OPTOELECTRONICS DEVICES

LEARNING MATERIALS

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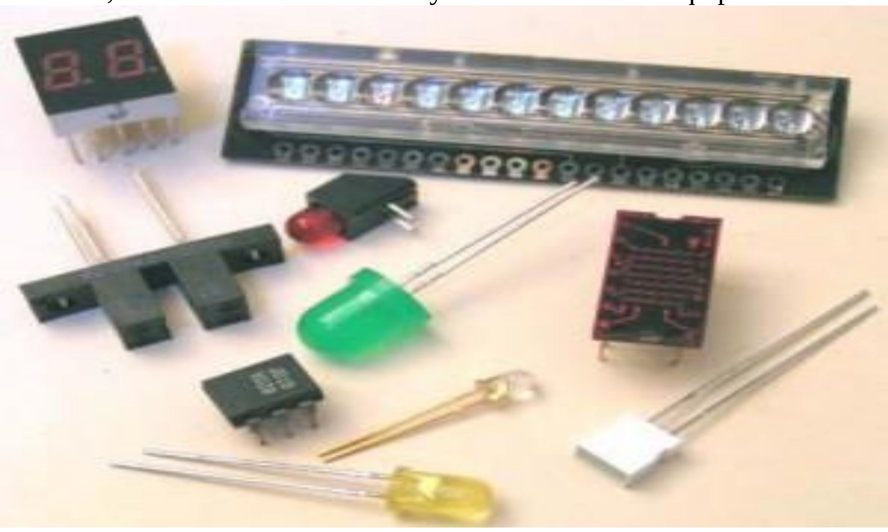
INTRODUCTION

Optoelectronics is the communication between optics and electronics which includes the study, design and manufacture of a hardware device that converts electrical energy into light and light into energy through semiconductors. This device is made from solid crystalline materials which are lighter than metals and heavier than insulators. Optoelectronics device is basically an electronic device involving light. This device can be found in many optoelectronics applications like military services, telecommunications, automatic access control systems and medical equipments.



Optoelectronics Devices

This academic field covers a wide range of devices including LEDs and elements, image pick up devices, information displays, optical communication systems, optical storages and remote sensing systems, etc. Examples of optoelectronic devices include telecommunication laser, blue laser, optical fiber, LED traffic lights, photo diodes and solar cells. Majority of the optoelectronic devices (direct conversion between electrons and photons) are LEDs, laser diodes, photo diodes and solar cells.

Types of Optoelectronics Devices

Optoelectronics are classified into different types such as

- Photodiode
- Solar Cells
- Light Emitting Diodes
- Optical Fiber
- Laser Diodes
- LDR

UNIT- I - LIGHT-EMITTING DIODES – LED

1.1 INTRODUCTION:

A **light-emitting diode** (**LED**) is a P-N semiconductor diode which acts as a light source that emits light when current flows through it. Electrons in the semiconductor recombine with holes, releasing energy in the form of photons. The colour of the light (corresponding to the energy of the photons) is determined by the energy required for electrons to cross the band gap of the semiconductor. White light is obtained by using multiple semiconductors or a layer of light-emitting phosphor on the semiconductor device.

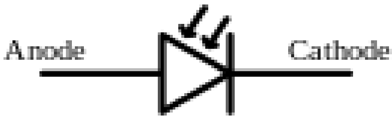
Introduced as an electronic component in 1962. The earliest LEDs emitted low-intensity infrared (IR) light. Infrared LEDs are used in remote-control circuits, in variety of consumer electronics. The first visible-light LEDs were of low intensity and limited to red. Modern LEDs are available across the visible, ultraviolet (UV), and infrared wavelengths, with high light output.

1.2, TYPES OF LIGHT EMITTING DIODES

There are different types of light emitting diodes present and some of them are mentioned below.

- Gallium Arsenide (GaAs) – infra-red
- Gallium Arsenide Phosphide (GaAsP) – red to infra-red, orange
- Aluminium Gallium Arsenide Phosphide (AlGaAsP) – high-brightness red, orange-red, orange, and yellow
- Gallium Phosphide (GaP) – red, yellow and green
- Aluminium Gallium Phosphide (AlGaP) – green
- Gallium Nitride (GaN) – green, emerald green
- Gallium Indium Nitride (GaInN) – near ultraviolet, bluish-green and blue
- Silicon Carbide (SiC) – blue as a substrate
- Zinc Selenide (ZnSe) – blue
- Aluminium Gallium Nitride (AlGaN) – ultraviolet.

Symbol



1.3. COSTRUCTION:

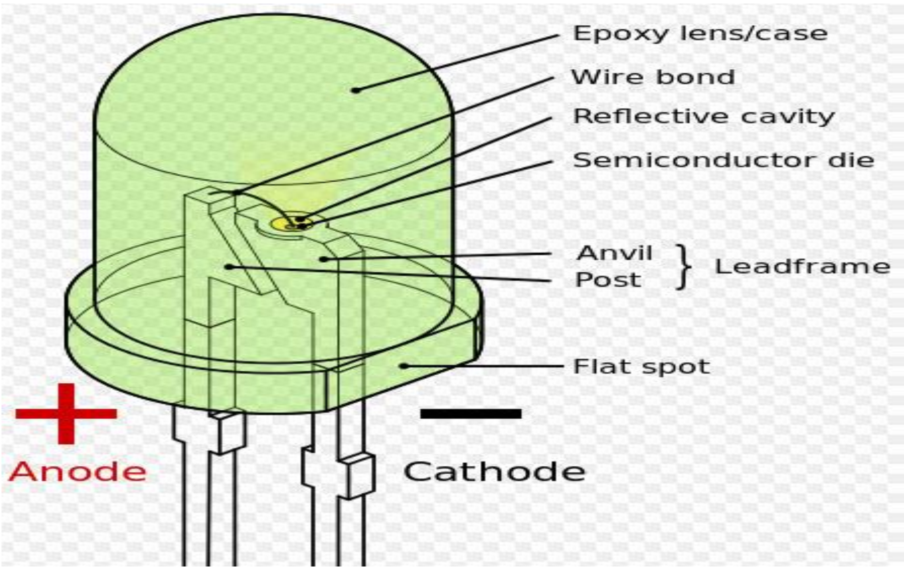


Fig 1.1 LED

The construction of LED is similar to the normal p-n junction diode except that gallium, phosphorus and arsenic materials are used for construction instead of silicon or germanium materials. However, silicon or germanium diodes do not emit energy in the form of light. Instead, they emit energy in the form of heat. Thus, silicon or germanium is not used for constructing LEDs.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.

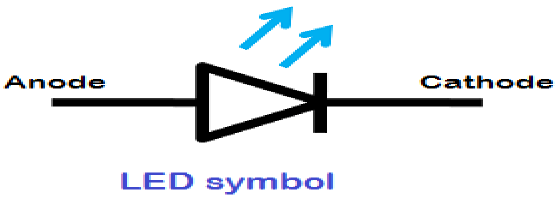


Fig 1.2 LED symbol

1.3.1 Layers of LED

A Light Emitting Diode (LED) consists of three layers: p-type semiconductor, n-type semiconductor and depletion layer. The p-type semiconductor and the n-type semiconductor are separated by a depletion region or depletion layer.

1.3.2 P-type semiconductor

When trivalent impurities are added to the intrinsic or pure semiconductor, a p-type smiconductor is formed. In p-type semiconductor, holes are the majority charge carriers and free electrons are the minority charge carriers. Thus, holes arry most of the electric current in p-type semiconductor.

1.3.3 N-type semiconductor

When pentavalent impurities are added to the intrinsic semiconductor, an n-type semiconductor is formed.In n-type semiconductor, free electrons are the majority charge carriers and holes are the minority charge carriers. Thus, free electrons carry most of the electric current in n-type semiconductor.

1.3.4 Depletion layer or region

Depletion region is a region present between the p-type and n-type semiconductor where no mobile charge carriers (free electrons and holes) are present. This region acts as barrier to the electric current. It opposes flow of electrons from n-type semiconductor and flow of holes from p-type semiconductor. To overcome the barrier of depletion layer, we need to apply voltage which is greater than the barrier potential of depletion layer. If the applied voltage is greater than the barrier potential of the depletion layer, the electric current starts flowing.

1.3.5 LED construction

One of the methods used to construct LED is to deposit three semiconductor layes 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.

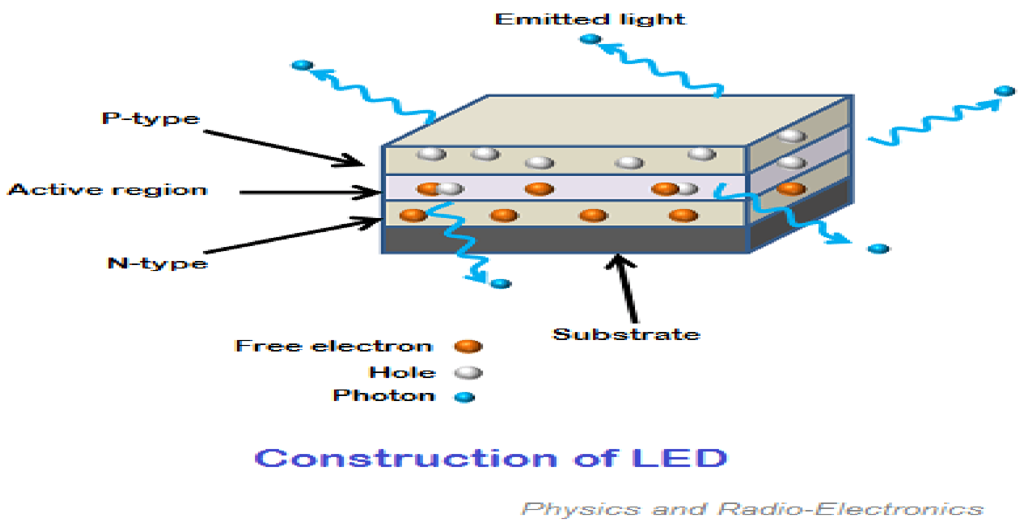


Fig 1.3 Construction of LED

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.

1.4. WORKING PRINCIPLE:

The light emitting diode simply, we know as a diode. When the diode is forward biased, then the electrons & holes are moving fast across the junction and they are combining constantly, removing one another out. Soon after the electrons are moving from the n-type to the p-type silicon, it combines with the holes, then it disappears. Hence it makes the complete atom & more stable and it gives the little burst of energy in the form of a tiny packet or photon of light.

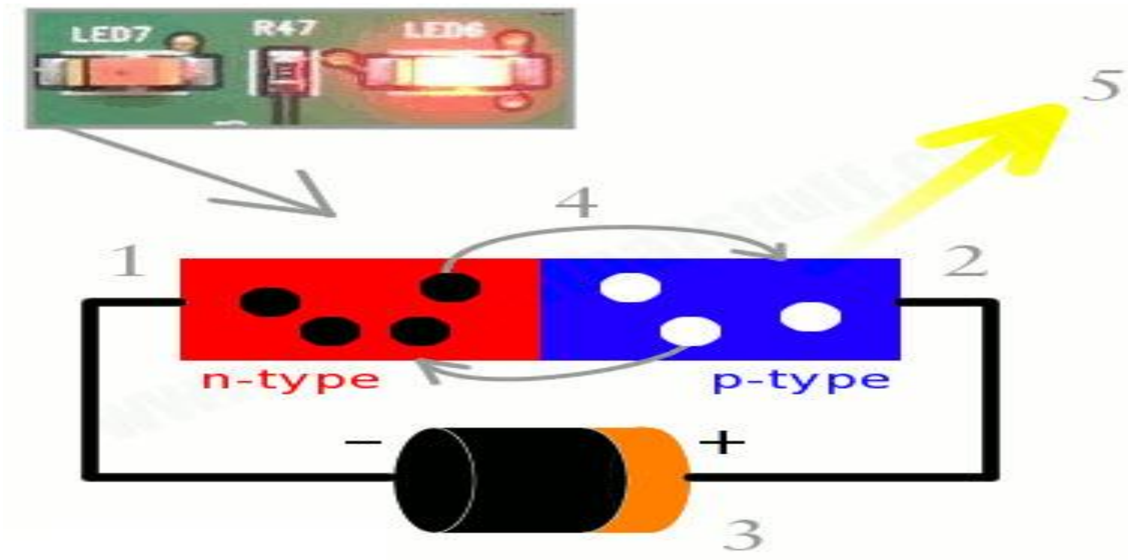


Fig 1.4 Working of Light Emitting Diode

From the diagram, we can observe that the N-type silicon is in red colour and it contains the electrons, they are indicated by the black circles.

- The P- type silicon is in the blue colour and it contains holes, they are indicated by the white circles.
- The power supply across the p-n junction makes the diode forward biased and pushing the electrons from n-type to p-type. Pushing the holes in the opposite direction.
- Electron and holes at the junction are recombined.

1.4.1 How Light Emitting Diode (LED) works?

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.

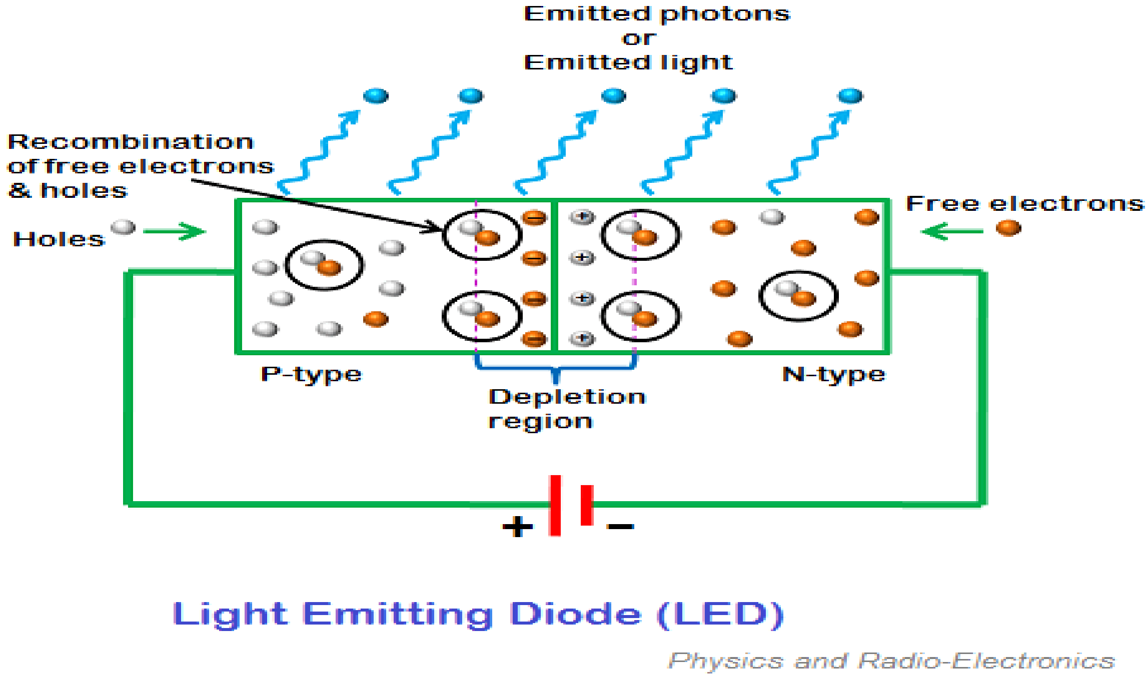


Fig 1.5 Light emitting action of LED

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.

1.4.2 How LED emits 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.

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.

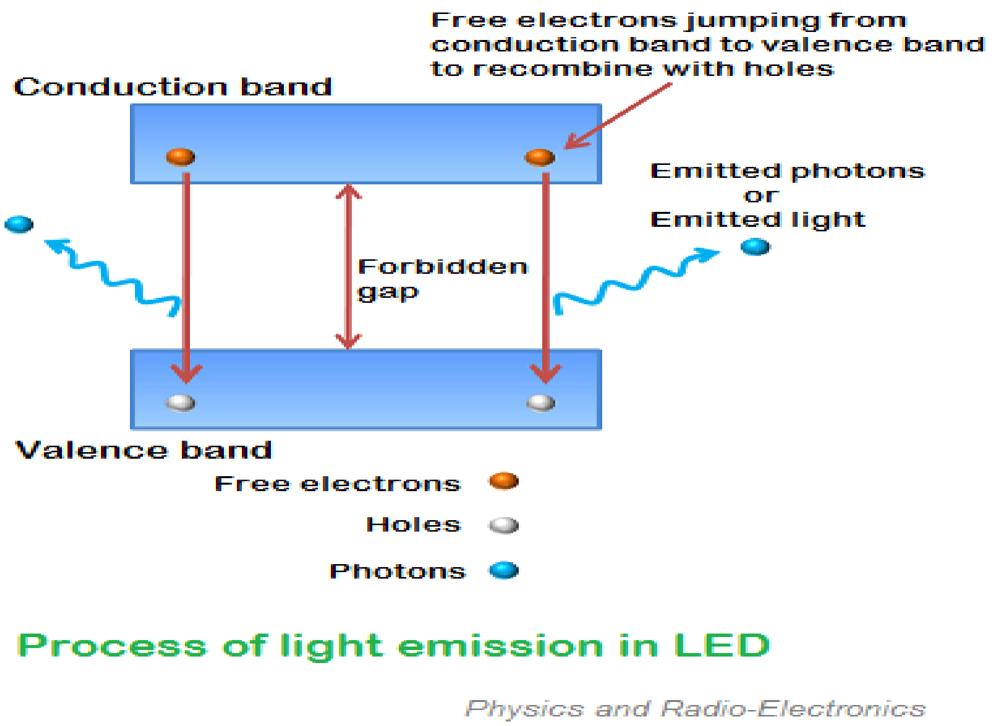


Fig 1.6 process of light emission

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.

1.5. I-V CHARACTERISTICS OF LED

1.5.1 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 (R_s) in series with the LED. The resistor (R_s) must be placed in between voltage source (Vs) and LED.

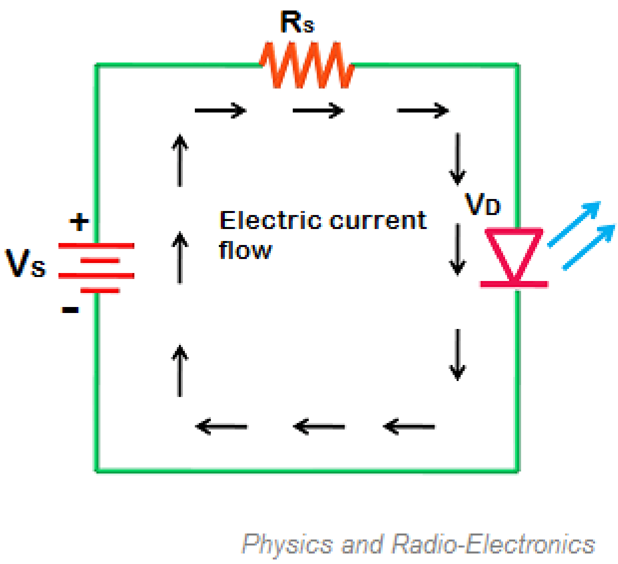


Fig 1.6

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,

I_F = Forward current
V_S = Source voltage or supply voltage
V_D = Voltage drop across LED
R_S = 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.

1.5.2 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.

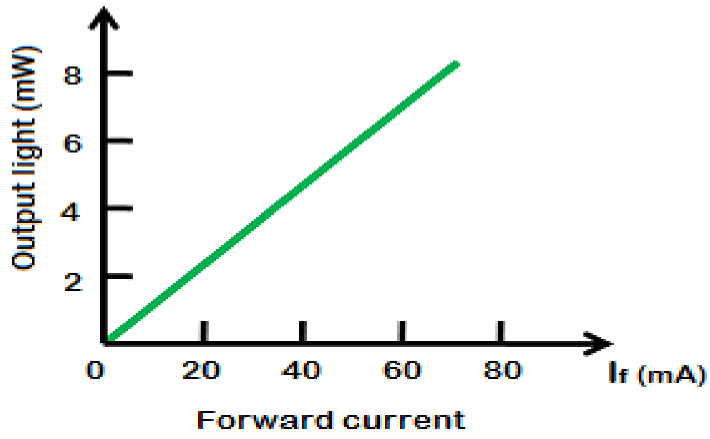


Fig 1.7 of forward current vs output light

1.5.3 Visible LEDs and invisible LEDs LDs are mainly classified into two types: visible LEDs and invisible LEDs.Visible LED is a type of LED tht 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.

1.6. DIFFERENT COLOURED LEDS

What determines the colour of an LED? The material used for constructing LED determines its colour. In other words, the wavelength or colour of the emitted light depends on the forbidden gap orenergy gap of the material. Different materials emit different colours of light.

1. Gallium arsenide LEDs emit red and infrared light.
2. Gallium nitride LEDs emit bright blue light.
3. Yttrium aluminium garnet LEDs emit white light.
4. Gallium phosphide LEDs emit red, yellow and green light.
5. Aluminium gallium nitride LEDs emit ultraviolet light.
6. Aluminum gallium phosphide LEDs emit green light.

1.7. ADVANTAGES OF LED

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

1.8. DISADVANTAGES OF LED LEDs need more power to operate than normal p-n junction diodes.

1. Luminous efficiency of LEDs is low.

1,9. 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
12. **Common Uses**: The first commercial visible-wavelength LEDs were commonly used as replacements for incandescent and neon indicator lamps, and in seven-segment displays, first in expensive equipment such as laboratory and electronics test equipment, then later in such appliances as calculators, TVs, radios, telephones, as well as watches.

UNIT – II - LIQUID CRYSTAL DISPLAY - LCD

2.1. INTRODUCTION:

A **liquid-crystal display** (**LCD**) is a flat-panel display or other electronically modulated optical device that uses the light-modulating properties of liquid crystals combined with polarizers. Liquid crystals do not emit light directly, instead using a backlight or reflector to produce images in colour or monochrome. LCDs are available to display arbitrary images (as in a general-purpose computer display) or fixed images with low information content, which can be displayed or hidden, such as preset words, digits, and seven-segment displays, as in a digital clock. They use the same basic technology, except that arbitrary images are made from a matrix of small pixels, while other displays have larger elements. LCDs can either be normally on (positive) or off (negative), depending on the polarizer arrangement. For example, a character positive LCD with a backlight will have black lettering on a background that is the colour of the backlight, and a character negative LCD will have a black background with the letters being of the same colour as the backlight. Optical filters are added to white on blue LCDs to give them their characteristic appearance.

2.2. CONSTRUCTION:

Simple facts that should be considered while making an LCD:

1. The basic structure of the LCD should be controlled by changing the applied current.
2. We must use polarized light.
3. The liquid crystal should able be to control both of the operations to transmit or can also able to change the polarized light.

As mentioned above that we need to take two polarized glass pieces filter in the making of the liquid crystal. The glass which does not have a polarized film on the surface of it must be rubbed with a special polymer that will create microscopic grooves on the surface of the polarized glass filter. The grooves must be in the same direction as the polarized film. Now we have to add a coating of pneumatic liquid phase crystal on one of the polarizing filters of the polarized glass. The microscopic channel causes the first layer molecule to align with filter orientation. When the right angle appears at the first layer piece, we should add a second piece of glass with the polarized film. The first filter will be naturally polarized as the light strikes it at the starting stage.

Thus the light travels through each layer and guided on the next with the help of a molecule. The molecule tends to change its plane of vibration of the light to match its angle. When the light reaches the far end of the liquid crystal substance, it vibrates at the same angle as that of the final layer of the molecule vibrates. The light is allowed to enter into the device only if the second layer of the polarized glass matches with the final layer of the molecule.

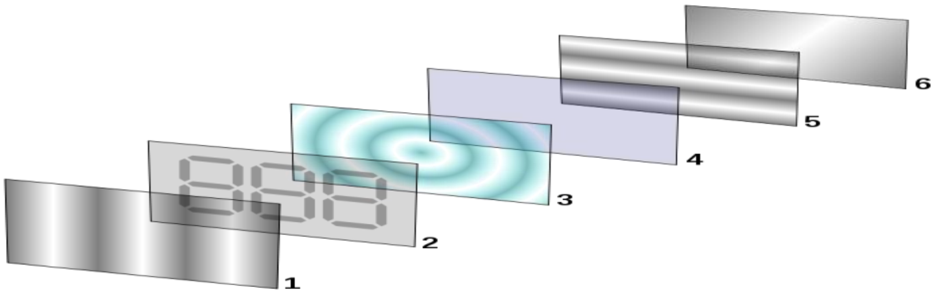


Fig 2.1 Reflective twisted nematic liquid crystal display.

1. Polarizing filter film with a vertical axis to polarize light as it enters.
2. Glass substrate with ITO electrodes. The shapes of these electrodes will determine the shapes that will appear when the LCD is switched ON. Vertical ridges etched on the surface are smooth.
3. Twisted nematic liquid crystal.
4. Glass substrate with common electrode film (ITO) with horizontal ridges to line up with the horizontal filter.
5. Polarizing filter film with a horizontal axis to block/pass light.
6. Reflective surface to send light back to viewer. (In a backlit LCD, this layer is replaced or complemented with a light source.)

2.3. WORKING PRINCIPLE

1. In the absence of the electrical signal, orientation order is maintained in the crystal allowing light to transmit. This makes LCD display clear. The current through the liquid crystal causes orientation order to collapse. The random orientation results scattering of light which lights display segment on a dark background.

2. Next comes the second piece of glass with an electrode in the form of the rectangle on the bottom and, on top, another polarizing film. It must be considered that both the pieces are kept at the right angles. When there is no current, the light passes through the front of the LCD it will be reflected by the mirror and bounced back.

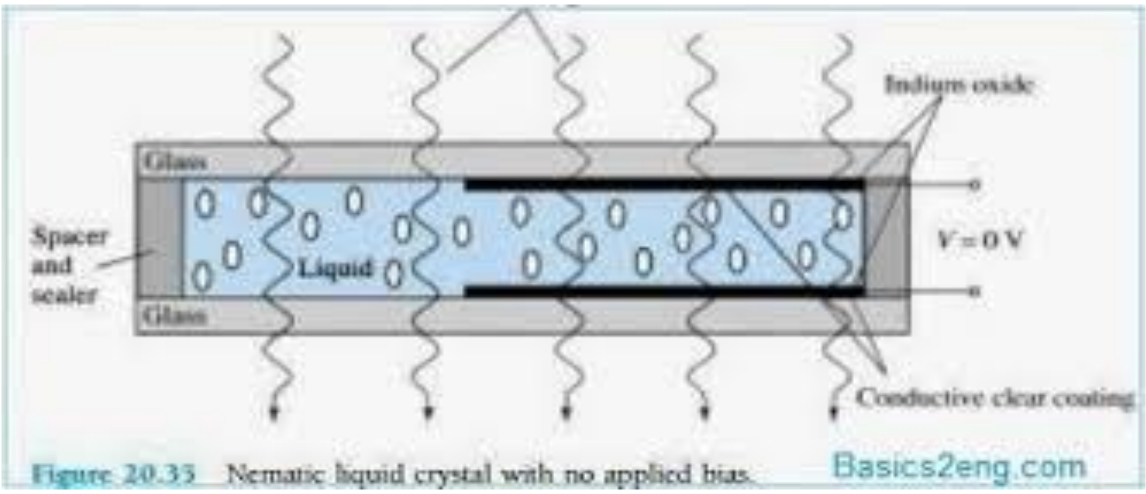


Fig. 2.2 shows the typical LCD Displays.

2. As the electrode is connected to a battery the current from it will cause the liquid crystals between the common-plane electrode and the electrode shaped like a rectangle to untwist. Thus the light is blocked from passing through. That particular rectangular area appears blank.

3. As a result, a little light is allowed to pass the polarized glass through a particular area of the LCD. Thus that particular area will become dark compared to others. The LCD works on the principle of blocking light. While constructing the LCD's, a reflected mirror is arranged at the back. An electrode plane is made of indium-tin-oxide which is kept on top and a polarized glass with a polarizing film is also added on the bottom of the device. The complete region of the LCD has to be enclosed by a common electrode and above it should be the liquid crystal matter.
4. Next comes the second piece of glass with an electrode in the form of the rectangle on the bottom and, on top, another polarizing film. It must be considered that both the pieces are kept at the right angles. When there is no current, the light passes through the front of the LCD it will be reflected by the mirror and bounced back. As the electrode is connected to a battery the current from it will cause the liquid crystals between the common-plane electrode and the electrode shaped like a rectangle to untwist. Thus the light is blocked from passing through. That particular rectangular area appears blank.
5. The glass plates cause a change in the angle of the top polarizing filter. As a result, a little light is allowed to pass the polarized glass through a particular area of the LCD. Thus that particular area will become dark compared to others. The LCD works on the principle of blocking light. While constructing the LCD's, a reflected mirror is arranged at the back. An electrode plane is made of indium-tin-oxide which is kept on top and a polarized glass with a polarizing film is also added on the bottom of the device. The complete region of the LCD has to be enclosed by a common electrode and above it should be the liquid crystal matter.

It consists of two glass plates with a liquid crystal fluid in between. The back plate is coated with thin transparent layer of conductive material, where as front plate has a photoetched conductive coating with seven segment pattern as shown in below

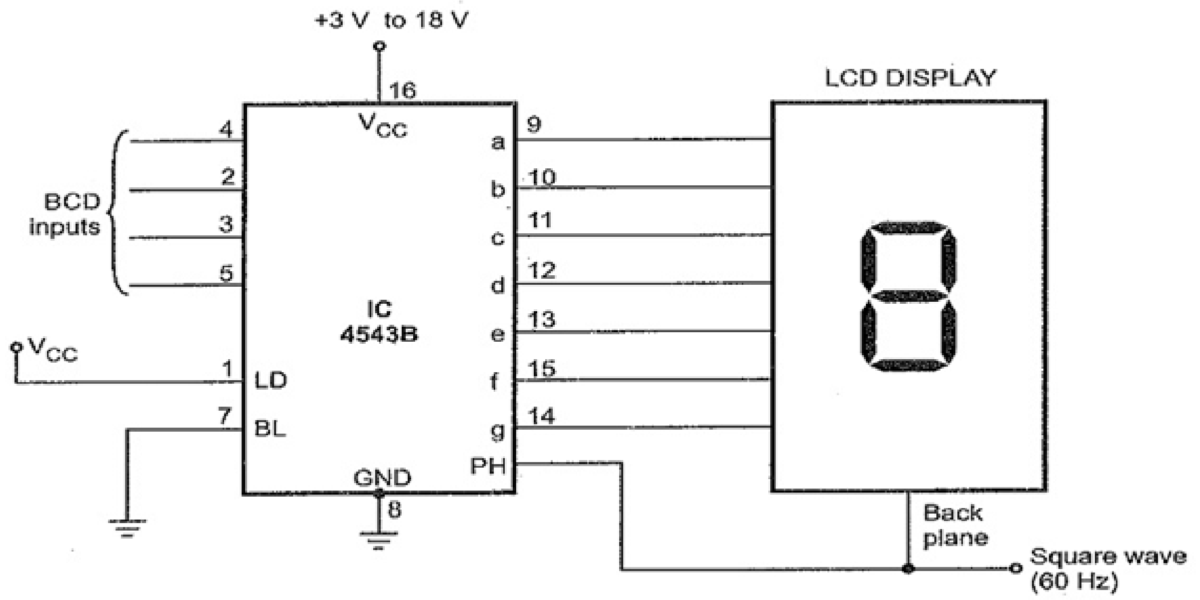


Fig 2.3. shows the circuit for driving LCD seven segment display using IC 4543 B.

The 4543B BCD-to-7 segment latch/decoder/driver is designed for Types of LCD Displays. Pins A, B, C and D represent BCD inputs with A as a least significant bit (LSB) and D as a most significant bit (MSB). Pins a through g are the seven segment outputs. The 4543 B has three control terminals : LD (Latch Disable), PH (Phase), and BL (Blank). In normal use the LD terminal is held high and BL terminal is tied low. The state of the PH terminal depends on the type of display that is being driven. For driving LCD displays, a square wave (about 60 Hz. swinging fully between the GND and V_{CC} values) must be applied to the phase terminal.

2.4. TYPES OF LIQUID CRYSTAL DISPLAY AND WORKING

Types of LCD Displays:

The Types of LCD Displays are one of the most fascinating material systems in nature, having properties of liquids as well as of a solid crystal. The terms liquid crystal refers to the fact that these compounds have a crystalline arrangement of molecules, yet they flow like a liquid. Liquid crystal displays do not emit or generate light, but rather alter externally generated illumination. Their ability to modulate light when electrical signal is applied has made them very useful in flat panel display technology. There are two Types of LCD Displays according to the theory of operation : (i) dynamic scattering mode and (ii) **Field effect mode.**

2.4.1 Dynamic scattering

When **dynamic scattering** display is energized, the molecules of energized area of the display become turbulent and scatter light in all directions. ... Without electrical excitation, the light coming through the front polarizer is rotated 90° in the fluid. In the case of dynamic scattering display in absence of an applied voltage, the device is transparent. But, when the voltage is applied, the crystal becomes an efficient scatterer of white light.

It consists of a pure nematic liquid crystal in which impurities are added to increase its conductivity, due to ions in them. The liquid crystal filled inbetween two glass plates are coated with transparent in oxide and can act as electrodes. The spacer and scalar help in filling of liquid and to change the liquid level.

With no voltage applied the LC-cell with the homeotropically aligned LC is clear and transparent. With increasing voltage and current, the electric field is trying to align the long molecular axis of the LC perpendicular to the field while the ion transport through the layer has the tendency to align the LC perpendicular to the substrate plates. As a result, a striped repetitive pattern is generated in the cell, of which the building blocks are named "Williams domains". Upon further increase of the voltage this regular pattern is replaced by a turbulent state which is strongly scattering light.

This effect belongs to the class of electro-hydrodynamic effects in LCs. Electro-optic displays can be realized with that effect in the transmissive and reflective mode of operation. The driving voltages required for light scattering are in the range of several ten volts and the non-trivial current is depending on the area of the activated segments. The DMS effect was thus not suited for battery powered electronic devices.

In the normal state, without application of electric field, all the molecules in the nematic liquid crystal are parallel to the glass plate. The material is transparent. When the electric field is applied, the dipoles of molecules are rotated into alignment in the direction, exactly perpendicular to field direction. Now, the ions are pulled by the electrodes and hence the positive ions will go towards negative potential and vice versa. Therefore these ions disrupt, the molecules which are orderly arranged and create a small turbulence. Due to turbulence the negative charges are gathered as crests and positive charges are gathered as troughs, with respect to the field direction.

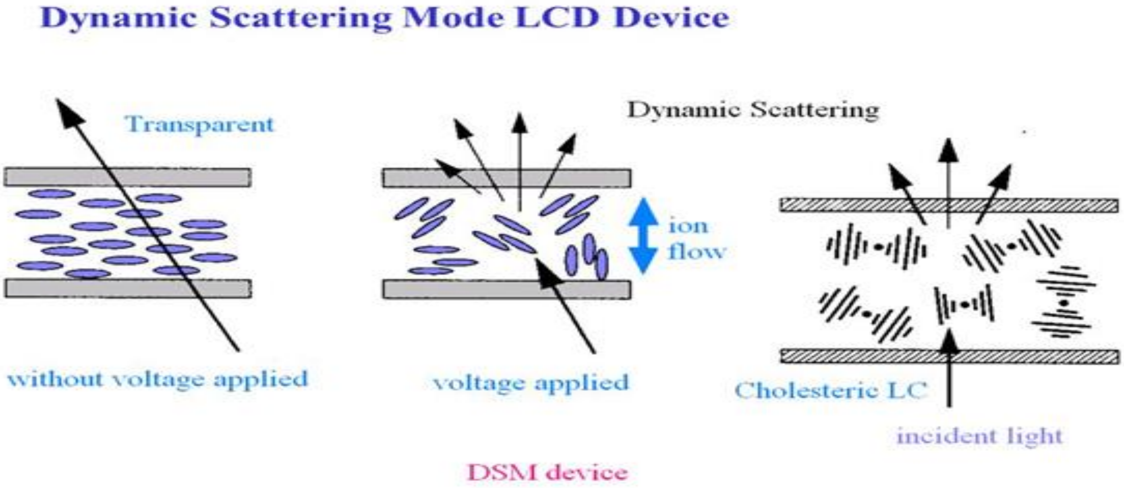
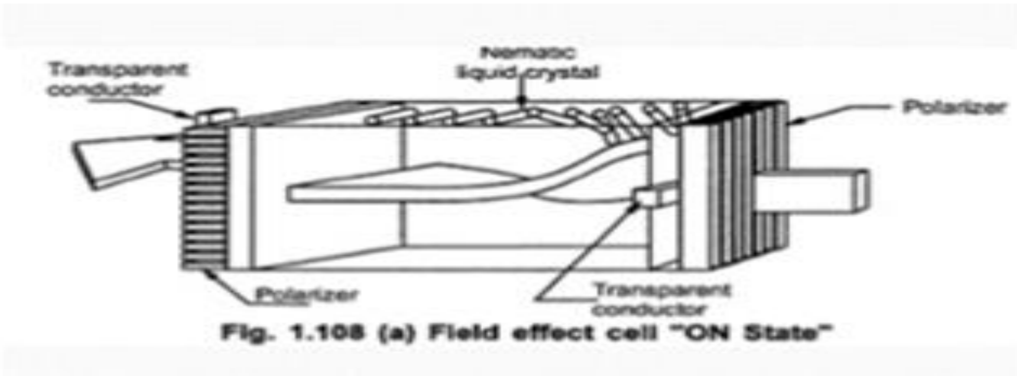


Fig 2.4 Dynamic scaterring mode

In this display LCD produces frosty white letters on a dark background. The field effect type of LCD works on the application of electric field.

2.4.2. Field effect LCD

The liquid crystals used in **field effect LCDs** are of different scattering types that operated in the dynamic scattering cell. The **field** affects type **LCD** uses the nematic material which twisted the unenergised light passing through the cell.



2.5. Field effect mode

Light is polarised in two perpendicular directions. When light goes through one polarisation filter, only light polarised in one direction is left. When light passes two crossed polarisation filters no

light remains.
When the incoming light of a LCD passes the front polarisation filter, the direction of polarisation follows the orientation of the molecules and turns ninety degrees.

Then, after it passes the crossed filter, it is mirrored back and follows the same way in the opposite direction resulting in a lighted display.
When a voltage is applied on the invisible electrodes on the glass plates, the electric field lines up the molecules, the polarisation is not altered and the crossed filters extinguish the light.

At this time a dark part of the display can be seen. Since, with this technique, it only takes 0.3 seconds to change a digit, it became possible to display the seconds. It took three years to develop a technique which lowered the voltage needed for these LC displays from 7 to 1.5 Volt. The higher voltage of 7 Volts is the reason for finding both an IC and a transformer in the early modules.
Nematic" in LCDs refers to a class of liquid-crystal materials commonly used in these displays.

Nematic liquid crystals are those in which the liquid crystal molecules - which are roughly rod-shaped - tend to arrange themselves so that their long axes are pointing in the same direction. This, along with the fact that the molecules also will align with an electric field when one is present, makes it possible to use these materials to construct an electrically controllable light valve, which is really all an LCD is.

2.5. CHARACTERISTICS

LCD Features and Attributes

- Native Resolution. Unlike CRT monitors, **LCD** monitors display information well at only the resolution they are designed for, which is known as the native resolution.
- Viewing Angle.
- Brightness or Luminance.
- Contrast Ratio.
- Response Rate.
- Adjustability.

2.6. ADVANTAGES OF LCDS:

- LCDs consumes less amount of power compared to CRT and LED
- LCDs are consist of some microwatts for display in comparison to some mill watts for LED's
- LCDs are of low cost
- Provides excellent contrast
- LCDs are thinner and lighter when compared to cathode-ray tube and LED
- Unaffected by magnetic fields, including the Earth's.
- Little heat emitted during operation, due to low power consumption.
- No geometric distortion.
- Emits almost no undesirable electromagnetic radiation unlike a CRT monitor.

2.7. DISADVANTAGES OF LCD'S:

- Require additional light sources
- Range of temperature is limited for operation
- Low reliability
- Speed is very low
- LCDs need an AC drive
- Loss of brightness and much slower response times in low temperature environments. In sub-zero environments, LCD screens may cease to function.
- Loss of contrast in high temperature environments.

2.8. APPLICATIONS OF LIQUID CRYSTAL DISPLAY

Liquid crystal technology has major applications in the field of science and engineering as well on electronic devices.

- Liquid crystal thermometer.

- Optical imaging.
- The liquid crystal display technology is also applicable in the visualization of the radio frequency waves in the waveguide.
- Used in the medical applications.
- Can be made with very narrow frame borders, allowing multiple LCD screens to be arrayed side-by-side to make up what looks like one big screen.
- **Common Uses:**
    - ❖ LCDs are used in a wide range of applications, including LCD televisions, computer monitors, instrument panels, aircraft cockpit displays, and indoor and outdoor signage.
    - ❖ Small LCD screens are common in portable consumer devices such as digital cameras, digital watches, calculators, and mobile telephones, including smartphones.
    - ❖ LCD screens are also used on consumer electronics products such as DVD players, video game devices and clocks. LCD screens have replaced heavy, bulky cathode ray tube (CRT) displays in nearly all applications.
    - ❖ LCD screens are available in a wider range of screen sizes than CRT and plasma displays, with LCD screens available in sizes ranging from tiny digital watches to very large television receivers.

UNIT-III - LIGHT DETECTING DEVICES I

Light detecting devices of light Sensors include Photocells, LDR, Photodiodes, Phototransistors, Photovoltaic Cells and Light Dependent Resistor.

PRINCIPLE OF PHOTO DETECTION

A photodetector is a device which absorbs light and converts the optical energy to measurable electric current. Detectors are classified as Thermal detectors and Photon detectors.

Thermal detectors : When light falls on the device, it raises its temperature, which, in turn, changes the electrical properties of the device material, like its electrical conductivity. Examples of thermal detectors are thermopile (which is a series of thermocouples), pyroelectric detector etc.

Photon detectors : Photon detectors work on the principle of conversion of photons to electrons. Unlike the thermal detectors, such detectors are based on the rate of absorption of photons rather than on the rate of energy absorption. However, a device may absorb photons only if the energy of incident photons is above a certain minimum threshold. Photon detectors, in terms of the technology, could be base

Photodetectors, also called photosensors, are sensors of light or other electromagnetic radiation. A **photo detector** has a p–n junction that converts light photons into current. The absorbed photons make electron–hole pairs in the depletion region. Photodiodes and **photo** transistors are a few examples of **photo detectors**.

3.1. PHOTODIODES

3.1.1 INTRODUCTION

A **photodiode** is a semiconductor device that converts light into an electrical current. The current is generated when photons are absorbed in the photodiode. Photodiodes may contain optical filters, built-in lenses, and may have large or small surface areas. Photodiodes usually have a slower response time as their surface area increases. The common, traditional solar cell used to generate electric solar power is a large area photodiode.

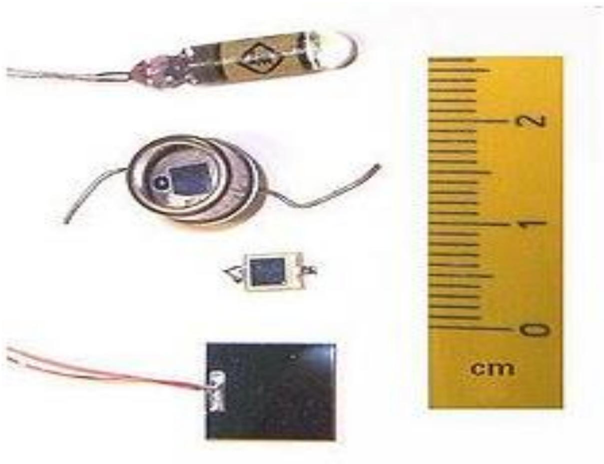
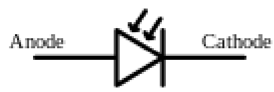


Fig 3.1 Photodiode Electronic symbol

3.1.2. CONSTRUCTION

Photodiodes are similar to regular semiconductor diodes except that they may be either exposed (to detect vacuum UV or X-rays) or packaged with a window or optical fiber connection to allow light to reach the sensitive part of the device. Many diodes designed for use especially as a photodiode use a PIN junction rather than a p–n junction, to increase the speed of response. A photodiode is designed to operate in reverse bias.

The photodiode is a type of semiconductor diode which converts the light into the electric current. This type of diode is also called photo-detector or light sensor. It works on both the reversed and forward biasing. The small leakage current flows in the reversed direction, even when no light incident on it. The current constitutes in the diode are directly proportional to the intensity of light absorb it.



The material used to make a photodiode is critical to defining its properties, because only photons with sufficient energy to excite electrons across the material's bandgap will produce significant photocurrents. Materials commonly used to produce photodiodes are listed in the table below:

Material	**Electromagnetic spectrum wavelength range (nm)**
Silicon	190–1100
Germanium	400–1700
Indium gallium arsenide	800–2600
Lead(II) sulfide	<1000–3500
Mercury cadmium telluride	400–14000

Because of their greater bandgap, silicon-based photodiodes generate less noise than germanium-based photodiodes. Binary materials such as MoS_2 and graphene emerged as new materials for the production of photodiodes.

3.1.3. PRINCIPLES OF WORKING

A photodiode is a PIN structure or p–n junction. When a photon of sufficient energy strikes the diode, it creates an electron–hole pair. This mechanism is also known as the inner photoelectric effect. If the absorption occurs in the junction's depletion region, or one diffusion length away from it, these carriers are swept from the junction by the built-in electric field of the depletion region. Thus holes move toward the anode, and electrons toward the cathode, and a photocurrent is produced. The total current through the photodiode is the sum of the dark current (current that is generated in the absence of light) and the photocurrent, so the dark current must be minimized to maximize the sensitivity of the device. To first order, for a given spectral distribution, the photocurrent is linearly proportional to the irradiance.

3.1.4. WORKING MODES

a). Photovoltaic mode

In photovoltaic mode (zero bias), photocurrent flows out of the anode through a short circuit to the cathode. If the circuit is opened or has a load impedance, restricting the photocurrent out of the device, a voltage builds up in the direction that forward biases the diode, that is, anode positive with respect to cathode.

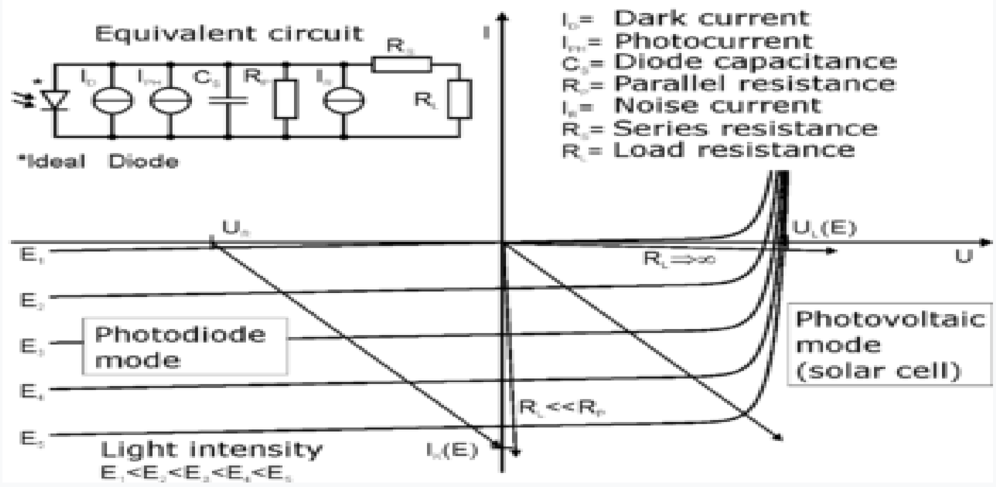


Fig 3.2 I-V characteristic of a photodiode.

If the circuit is shorted or the impedance is low, a forward current will consume all or some of the photocurrent. This mode exploits the photovoltaic effect, which is the basis for solar cells – a traditional solar cell is just a large area photodiode. For optimum power output, the photovoltaic cell will be operated at a voltage that causes only a small forward current compared to the photocurrent.

b). Photoconductive mode

In photoconductive mode the diode is reverse biased, that is, with the cathode driven positive with respect to the anode. This reduces the response time because the additional reverse bias increases the width of the depletion layer, which decreases the junction's capacitance and increases the region with an electric field that will cause electrons to be quickly collected. The reverse bias also creates dark current without much change in the photocurrent.

Although this mode is faster, the photoconductive mode can exhibit more electronic noise due to dark current or avalanche effects.[4] The leakage current of a good PIN diode is so low (<1 nA) that the Johnson–Nyquist noise of the load resistance in a typical circuit often dominates.

Avalanche photodiodes are photodiodes with structure optimized for operating with high reverse bias, approaching the reverse breakdown voltage. This allows each *photo-generated* carrier to be multiplied by avalanche breakdown, resulting in internal gain within the photodiode, which increases the effective *responsivity* of the device.

Any p–n junction, if illuminated, is potentially a photodiode. Semiconductor devices such as diodes, transistors and ICs contain p–n junctions, and will not function correctly if they are illuminated by unwanted electromagnetic radiation (light) of wavelength suitable to produce a photocurrent. This is avoided by encapsulating devices in opaque housings. If these housings are not completely opaque to high-energy radiation (ultraviolet, X-rays, gamma rays), diodes, transistors and ICs can malfunction due to induced photo-currents. Background radiation from the packaging is also significant. Radiation hardening mitigates these effects.

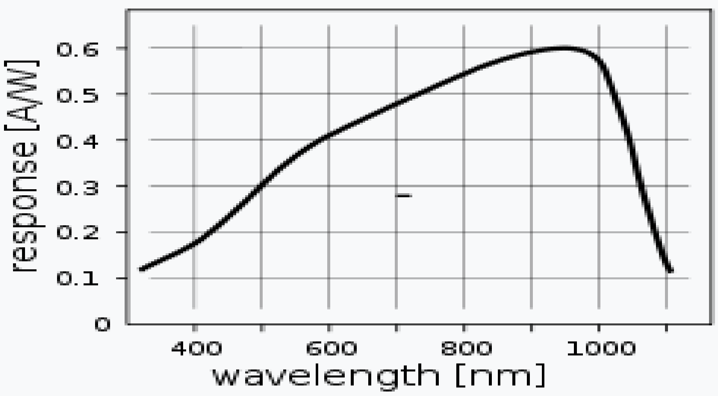


Fig.3.3 Response of a silicon photo diode vs wavelength of the incident light

3.1.5 CRITICAL PERFORMANCE PARAMETERS

Critical performance parameters of a photodiode include spectral responsivity, dark current, response time and noise-equivalent power.

i). **Spectral responsivity**

The spectral responsivity is a ratio of the generated photocurrent to incident light power, expressed in A/W when used in photoconductive mode. The wavelength-dependence may also be expressed as a *quantum efficiency* or the ratio of the number of photogenerated carriers to incident photons which is a unitless quantity.

ii). **Dark current**

The dark current is the current through the photodiode in the absence of light, when it is operated in photoconductive mode. The dark current includes photocurrent generated by background radiation and the saturation current of the semiconductor junction. Dark current must be accounted for by calibration if a photodiode is used to make an accurate optical power measurement, and it is also a source of noise when a photodiode is used in an optical communication system.

iii). **Response time**

The response time is the time required for the detector to respond to an optical input. A photon absorbed by the semiconducting material will generate an electron–hole pair which will in turn start moving in the material under the effect of the electric field and thus generate a current. When used in an optical communication system, the response time determines the bandwidth available for signal modulation and thus data transmission.

iv). **Noise-equivalent power**

Noise-equivalent power (NEP) is the minimum input optical power to generate photocurrent, equal to the rms noise current in a 1 hertz bandwidth. NEP is essentially the minimum detectable power. The related *characteristic detectivity* is the inverse of NEP

(1/NEP) and the *specific detectivity* is the detectivity multiplied by the square root of the area of the photodetector for a 1 Hz bandwidth.

When a photodiode is used in an optical communication system, all these parameters contribute to the *sensitivity* of the optical receiver which is the minimum input power required for the receiver to achieve a specified *bit error rate*.

3.1.4. ADVANTAGES

Excellent linearity of output current as a function of incident light

1. Spectral response from 190 nm to 1100 nm (silicon), longer wavelengths with other semiconductor materials
2. Low noise
3. Ruggedized to mechanical stress
4. Low cost
5. Compact and light weight
6. Long lifetime
7. High quantum efficiency, typically 60–80%[18]
8. No high voltage required

3.1.5. DISADVANTAGES

1. Small area
2. No internal gain (except avalanche photodiodes, but their gain is typically 10^2–10^3 compared to 10^5-10^8 for the photomultiplier)
3. Much lower overall sensitivity
4. Photon counting only possible with specially designed, usually cooled photodiodes, with special electronic circuits
5. Response time for many designs is slower
6. Latent effect.

3.1.6. APPLICATIONS

P–n photodiodes are used in similar applications to other photodetectors, such as photoconductors, charge-coupled devices (CCD, and photomultiplier tubes. They may be used to generate an output which is dependent upon the illumination (analog for measurement), or to change the state of circuitry (digital, either for control and switching or for digital signal processing).

(i) photodiodes are used in consumer electronics devices such as compact disc players, smoke detectors, medical devices and the receivers for infrared remote control devices used to control equipment from televisions to air conditioners.

(ii) photodiodes may be used for light measurement, as in camera light meters, or to respond to light levels, as in switching on street lighting after dark.

(iii) photosensors of all types may be used to respond to incident light or to a source of light which is part of the same circuit or system. A photodiode is often combined into a single component with an emitter of light, usually a light-emitting diode (LED), either to detect the presence of a mechanical obstruction to the beam (slotted optical switch) or to couple two digital or analog circuits.

(iv) The combination of LED and photodiode is also used in many sensor systems to characterize different types of products based on their optical absorbance.

(v) Photodiodes are often used for accurate measurement of light intensity in science and industry. They generally have a more linear response than photoconductors.

(vi) They are also widely used in various medical applications, such as detectors for computed tomography (coupled with scintillators), instruments to analyze samples (immunoassay), and pulse oximeters.

(vii) PIN diodes (avalanche photodiodes) are much faster and more sensitive than p–n junction diodes, and hence are often used for optical communications and in lighting regulation.

(viii) P–n photodiodes are not used to measure extremely low light intensities. Instead, if high sensitivity is needed, avalanche photodiodes are used.

(ix) A 2 x 2 cm photodiode array chip with more than 200 diodes.

A one-dimensional array of hundreds or thousands of photodiodes can be used as a position sensor, for example as part of an angle sensor

The passive-pixel sensor (PPS) is a type of photodiode array.

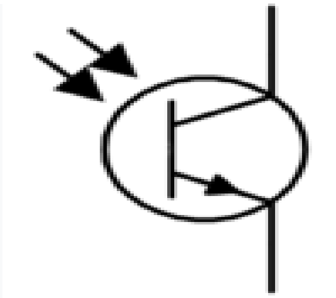
3.2. PHOTOTRANSISTORS

3.2.1. INTRODUCTION

A **phototransistor** is a light-sensitive transistor. A common type of phototransistor, the *bipolar phototransistor*, is in essence a bipolar transistor encased in a transparent case so that light can reach the *base–collector junction.* It was invented by Dr. John N. Shive (more famous for his wave machine) at Bell Labs in 1948 but it was not announced until 1950.

Definition: Phototransistors resemble normal transistor except the fact that the base terminal is not present in case of the phototransistor. Phototransistors convert the incident light into photocurrent. Instead of providing the base current for triggering the transistor, the light rays are used to illuminate the base region.

3.2.2. CONSTRUCTION



3.4. Electronic symbol for a phototransistor

The base terminal is made up of the material which shows sensitivity towards the light. The circuit symbol of the phototransistor is similar to that of the conventional transistor but the base terminal can be omitted. The two arrows point towards phototransistor indicates that the phototransistor is triggered by the light incident on it.

The Phototransistors are manufactured in the similar way by which normal transistor is manufactured, the only difference is the area of the base and collector region in case of phototransistors is quite large as compared to the normal transistor. This is because the more the light falls on the phototransistor the more current it will generate.

The collector and base region are formed by the techniques of ion-implantation and diffusion. The transistor which were used earlier was made of semiconductor material such as Germanium and Silicon and the resulting structure becomes a homogeneous material consist of either Silicon or Germanium.

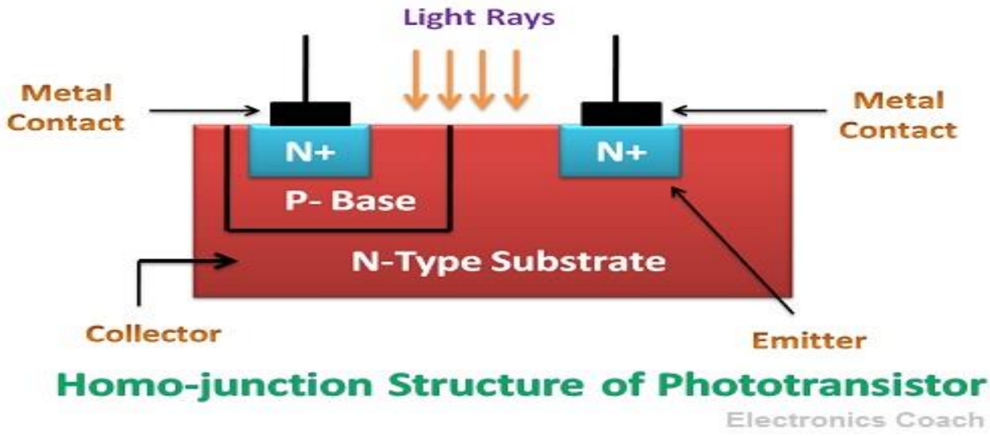


Fig 3.5 Construction of the Phototransistor

On the contrary, contemporarily, phototransistors are made up of Group-III and Group-V materials such as GaAs (Gallium Arsenide) in such a way that gallium and arsenide, each of these are used on either side of the transistor. The resulting structure becomes heterogeneous in nature. This type of structure is used widely because the conversion efficiency increases several times as compared to the conversion efficiency of the homogenous transistor.

3.2.3. WORKING

The electrons that are generated by photons in the base–collector junction are injected into the base, and this photodiode current is amplified by the transistor's current gain β (or h_{fe}). If the base and collector leads are used and the emitter is left unconnected, the phototransistor becomes a photodiode. While phototransistors have a higher responsivity for light they are not able to detect low levels of light any better than photodiodes Phototransistors also have significantly longer response times. Another type of phototransistor, the *field-effect phototransistor* (also known as photoFET), is a light-sensitive field-effect transistor. Unlike photobipolar transistors, photoFETs control drain-source current by creating a gate voltage.

The output of the phototransistor is taken from the emitter terminal and the light rays are allowed to enter the base region. The magnitude of the photocurrent generated by the phototransistor depends on the light intensity of the light falling on the transistor.

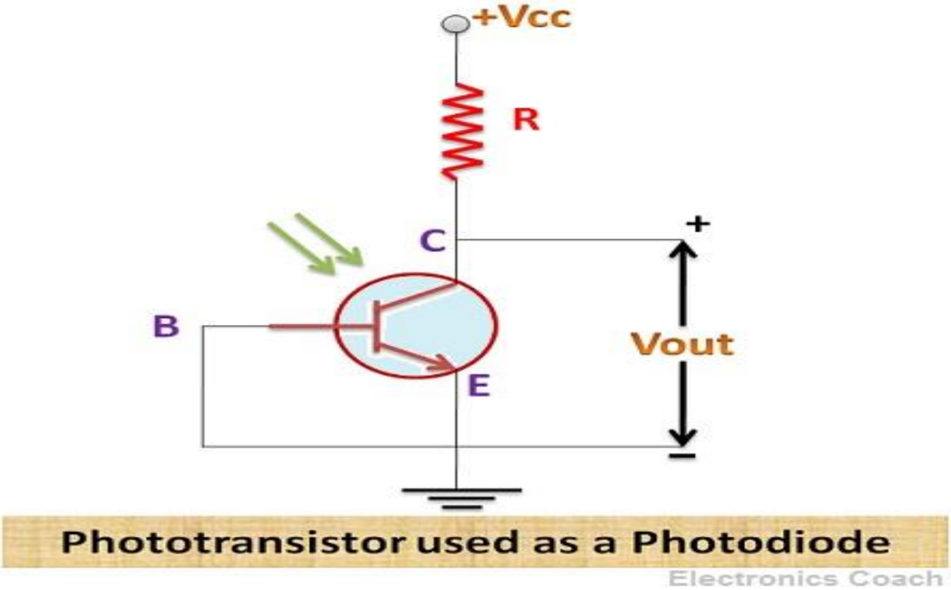


Fig 3.6. The circuit diagram of the **phototransistor**

It can be of three terminals or two terminals we can omit base as per our requirement. The phototransistor can be operated in three regions that are the cut-off region, active region, and the saturation region. The cut-off region and saturation region can be used to operate the transistor as the switch. The active region is used for generating current. The current generated from phototransistor depends on several factors apart from luminous intensity such as

1. **DC current gain of the transistor:** The higher the DC current gain of the transistor, the higher will be the intensity of photocurrent generated.
2. **Time constant:** Response time of the transistor also effects the efficiency of phototransistor to generate photocurrent.
3. **Luminous Sensitivity:** The luminous sensitivity can be determined by the ratio between the photoelectric current and incident luminous flux.
4. **Area of the collector-base junction:** The area of the collector-base junction is crucial for the generation of photocurrent, the higher the area of the collector-base junction the higher will be the magnitude of photocurrent generated by the phototransistor.
5. **Wavelength of the incident light:** The wavelength of the light incident on phototransistor controls the amount of photocurrent generated. The higher the wavelength the lower will be the frequency.

Output Characteristics of Phototransistor

The output characteristics of phototransistor can be understood with the help of the diagram below. It shows the variation of collector current with respect to the variation in the emitter-collector voltage.

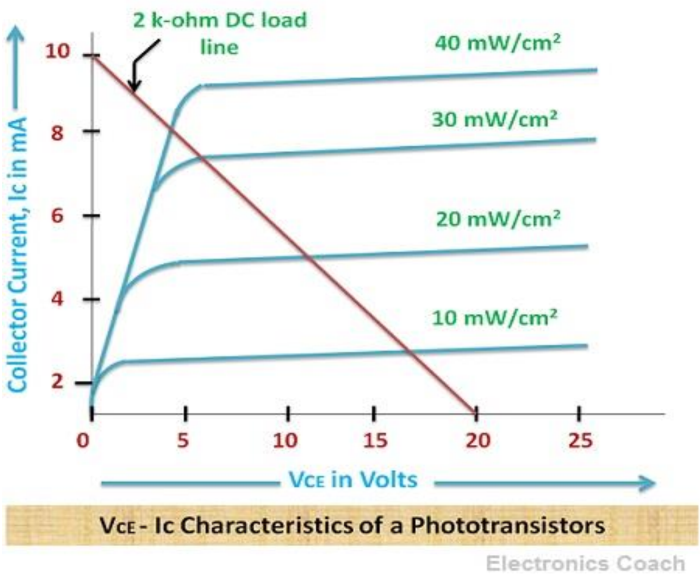


Fig 3.7. The V-I characteristics of the **phototransistor**

3.2.4. ADVANTAGES

Higher Efficiency in Comparison to Photodiode: The efficiency of the phototransistor is higher than that of the photodiode. This is because the current gain in case of the phototransistor is more than that of the photodiode, thus, even if the amount of light incident on both is same the phototransistor will generate more photocurrent than the photodiode.

1. **Faster Response:** The response time of phototransistor is more than that of the photodiode, this provides the advantage of using the phototransistor in our circuit.
2. **Less Noise interference:** The major drawback of photodiodes especially that of avalanche photodiodes is that it is not immune to noise interference. On the contrary, the phototransistors are immune to noise interference.
3. **Economical:** Phototransistor is less costly than other light sensitive device, thus it is economical to use phototransistors in light-sensitive applications.
4. **Less Complex:** The designing of phototransistors is simple and less complex as compared to LDRs and photodiodes.

3.2.5. DISADVANTAGES

1. **Effect of Electromagnetic energy:** The efficiency of phototransistors decreases when electromagnetic field interferes within the operation region. This results in poor conversion efficiency of phototransistors.
2. **Poor Performance at high frequency:** Due to the large area of the collector-base region, the capacitance increases. Due to this it cannot convert light into photocurrent effectively at higher frequency ranges.
3. **Electric spikes:** It arises in phototransistors more frequently as compared to photodiodes.

A **solaristor** is a two-terminal gate-less phototransistor. A compact class of two-terminal phototransistors or solaristors have been demonstrated in 2018 by ICN2 researchers. The novel concept is a two-in-one power source plus transistor device that runs on solar energy.

3.2.6. APPLICATIONS

(i) **Counting Systems:** The phototransistors are commonly used in counting systems. As this device works with the help of incident light, thus it is much easy to utilize such device in the computing system, as we don't need to worry about power supply.

(ii) **Encoder sensing and object detection:** The phototransistors can be used to detect the object or for encoding.

(iii) **Printers and Optical control remotes:** Due to its high light to current conversion efficiency, it is commonly used in optical devices such as remotes, printers etc.

(iv) **Light detector:** The most crucial application of phototransistor is to use it as the light detector. This is because it can detect even a small amount of light because it is highly efficient.

(v) **Level Indication and Relays:** The phototransistors are also used to indicate the level in the various system. They also play a vital role in relays and punch cards.

(vi) Phototransistors are the crucial optoelectronics device, it is also used in optical fibres. Due to its several advantages over photodiodes, it is more preferred over photodiodes.

3.3. PHOTOMULTIPLIERS

3.3.1. INTRODUCTION

A photomultiplier is a device that converts incident photons into an electrical signal. Kinds of photomultiplier include: Photomultiplier tube, a vacuum tube converting incident photons into an electric signal.

PMT is the technology state of the art at present. The photomultiplier is an extremely sensitive light detector providing a current output proportional to light intensity. Photomultipliers are used to measure any process which directly or indirectly emits light. PMT is a well established technology.

Photomultiplier tubes (PMTs) are generally used as the photo detectors because of their fast response, high gain, and high signal-to-noise ratio. They are sensitive for detection of light in the UV, visible, and near-IR region of ~200–900 nm. ... The spectral response of the PMT must be considered to avoid spurious results.

3.3.2. CONSTRUCTION

A **photomultiplier** is a device that converts incident photons into an electrical signal.

Kinds of photomultiplier include: Photomultiplier tube, a vacuum tube converting incident photons into an electric signal. Photomultiplier tubes (PMTs for short) are members of the class of vacuum tubes, and more specifically vacuum phototubes which are extremely sensitive detectors of light in the ultraviolet, visible, and near-infrared ranges of the electromagnetic spectrum.

- o Magnetic photomultiplier, developed by the Soviets in the 1930s.
- o Electrostatic photomultiplier, a kind of photomultiplier tube demonstrated by Jan Rajchman of RCA Laboratories in Princeton, NJ in the late 1930s which became the standard for all future commercial photomultipliers. The first mass-produced photomultiplier, the Type 931, was of this design and is still commercially produced today.[1]

- Silicon photomultiplier, a solid-state device converting incident photons into an electric signal. Silicon photomultipliers, often called "SiPM" in the literature, are solid-state single-photon-sensitive devices based on Single-photon avalanche diode (SPAD) implemented on common silicon substrate.

3.3.3. WORKING

Silicon photomultipliers, often called "**SiPM**" in the literature, are solid-state single-photon-sensitive devices based on Single-photon avalanche diode (SPAD) implemented on common silicon substrate. The dimension of each single SPAD can vary from 10 to 100 micrometres, and their density can be up to 10000 per square millimeter.

Every SPAD in SiPM operates in Geiger mode and is coupled with the others by a metal or polysilicon quenching resistor. Although the device works in digital/switching mode, most of SiPM are an analog device because all the microcells are read in parallel, making it possible to generate signals within a dynamic range from a single photon to 1000 photons for a device with just a square-millimeter area. More advanced readout schemes are utilized for the lidar applications. The supply voltage (V_b) depends on APD technology used and typically varies between 20 V and 100 V, thus being from 15 to 75 times lower than the voltage required for a traditional photomultiplier tube's (PMT) operation.

Typical specifications for a SiPM:

- Photo detection efficiency (PDE) ranges from 20 to 50%, depending on device and wavelength, being similar to a traditional PMT
- Gain (G) is also similar to a PMT, being about 10^6
- G vs. V_b dependence is linear and does not follow a power law like in the case of PMTs
- Timing jitter is optimized to have a photon arrival time resolution of about 100-300 ps
- Signal decay time is inversely proportional to square root of photoelectrons number within an excitation event
- The signal parameters are practically independent of external magnetic fields, in contrast to vacuum PMTs
- After pulsing probability (3-30%), defined as probability of spurious second pulses after single photon arrival
- Dark count density is frequency of pulses in absence of illumination (10^5-10^6 pulses/s/mm^2)
- Small dimensions permit extremely compact, light and robust mechanical design

SiPM for medical imaging are attractive candidates for the replacement of the conventional PMT in PET and SPECT imaging, since they provide high gain with low voltage and fast response, they are very compact and compatible with magnetic resonance setups. Nevertheless, there are still several challenges, for example, SiPM requires optimization for larger matrices, signal amplification and digitization.

3.3.4. APPLICATIONS

(i) A **photomultiplier tube**, useful for light detection of very weak signals, is a photoemissive device in which the absorption of a photon results in the emission of an electron. These detectors work by amplifying the electrons generated by a photocathode exposed to a photon flux

(ii) Photomultipliers are used in conjunction with scintillators to detect Ionizing radiation by means of hand held and fixed radiation protection instruments, and particle radiation in physics experiments.

(iii) Photomultipliers are used in research laboratories to measure the intensity and spectrum of light-emitting materials such as compound semiconductors and quantum dots.

(iv) Photomultipliers are used as the detector in many spectrophotometers. This allows an instrument design that escapes the thermal noise limit on sensitivity, and which can therefore substantially increase the dynamic range of the instrument.

(v) Photomultipliers are used in numerous medical equipment designs. For example, blood analysis devices used by clinical medical laboratories, such as flow cytometers, utilize photomultipliers to determine the relative concentration of various components in blood samples, in combination with optical filters and incandescent lamps.

(vi) An array of photomultipliers is used in a gamma camera. Photomultipliers are typically used as the detectors in flying-spot scanners.

(vii) Photomultiplier tubes are used for **applications** such as astronomy, spectroscopy, night vision equipment and laser range finding.

UNIT IV – PHOTORESISTOR

4.1. INTRODUCTION

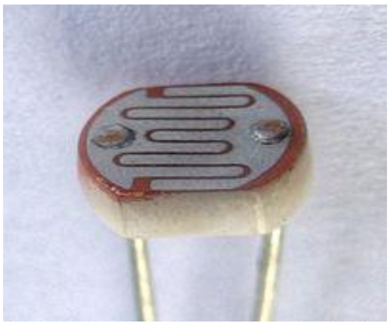


Fig 4.1 The symbol for a photoresistor

A photoresistor (acronymed LDR for Light Decreasing Resistance, or light-dependent resistor, or photo-conductive cell) is a passive component that decreases resistance with respect to receiving luminosity (light) on the component's sensitive surface. The resistance of a photoresistor decreases with increase in incident light intensity; in other words, it exhibits photoconductivity.

4.2. CONSTRUCTION

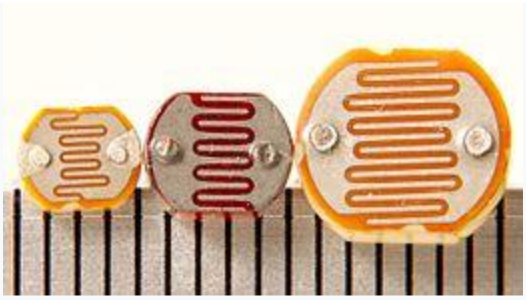


Fig 4.2. Three photoresistors with scale in mm

Fig 4.3. Large CdS Photocell from a street light.

Photoresistors are less light-sensitive devices than photodiodes or phototransistors: the two latter components are true semiconductor devices, while a photoresistor is an active component that does not have a PN-junction. The photoresistivity of any photoresistor may vary widely depending on ambient temperature, making them unsuitable for applications requiring precise measurement of or sensitivity to light photons.

Photoresistors also exhibit a certain degree of latency between exposure to light and the subsequent decrease in resistance, usually around 10 milliseconds. The lag time when going from lit to dark environments is even greater, often as long as one second. This property makes them unsuitable for sensing rapidly flashing lights, but is sometimes used to smooth the response of audio signal compression.

4.3. WORKING

A photoresistor can be applied in light-sensitive detector circuits and light-activated and dark-activated switching circuits acting as a resistance semiconductor. In the dark, a photoresistor can have a resistance as high as several megaohms (MΩ), while in the light, a photoresistor can have a resistance as low as a few hundred ohms. If incident light on a photoresistor exceeds a certain frequency, photons absorbed by the semiconductor give bound electrons enough energy to jump into the conduction band. The resulting free electrons (and their hole partners) conduct electricity, thereby lowering resistance. The resistance range and sensitivity of a photoresistor can substantially differ among dissimilar devices. Moreover, unique photoresistors may react substantially differently to photons within certain wavelength bands.

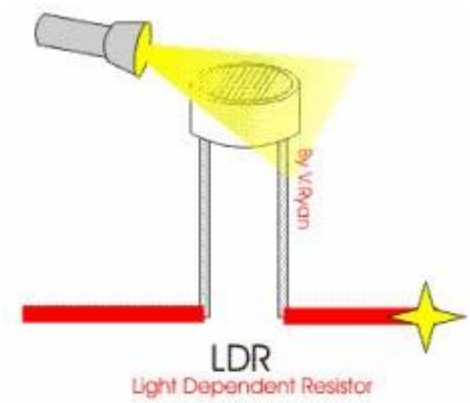


Fig 4.4. working principle of LDR

A photoelectric device can be either intrinsic or extrinsic. An intrinsic semiconductor has its own charge carriers and is not an efficient semiconductor, for example, silicon. In intrinsic devices, the only available electrons are in the valence band, and hence the photon must have enough energy to excite the electron across the entire bandgap. Extrinsic devices have impurities, also called dopants, added whose ground state energy is closer to the conduction band; since the electrons do not have as far to jump, lower energy photons (that is, longer wavelengths and lower frequencies) are sufficient to trigger the device. If a sample of silicon has some of its atoms replaced by phosphorus atoms (impurities), there will be extra electrons available for conduction. This is an example of an extrinsic semiconductor.

Fig 4.5. The internal components of a photoelectric control

The internal components of a photoelectric control for a typical American streetlight. The photoresistor is facing rightwards and controls whether current flows through the heater which opens the main power contacts. At night, the heater cools, closing the power contacts, energizing the street light. Photoresistors come in many types. Inexpensive cadmium sulfide cells can be found in many consumer items such as camera light meters, clock radios, alarm devices (as the detector for a light beam), nightlights, outdoor clocks, solar street lamps, and solar road studs, etc.

Photoresistors can be placed in streetlights to control when the light is on. Ambient light falling on the photoresistor causes the streetlight to turn off. Thus energy is saved by ensuring the light is only on during hours of darkness.

Photoresistors or LDRs are also used in laser-based security systems to detect the change in the light intensity when a person/object passes through the laser beam. They are also used in some dynamic compressors together with a small incandescent or neon lamp, or light-emitting diode to control gain reduction. A common usage of this application can be found in many guitar amplifiers that incorporate an onboard tremolo effect, as the oscillating light patterns control the level of signal running through the amp circuit.

4.3.1. WORKING PRINCIPLE OF LDR

The circuit diagram of a LDR is shown below. When the light intensity is low, then the resistance of the LDR is high. This stops the current flow to the base terminal of the transistor. So, the LED does not light. However, when the light intensity onto the LDR is high, then the resistance of the LDR is low.So current flows onto the base of the first transistor and then the second transistor.Consequently the LED lights.Here, a preset resistor is used to turn up or down to increase or decrease the resistance.

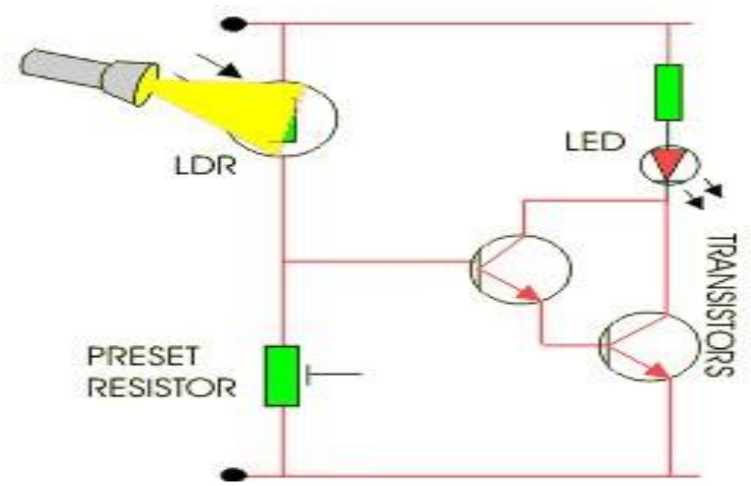


Fig 4.6. Circuit Diagram of a Light Dependent Resistor

This resistor works on the principle of photo conductivity. It is nothing but, when the light falls on its surface, then the material conductivity reduces and also the electrons in the valence band of the device are excited to the conduction band. These photons in the incident light must have energy greater than the band gap of the semiconductor material.This makes the electrons to jump from the valence band to conduction.

4.4. TYPES OF LIGHT DEPENDENT RESISTORS

Light dependent resistors are classified based on the materials used.

a). Intrinsic Photo Resistors

These resistors are pure semiconductor devices like silicon or germanium. When the light falls on the LDR, then the electrons get excited from the valence band to the conduction band and number of charge carriers increases.

b). Extrinsic Photo Resistors

These devices are doped with impurities and these impurities creates a new energy bands above the valence band. These bands are filled with electrons. Hence this decrease the band gap and small amount of energy is required in

4.5. ADVANTAGES OF LDR

- LDRs are very low-cost devices.
- LDRs are very smaller in sizes.
- LDR is a very simple device.
- The connection of LDR is also very simple.

4.6. DISADVANTAGES

- Narrow spectral response.
- Hysteresis effect.
- Low temperature stability for the fastest materials.
- The variation of the value of the resistance has a certain delay, different if it goes from dark to illuminated or from illuminated to dark. ...
- Slow response in stable materials.

4.7. APPLICATIONS

Light-dependent resistors are simple and low-cost devices. ... These resistors are used as light sensors and the **applications of LDR** mainly include alarm clocks, street lights, light intensity meters, burglar alarm circuits.

- LDRs are used in Light Sensors
- LDR is also used in some cameras to detect the presence of the light.
- LDRs are used Ligh Intensity measurement meters.
- In the manufacturing industry, LDR is used as a sensor for the counting of the packets moving on a conveyor belt.
- LDRs are also used in Light Activated Control Circuits.
- LDRs are used in Street Lights which are automatically turn ON in the night time.

a). Light Dependent Resistor Applications

Light dependent resistors have a low cost and simple structure. These resistors are frequently used as light sensors. These resistors are mainly used when there is a need to sense the absence and presence of the light such as burglar alarm circuits, alarm clock, light intensity meters, etc. LDR resistors mainly involves in various electrical and electronic projects. For better understanding of this concept, here we are explaining some real time projects where the LDR resistors are used.

b). Security System Controlled by An Electronic Eye

This security system controlled by an electronic eye project is based on photo sensing arrangement. The proposed system uses a 14-stage ripple carry binary counter to sense the intensity of light using LDR. The o/p makes a relay and buzzer for the required action. This project is very useful to deter burglars from shopping malls, banks and jewelry shops, etc.

This project uses a light dependent resistor. When light falls on the LDR sensor, then the resistance of the sensor decreases, which lead to activate an alarm to give an alert to the user. This project is suitable in the application of providing security system for lockers, cash boxes which can be found in the banks, shopping malls, jewel shops.

The circuit of this project is placed inside of the cash box in shopping malls or inside of the lockers in banks in such a way that, when a burglar opens the cash box or locker and uses a torch light to search the valuables. When the light falls on the circuit which includes an electronic eye and gives a command to the ripple counter. This triggers the alarm and shows a burglary attempt. A lamp is also used to indicate the theft when light falls on the sensor.In future, this project can be developed by using a GSM modem and also a microcontroller. This modem can be interfaced to send an SMS to the user in case of burglary

c). LDR Based light Intensity Control for Street Lights

In the proposed system, generally the lighting up of highways is done through HID lamps. Because, the energy consumption of these lamps is high. This project uses an LEDs to overcome the drawbacks of HID lamps. This project demonstrates the usage of light emitting diodes as a light source. These lights consumes low power and its life is more as compared to HID lamps.A light depending resistor is used to detect the light. The resistance of the LDR drastically reduces according to the daylight.

A bunch of LEDs are used to make a street light. The microcontroller comprises programmable instructions that controls the light intensity based on the Pulse width modulation signals generated. The light intensity is kept high during the peak hours, and as the traffic on the highways tend to decrease in late nights: and the light intensity also decreases till morning. Finally, the street lights completely shut down at morning and continues again at evening 6pm. In future, this project can be developed by connecting it with a solar panel, which converts the intensity of the solar into corresponding voltage, and this energy is used to feed the street lights on highways.

d*). Lighting Switch from Sunset to Sunrise*

This sunset to sunrise lighting switch is designed to control the light illuminated on the LDR sensor.

The resistance of the LDR sensor changes with the change in intensity of light falling on LDR. This sensor output is given to IC 555 timer connected in bistable mode. The o/p of the IC 555 timer is used to control the prompting of load through a TRIAC. Hence, this circuit switches on the load in the sunset and switches off the load in the sun rise automatically.

UNIT – V: CATHODE-RAY OSCILLOSCOPE (CRO)

5.1. INTRODUCTION

The CRO stands for a cathode ray oscilloscope. It is a device which is used for showing the signals on the screen. In 1879, Willan Crooks demonstrated that the cathode rays can be deflected in a vacuum tube type by using a magnet. Basically, It has four parts which are display, vertical and horizontal deflection plates, Triggers and Electron Gun. The oscilloscopes have used the probes which is coaxial cable and these cables are used for taking input from or giving output to any instrument. With the help of an oscilloscope, we can analyze the waveform by plotting amplitude along with the x-axis and time on the y-axis. The major applications of CRO are in TV receivers and also in laboratory work involving research and design. It also plays a major role in the medical science field.

5.2. BLOCK DIAGRAM OF CRO

The **block diagram shows the general purpose of CRO internal contraction**. The CRO has the cathode ray tube which acts as a heart of the oscilloscope. In an oscilloscope, the CRT produces the electron beam which is accelerated, decelerated and focus with the help of accelerating and focusing anode at a high velocity and brings to the focal point on a fluorescent screen. After the collision of the electron on the screen, it produces a visible spot where the electron beam strikes with it and this spot is seen on another side of the screen. This collision or bombarding of electrons continually done on the screen which shows the electrical signal, this electron beam like an electrical pencil of light which produces a light where it collides with the screen.

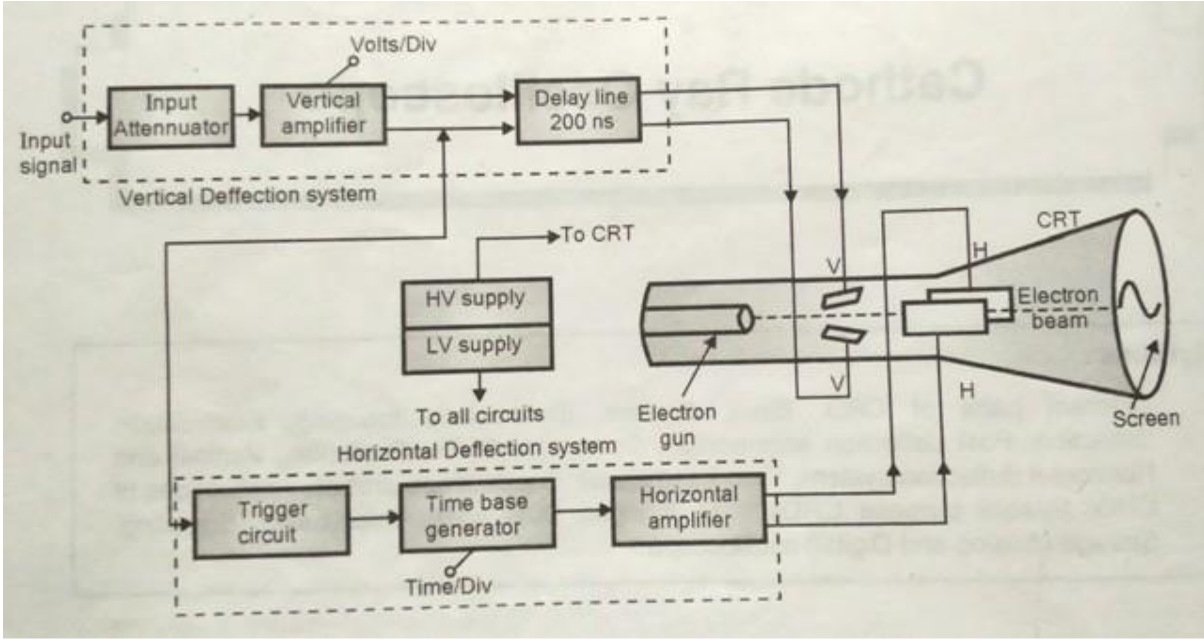


Fig 5.1. Block Diagram of CRO

For the completion of this task, we need many electrical signals. These electrical signals have many levels of voltages. The oscilloscope needs high voltage and low voltage for the complete display of the signal on the screen. The low voltage which is directly supplied to the mains supply is used for the heater of the electron gun to generate the electron beam. The high voltage is required for the cathode ray tube to enhancing the speed of the beam and avoids the secondary emission. The normal voltage supply is used for other controlling units of the CRO. The horizontal deflection plates and vertical deflection plates are placed between the electron gun and the screen, which are used to control the position of the electron beam as per the requirement of the electrical signal. The trigger circuit is used for synchronizing both axis i.e. X and Y-axis. So the electron beam strike on the desired position of the screen.

5.3. CONSTUCTION

1. Cathode Ray Tube (CRT)

   Main parts of CRT are –
   - **Electron Gum Assembly**
   - **Deflection plate assembly**
   - **Fluorescent Screen**
   - **Glass Tube**

2. Horizontal Deflection System
3. Vertical Deflection System
4. Power Supply

1. Cathode Ray Tube (CRT)

CRT is an essential part of CRO. This is also used in the Monocreme picture tube. CRT consists of an electron gun that produces an electron beam. This is a narrow beam that passes through the tube and falls on the screen. The point at which the electron beam will strike that point will glow due to the coating of fluorescent material on the screen.

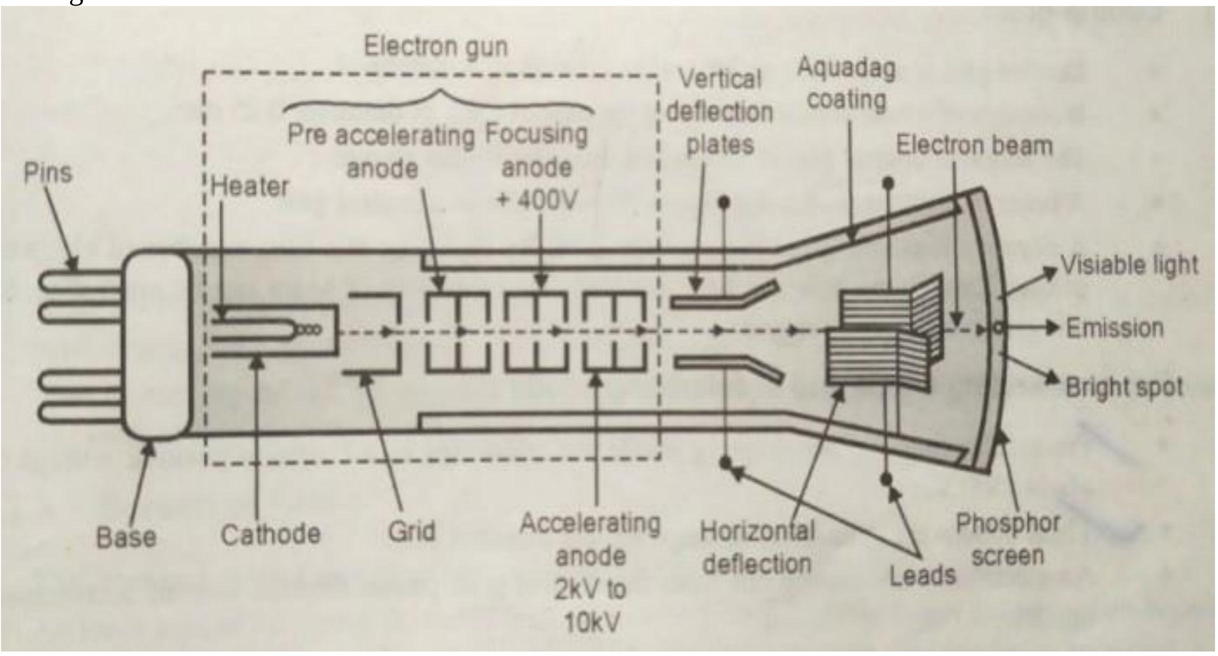


Fig 5.2 Block Diagram of CRT

2. Horizontal Deflection System

It has the following blocks

a). Time Base Generator

b). Trigger Circuit

c). Horizontal Amplifier

a). **Time Base Generator**

Time Base Generator is used to generate a sawtooth voltage which is applied to horizontal deflection plates. Which is generated due to the voltage decrease to zero must be fast so the beam can very rapidly move from right to left.

b). Trigger Circuit

Trigger Circuit triggers the time base generator to generate a sawtooth waveform when the vertical input signal is present. It is used to convert the incoming signal into a trigger pulse so that the input signal and the sweep frequency can be synchronized.

c). Horizontal Amplifier

A horizontal Amplifier is used to amplify the sawtooth voltage before it is applied to horizontal deflection plates.

3. Vertical Deflection System

It consists of the following parts Attenuator Vertical Amplifier Delay Line

Attenuator

An attenuator is a voltage divider network consisting of a number of resistors. By selecting the proper resistor, the corresponding voltage is obtained.

Vertical Amplifier

Vertical Amplifier is a wideband amplifier used to amplify the signal in the vertical section of the signal.

Delay Line

Delay Line is used to delaying signals for some time in the vertical section.

4. Power Supply

There are two power supplies-

a) Negative high voltage (HV) Supply

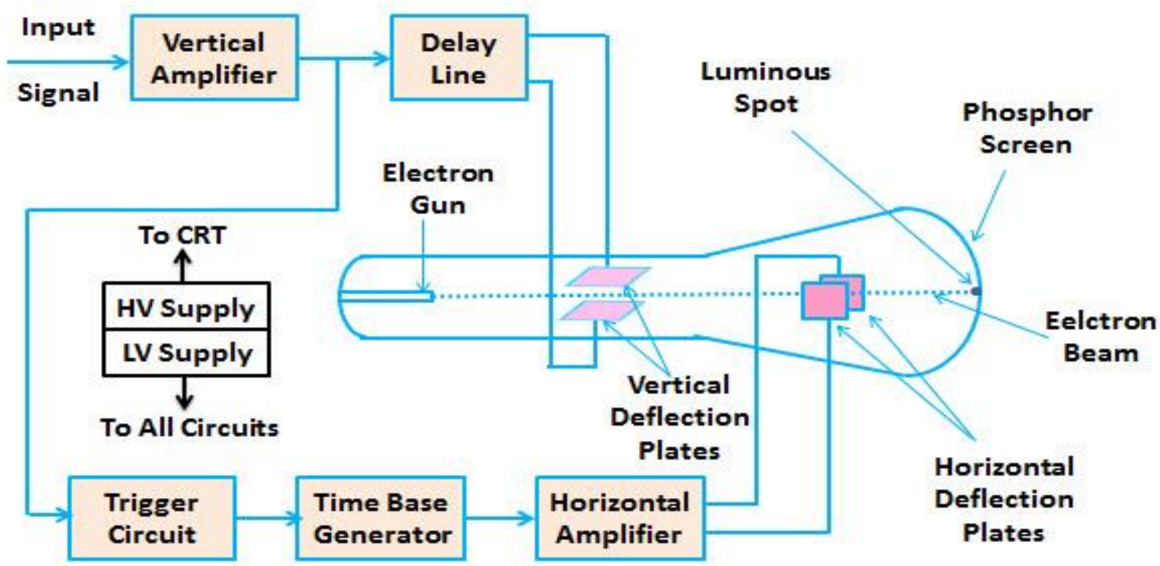
b) Positive low voltage supply (LV). The +ve voltage supply is from +300V to 400V, the negative voltage supply is from -1000 V to -1500 V.

5.4. PRINCIPLE OF WORKING

Cathode Ray Oscilloscope (CRO) is basically a graph displaying device. It draws a graph of an electric signal. It **is an electronic test instrument,** which is used to obtain waveforms when the differential input signals are given. The vertical axis (Y) represents Voltage and the horizontal axis (X) represents time. The intensity or brightness of the display is sometimes called Z-axis.

The oscilloscope shows the variations in the electrical signals over time, thus the voltage and time describe a shape and it is continuously graphed beside a scale. Form the screen of the oscilloscope, we can easily see some properties like amplitude, frequency, time interval and etc. The Oscilloscope is used for finding the frequency and time period of any wave. We can also check the electronic components very easily.

The CRO recruit the cathode ray tube and acts as a heart of the oscilloscope. In an oscilloscope, the CRT produces the electron beam which is accelerated to a high velocity and brings to the focal point on a fluorescent screen. Thus, the screen produces a visible spot where the electron beam strikes with it. By detecting the beam above the screen in reply to the electrical signal, the electrons can act as an electrical pencil of light which produces a light where it strikes.



Block Diagram of Cathode Ray Oscilloscope (CRO)

Fig 5.4. CRO

To complete this task we need various electrical signals and voltages. This provides the power supply circuit of the oscilloscope. Here we will use high voltage and low voltage. The low voltage is used for the heater of the electron gun to generate the electron beam. The high voltage is required for the cathode ray tube to speed up the beam. The normal voltage supply is necessary for other control units of the oscilloscope.

The horizontal and vertical plates are placed between the electron gun and the screen, thus it can detect the beam according to the input signal. Just before detecting the electron beam on the screen in the horizontal direction which is in X-axis a constant time-dependent rate, a time base generator is given by the oscillator. The signals are passed from the vertical deflection plate through the vertical amplifier. Thus, it can amplify the signal to a level will be provided the deflection of the electron beam.

5.5. TYPES OF CRO

1.Dual Trace Oscilloscope: A dual trace CRO displays simultaneously two signals in two separate traces. ...

2. Dual Beam CRO

3. Storage CRO
4. Sampling CRO
5. Digital Read-Out CRO

5.6. APPLICATIONS OF CRO

- Voltage measurement
- Current measurement
- Identification of waveform
- Measurement of phase and frequency using Lissajous pattern
- Component Testing
- **Other Uses** of CRO : In laboratory, the CRO can be used as
  - It can display different types of waveforms
  - It can measure short time interval
  - In voltmeter, it can measure potential difference.