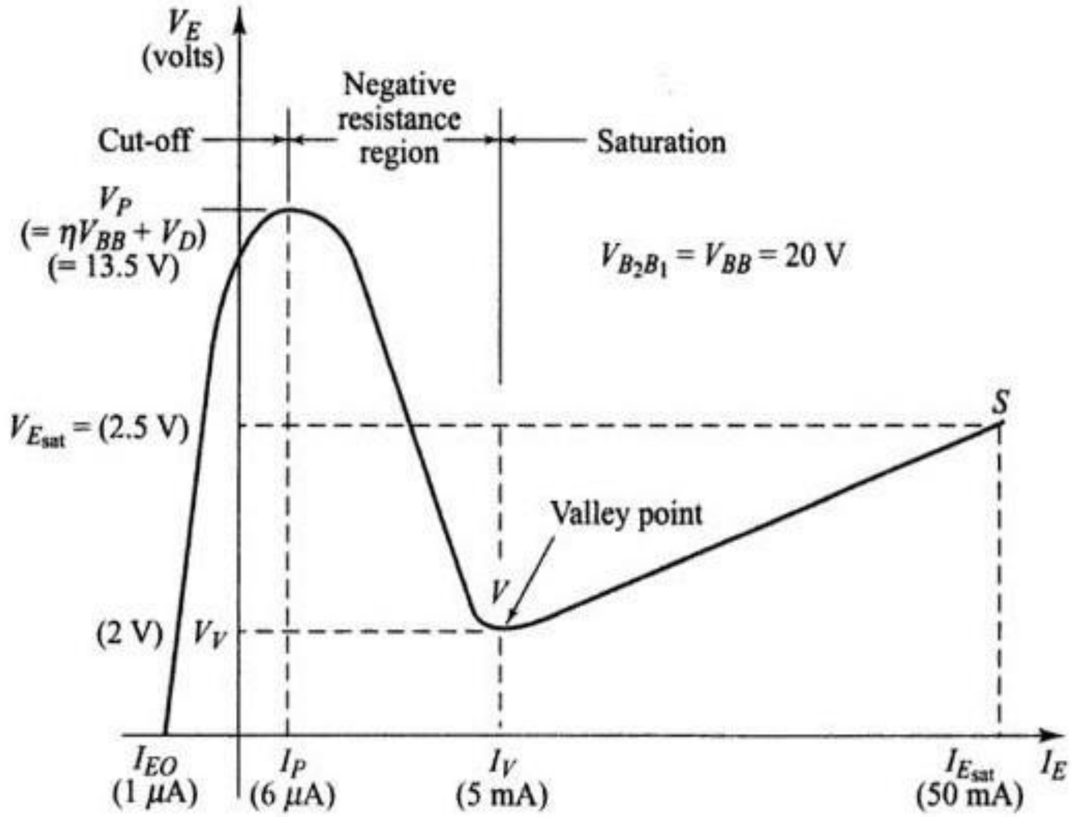

Fig:5.1.5 VI Characteristics of UJT

The UJT operation has switched to the low-voltage. high-current region of its VE- IE curve. The slope of this "on" region is very steep, indicating a low resistance. In this region, the emitter voltage VE, will be relatively small, typically 2V, and remains fairly constant as IE is increased up to its maximum rated value,IE(sat). Thus, once the UJT is "on," increasing VEE will serve to increase IE while VE remains around 2V.

Turning "Off" the UJT Once it is "on," the UJT's emitter current depends mainly on VEE and RE. As VEE decreases, IE will decrease along the "on" portion of the VE - IE curve. When IE decreases to point V, the valley point, the emitter current is equal to IV, the valley current, which is essentially the holding current needed to keep the UJT "on". When 15 is decreased below IV, the UJT turns "off" and its operation rapidly switches back to the "off" region of its VE - IE curve,where IE = 0 and VE - VEE. The valley current is the counterpart of the holding current in PNPN devices, and generally ranges between 1 and 10 mA.

Unijunction Transistor Relaxation Oscillator

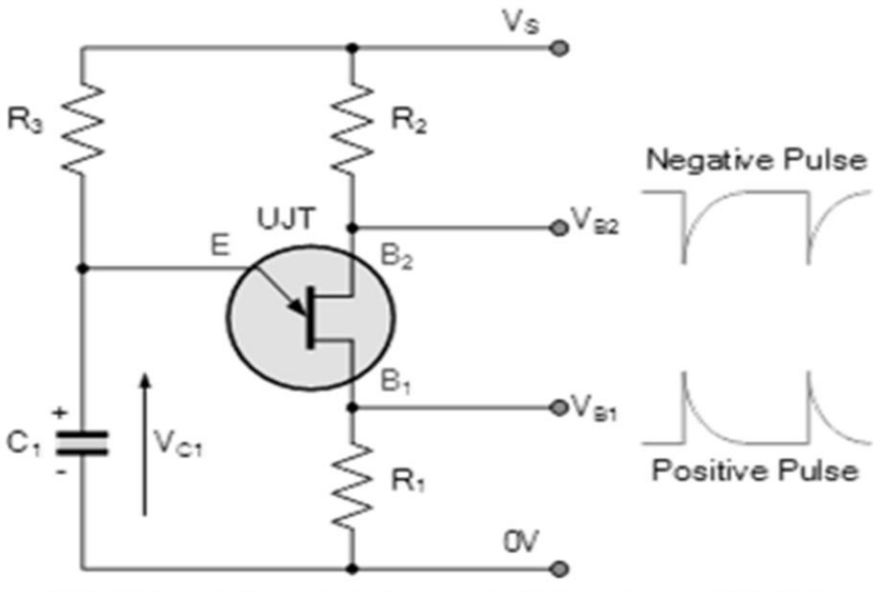

Fig:5.1.6 UJT Relaxation Oscillator

When a voltage (Vs) is firstly applied, the unijunction transistor is "OFF" and the capacitor C1 is fully discharged but begins to charge up exponentially through resistor R3. As the Emitter of the UJT is connected to the capacitor, when the charging voltage Vc across the capacitor becomes greater than the diode volt drop value, the p-n junction behaves as a normal diode and becomes forward biased triggering the UJT into conduction. The unijunction transistor is "ON". At this point the Emitter to B1 impedance collapses as the Emitter goes into a low impedance saturated state with the flow of Emitter current through R1 taking place.

As the ohmic value of resistor R1 is very low, the capacitor discharges rapidly through the UJT and a fast rising voltage pulse appears across R1. Also, because the capacitor discharges more quickly through the UJT than it does charging up through resistor R3, the discharging time is a lot less than the charging time as the capacitor discharges through the low resistance UJT.

When the voltage across the capacitor decreases below the holding point of the p-n junction (VOFF), the UJT turns "OFF" and no current flows into the Emitter junction so once again the capacitor charges up through resistor R3 and this charging and discharging process between VON and VOFF is constantly repeated while there is a supply voltage, Vs applied.

UJT Oscillator Waveforms

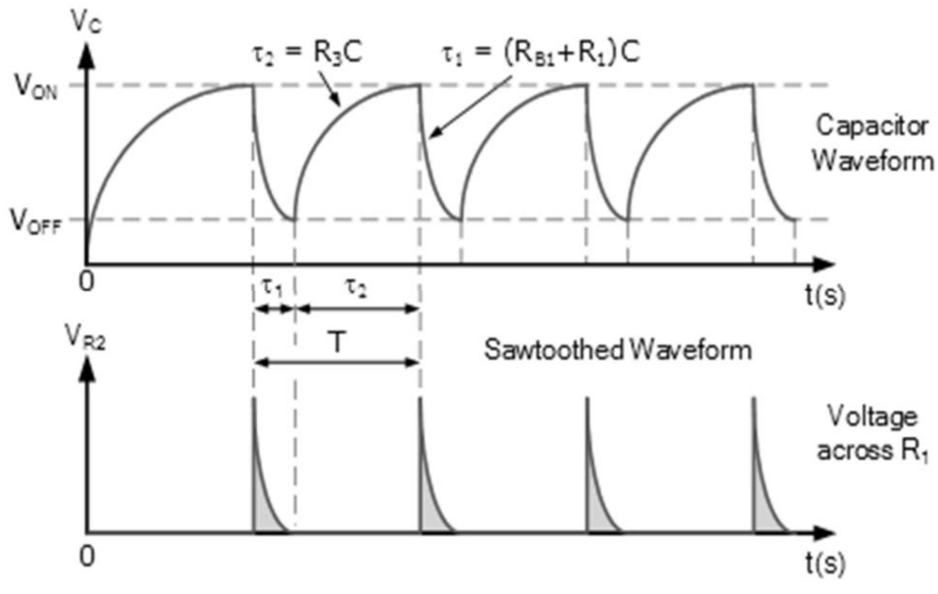

Fig:5.1.7 UJT Oscillator Waveforms

Then we can see that the unijunction oscillator continually switches "ON" and "OFF" without any feedback. The frequency of operation of the oscillator is directly affected by the value of the charging resistance R3, in series with the capacitor C1 and the value of η. The output pulse shape generated from the Base1 (B1) terminal is that of a sawtooth waveform and to regulate the time period, you only have to change the ohmic value of resistance, R3 since it sets the RC time constant for charging the capacitor.

The time period, T of the sawtoothed waveform will be given as the charging time plus the discharging time of the capacitor. As the discharge time, τ1 is generally very short in comparison to the larger RC charging time, τ2 the time period of oscillation is more or less equivalent to T ≅ τ2. The frequency of oscillation is therefore given by $f = 1/T$.

Applications of UJT:

Unijunction transistors are used extensively in oscillator, pulse and voltage sensing circuits. Some of the important applications of UJT are discussed below

(i) UJT relaxation oscillator.

(ii) Overvoltage detector.