LESSON 6 SEMICONDUCTOR THEORY

OPTICAL DEVICES

By the end of the lesson the learner should be able to:

i) Define Optical Devices such as Light Emitting Diode LED, photodiode, Liquid Crystal Display LCD, Photo cell, Solar cell

ii) Explain the working principle of various Optical Devices

iii) Describe the application of various Optical Devices

Light Emitting Diode LED

The lighting emitting diode is a p-n junction diode. It is a specially doped diode and made up of a special type of semiconductors. When the light emits in the forward biased, then it is called a light-emitting diode.

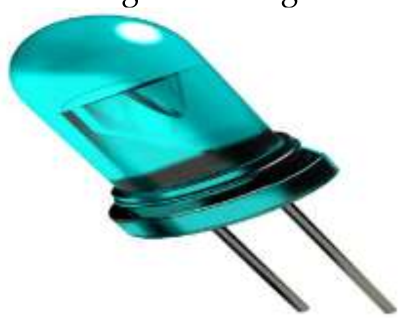


Fig 6.1 Light Emitting Diode

LED Symbol

The LED symbol is similar to a diode symbol except for two small arrows that specify the emission of light, thus it is called LED (light-emitting diode). The LED includes two terminals namely anode (+) and the cathode (-). The LED symbol is shown below.

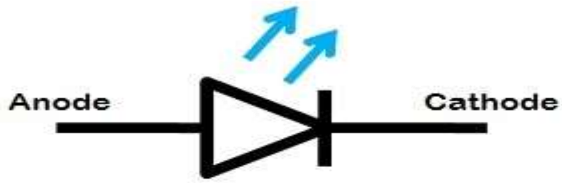


Fig 6.2 LED Symbol

Construction of LED

The construction of LED is very simple because it is designed through the deposition of three semiconductor material layers over a substrate. These three layers are arranged one by one where the top region is a P-type region, the middle region is active and finally, the bottom region is N-type. The three regions of semiconductor material can be observed in the construction. In the construction, the P-type region includes the holes; the N-type region includes elections whereas the active region includes both holes and electrons.

When the voltage is not applied to the LED, then there is no flow of electrons and holes so they are stable. Once the voltage is applied then the LED will forward biased, so the electrons in the N-region and holes from P-region will move to the active region. This region is also known as the depletion region. Because the charge carriers like holes include a positive charge whereas electrons have a negative charge so the light can be generated through the recombination of polarity charges.

How does the Light Emitting Diode Work?

When the diode is forward biased, then the electrons & holes are moving fast across the junction and they are combined 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.

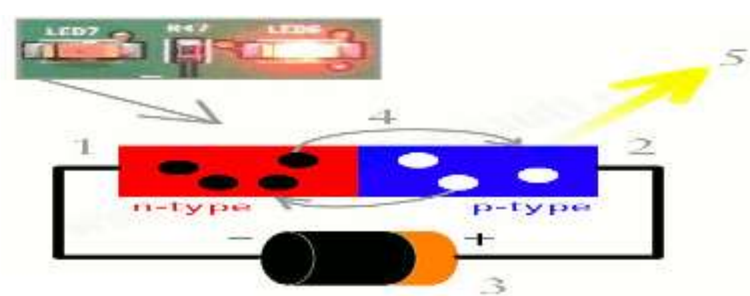


Fig 6.3 Working of Light Emitting Diode

The above diagram shows how the light-emitting diode works and the step by step process of the diagram.

- From the above diagram, we can observe that the N-type silicon is in red color including the electrons which are indicated by the black circles.
- The P-type silicon is in the blue color 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.
- Electrons and holes at the junction are combined.
- The photons are given off as the electrons and holes are recombined.

Working Principle of LED

The working principle of the Light-emitting diode is based on the quantum theory. The quantum theory says that when the electron comes down from the higher energy level to the lower energy level then, the energy emits from the photon. The photon energy is equal to the energy gap between these two energy levels. If the PN-junction diode is in the forward biased, then the current flows through the diode.

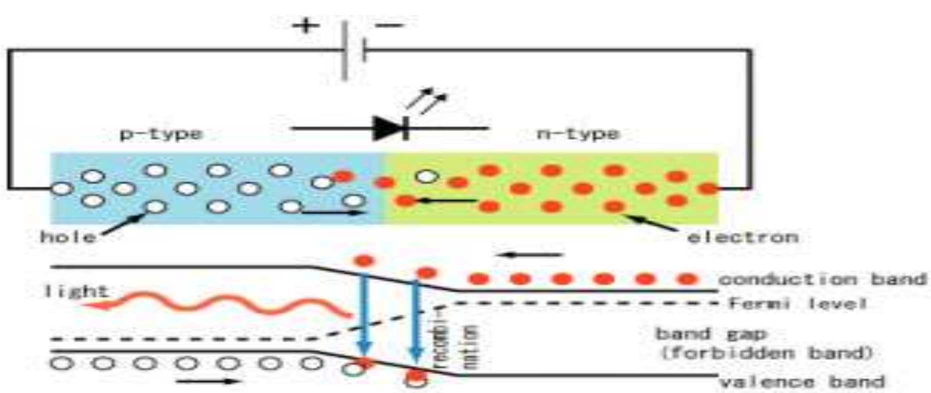


Fig 6.4 Working Principle of LED

The flow of current in the semiconductors is caused by the flow of holes in the direction of current and the flow of electrons in the opposite direction of the current. Hence there will be recombination due to the flow of these charge carriers.

The recombination indicates that the electrons in the conduction band jump down to the valence band. When the electrons jump from one band to another band the electrons will emit the electromagnetic energy in the form of photons and the photon energy is equal to the forbidden energy gap.

For example, let us consider the quantum theory, the energy of the photon is the product of both the Planck constant and frequency of electromagnetic radiation. The mathematical equation is shown

$$Eq = hf$$

Where h is known as a Planck constant, and the velocity of electromagnetic radiation is equal to the speed of light i.e c. The frequency radiation is related to the velocity of light as an $f= c / \lambda$. λ is denoted as a wavelength of electromagnetic radiation and the above equation will become as a $Eq = hc / \lambda$

We can say that the wavelength of electromagnetic radiation is inversely proportional to the forbidden gap. In general silicon, germanium semiconductors this forbidden energy gap is between the condition and valence bands are such that the total radiation of electromagnetic wave during recombination is in the form of infrared radiation.

The main difference between a diode and a LED includes the following.

Diode	LED
The semiconductor device like a diode conducts simply in one direction.	The LED is one type of diode, used to generate light.
The designing of the diode can be done with a semiconductor material & the flow of electrons in this material can give their energy the heat form.	The LED is designed with the gallium phosphide & gallium arsenide whose electrons can generate light while transmitting the energy.
The diode changes the AC into the DC	The LED changes the voltage into light
It has a high reverse breakdown voltage	It has a low-reverse breakdown voltage.
The on-state voltage of the diode is 0.7v for silicon whereas, for germanium, it is 0.3v	The on-state voltage of LED approximately ranges from 1.2 to 2.0 V.
The diode is used in voltage rectifiers, clamping circuits and voltage multipliers.	The applications of LED are traffic signals, automotive headlamps, in medical devices, camera flashes, etc.

I-V Characteristics of LED

There are different types of light-emitting diodes that are available in the market and there are different LED characteristics which include the color light, or wavelength radiation, light intensity. The important characteristic of the LED is color. In the starting use of LED, there is the only red color. As the use of LED is increased with the help of the semiconductor process and doing the research on the new metals for LED, the different colors were formed.

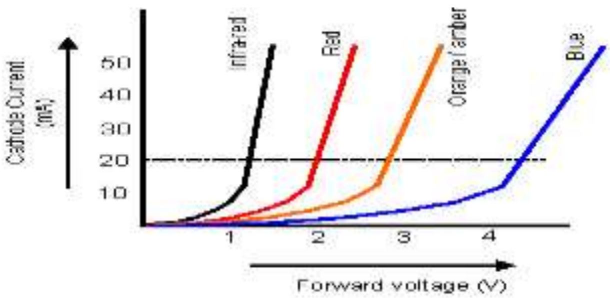


Fig 6.5 I-V Characteristics of LED

The following graph shows the approximate curves between the forward voltage and the current. Each curve in the graph indicates a different color.

Advantages and Disadvantages of LED’s

The advantages of light-emitting diode include the following.
- The cost of LED’s is less and they are tiny.
- By using the LED’s electricity is controlled.
- The intensity of the LED differs with the help of the microcontroller.
- Long Lifetime and Rugged
- Energy efficient/No warm-up period
- Not affected by cold temperatures
- Directional and Controllable
- Color Rendering is Excellent
- Environmentally friendly

The disadvantages of light-emitting diode include the following.
- Price/ Impact on insects
- Temperature sensitivity/Temperature dependence
- Light quality/Electrical polarity
- Voltage sensitivity/Efficiency drop

Applications of Light Emitting Diode

There are many applications of LED and some of them are explained below.

- LED is used as a bulb in the homes and industries
- The light-emitting diodes are used in motorcycles and cars
- These are used in mobile phones to display the message
- At the traffic light signals LED's are used

LED Displays

As well as individual colour or multi-colour LEDs, several light emitting diodes can be combined together within a single package to produce displays such as bar graphs, strips, arrays and seven segment displays.

A 7-segment LED display provides a very convenient way when decoded properly of displaying information or digital data in the form of numbers, letters or even alpha-numerical characters and as their name suggests, they consist of seven individual LEDs (the segments), within one single display package.

In order to produce the required numbers or characters from 0 to 9 and A to F respectively, on the display the correct combination of LED segments need to be illuminated. A standard seven segment LED display generally has eight input connections, one for each LED segment and one that acts as a common terminal or connection for all the internal segments.

- The Common Cathode Display (CCD) – In the common cathode display, all the cathode connections of the LEDs are joined together and the individual segments are illuminated by application of a HIGH, logic "1" signal.
- The Common Anode Display (CAD) – In the common anode display, all the anode connections of the LEDs are joined together and the individual segments are illuminated by connecting the terminals to a LOW, logic "0" signal.

A Typical Seven Segment LED Display

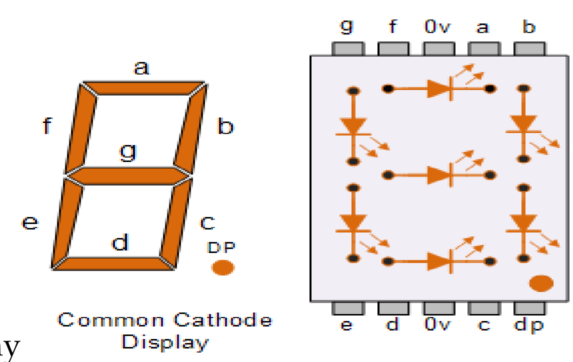


Fig 6.6 LED Display

Liquid Crystal Display LCD

A liquid crystal display or LCD draws its definition from its name. It is a combination of two states of matter, the solid and the liquid. LCD uses a liquid crystal to produce a visible image. Liquid crystal displays are super-thin technology display screens that are generally used in laptop computer screens, TVs, cell phones, and portable video games. LCD's technologies allow displays to be much thinner when compared to a Cathode Ray Tube (CRT) technology.
Liquid crystal display is composed of several layers which include two polarized panel filters and electrodes. LCD technology is used for displaying the image in a notebook or some other electronic devices like mini computers. Light is projected from a lens on a layer of liquid crystal. This combination of colored light with the grayscale image of the crystal (formed as electric current flows through the crystal) forms the colored image. This image is then displayed on the screen.

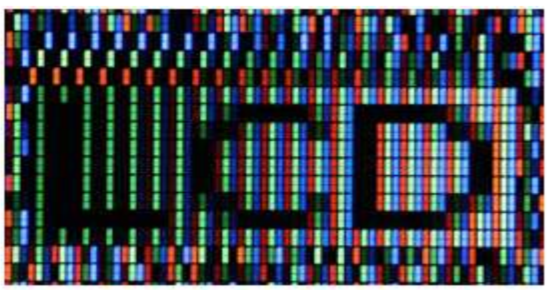


Fig 6.7 LCD

LCD is either made up of an active matrix display grid or a passive display grid. Most of the Smartphone's with LCD technology uses active matrix display, but some of the older displays still make use of the passive display grid designs. Most of the electronic devices mainly depend on liquid crystal display technology for their display. The liquid has a unique advantage of having low power consumption than the LED or cathode ray tube.
The liquid crystal display screen works on the principle of blocking light rather than emitting light. LCDs require a backlight as they do not emit light themselves. Cathode ray tube draws more power compared to LCDs and is also heavier and bigger.

Construction of LCD

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 be able to control both of the operations to transmit or is also able to change the polarized light.

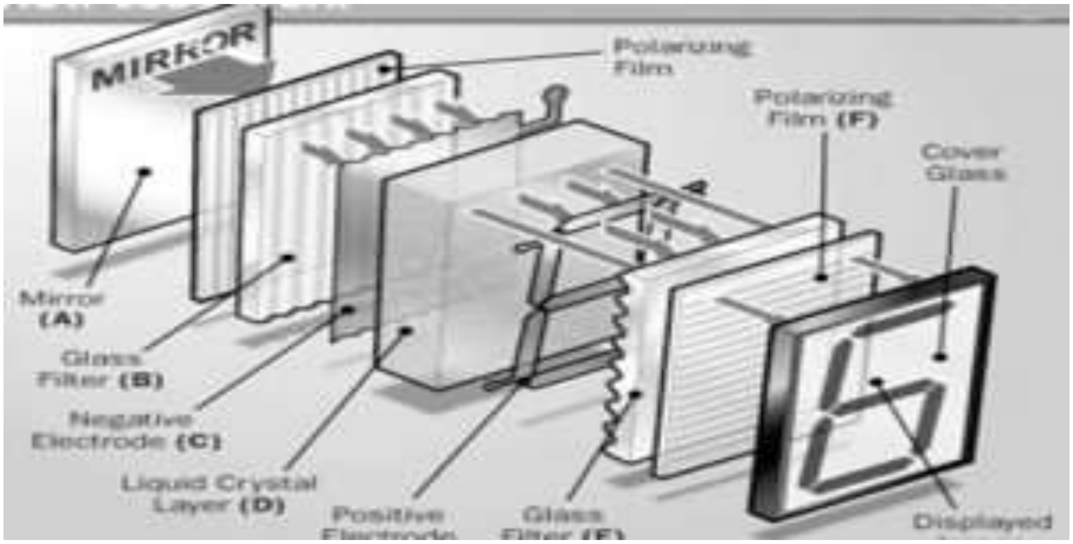


Fig 6.8 LCD Construction

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.

Light travels through each layer guided to 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.

How LCD utilizes Liquid Crystals & Polarized Light?

An LCD TV monitor utilizes the sunglasses concept to operate its colored pixels. On the flip side of the LCD screen, there is a huge bright light that shines out in the direction of the observer. On the front side of the display, it includes the millions of pixels. These are colored with different colors like green, blue, and red. Each pixel in the display includes a polarizing glass filter at the backside and the front side includes at 90 degrees, so the pixel looks dark normally.

How Colored Pixels Works in LCDs?

At the backside of the TV, a bright light is connected whereas on the front side, there are many colored squares that will be turned ON/OFF. Here, we are going to discuss how every colored pixel is turned ON/OFF:

How the Pixels of LCD Switched OFF

- In the LCD, the light travels from the backside to the front side
- A horizontal polarizing filter ahead of the light will block all the light signals apart from those horizontally vibrate. The pixel of the display can be switched off by a transistor by allowing the flow of current throughout its liquid crystals which makes the crystals sort out & the light supplies through them will not change.
- Light signals come out from the liquid crystals to vibrate horizontally.
- A vertical type polarizing filter ahead of the liquid crystals will block all light signals apart from those signals vertically vibrating. The light which is vibrating horizontally will travel throughout the liquid crystals so they cannot get during the vertical filter.
- At this position, light cannot reach the LCD screen because the pixel is dim.

How the Pixels of LCD Switched ON

- The bright light at the backside of the display shines like before.
- The horizontal polarizing filter ahead of the light will block all light signals apart from those vibrating horizontally.
- A transistor activates the pixel by turning off the flow of electricity in the liquid crystals so that crystals can rotate. These crystals turn light signals by 90° as they move through.
- Light signals that flow into the horizontally vibrating liquid crystals will come out from them to vibrate vertically.
- The vertical polarizing filter ahead of the liquid crystals will block all light signals apart from those vertically vibrating. The light which is vertically vibrating will come out from the liquid crystals can now acquire throughout the vertical filter.
- Once the pixel is activated then it gives color to the pixel.

Difference between Plasma & LCD

Both the displays like plasma and an LCD are similar, however, it works in a different way totally. Every pixel is a microscopic fluorescent lamp that glows through the plasma, whereas plasma is an extremely hot type of gas where the atoms are blown separately to make electrons (negatively charged) & ions (positively charged). These atoms flow very freely and generate a glow of light once they crash. The designing of the plasma screen can be done very bigger as compared with ordinary CRT (cathode-ray tube) TVs, but they are very expensive.

Advantages

The advantages of liquid crystal display include the following.

- LCD’s consumes less amount of power compared to CRT and LED
- LCD’s consists of some microwatts for display in comparison to some mill watts for LED’s/LCDs are of low cost
- Provides excellent contrast
- LCD’s are thinner and lighter when compared to cathode-ray tube and LED

Disadvantages

The disadvantages of liquid crystal display include the following.

- Require additional light sources/Range of temperature is limited for operation
- Low reliability/Speed is very low/LCD’s need an AC drive

Applications

The applications of liquid crystal display include the following.

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

- Liquid crystal thermometer
- The liquid crystal display technology is also applicable in the visualization of the radio frequency waves in the waveguide
- Used in the medical applications/ Optical imaging

Fig 6.9 Few LCD Based Displays

LCD Monitor

LCD Display Camera

LCD Display Smart Phone

What is a Photodiode?

It is a form of light sensor that converts light energy into electrical energy (voltage or current). Photodiode is a type of semi conducting device with PN junction. Between the p (positive) and n (negative) layers, an intrinsic layer is present (PIN diode). It is also called as Photodetector, Photo Sensor or Light Detector. Photodiode operates in reverse bias condition. The symbol of the photodiode is similar to that of an LED but the arrows point inwards as opposed to outwards in the LED.

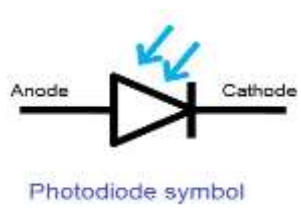


Fig 6.10 Photodiode symbol

Working of a Photodiode

Generally, when a light is made to illuminate the PN junction, covalent bonds are ionized. This generates hole and electron pairs. Photocurrents are produced due to generation of electron-hole pairs. Electron hole pairs are formed when photons of energy more than 1.1eV hits the diode. When the photon enters the depletion region of diode, it hits the atom with high energy. This results in release of electron from atom structure. After the electron release, free electrons and hole are produced.

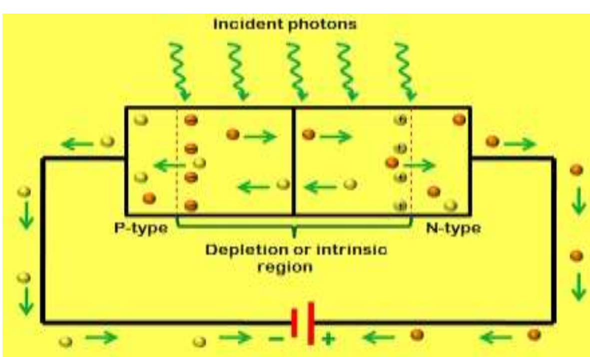


Fig 6.11 Photodiode construction

In general, an electron will have a negative charge and holes will have a positive charge. The depletion energy will have built-in electric field. Due to that electric field, electron-hole pairs move away from the junction. Hence, holes move to anode and electrons move to the cathode to produce photocurrent.

The photon absorption intensity and photon energy are directly proportional to each other. When energy of photons is less, the absorption will be more. This entire process is known as Inner Photoelectric Effect.

Intrinsic Excitations and Extrinsic Excitations are the two methods via which the photon excitation happens. The process of intrinsic excitation happens, when an electron in the valence band is excited by photon to conduction band.

Modes of operation of a Photodiode

Photodiode operates in three different modes. They are:

- Photovoltaic Mode
- Photoconductive Mode
- Avalanche Diode Mode

Connecting a Photodiode in an External Circuit

A Photodiode operates in a circuit in reverse bias. Anode is connected to circuit ground and cathode to positive supply voltage of the circuit. When illuminated by light, current flows from cathode to anode.

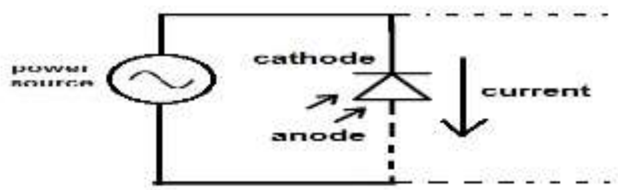
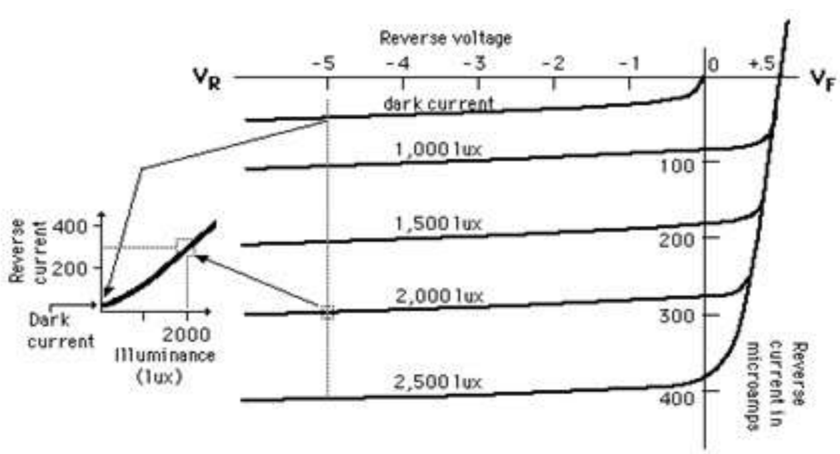


Fig 6.12 connecting Photo diode to external circuit.

When photodiodes are used with external circuits, they are connected to a power source in the circuit. The amount of current produced by a photodiode will be very small. This value of current will not be enough to drive an electronic device. So when they are connected to an external power source, it delivers more current to the circuit. The battery source helps to increase the current value, which helps the external devices to have a better performance

V-I Characteristics of Photodiode

Photodiode operates in reverse bias condition. Reverse current does not depend on reverse voltage. When there is no light illumination, reverse current will be almost zero. The minimum amount of current present is called as Dark Current. Once when the light illumination increases, reverse current also increases linearly.



Applications of Photodiode

- They have a linear response to a light illumination and the amount of current produced is proportional to amount of light falling on the sensor.
- Helps to provide an electric isolation with help of optic-couplers. When two isolated circuits are illuminated by light, optic-couplers is used to couple the circuit optically. But the circuits will be isolated electrically. Compared to conventional devices, optic-couplers are fast.
- Used in safety electronics like fire and smoke detectors. Also used in TV units.
- When utilized in cameras, they act as photo sensors. It is used in scintillators charge-coupled devices, photoconductors, and photomultiplier tubes.
- Photodiodes are also widely used in numerous medical applications like instruments to analyze samples, detectors for computed tomography and also used in blood gas monitors.

What is the difference between photodiode and solar cell?

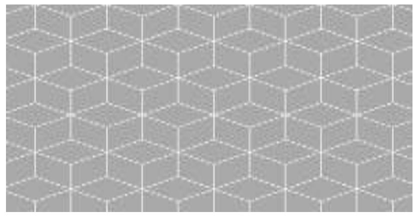
A solar cell also converts light energy into electrical energy. It's basically a large-area photodiode. Main difference between solar cell and photodiode: Solar cells are more concerned with the amount of absorbed photons (absorption efficiency) than with the reaction time.

Major difference between photodiode and solar cell:

- Size (solar cell are larger and larger than photodiodes)
- Load capacity (solar cell load capacity is greater than photodiodes)
- Physical design or manufacturing process
- time behavior
- Application (photodiodes are used as sensors, solar cells are used as transducers that convert light into electricity)
- The photodiodes can also be used in the reverse direction, which due to minority carriers only the blocking saturation current is generated. However, this significantly improves the response time, which is very important in many applications. Speed does not matter in solar cells. In addition, solar cells are never used in the reverse direction.

In general, photodiodes are used in electronics as components used in remote controls for receiving and detecting infrared signals. Solar cells are primarily intended to generate electricity by converting sunlight into electricity

Fig 6.13 Photoconductive cells



The photoconductive cell is a two terminal semiconductor device whose terminal resistance will vary (linearly) with the intensity of the incident light. For obvious reasons, it is frequently called a *photoresistive device.*

The photoconductive materials most frequently used include cadmium sulphide (CdS) and cadmium selenide (CdSe). Both materials respond rather slowly to changes in light intensity. The peak spectral response time of CdS units is about 100 ms and 10 ms for CdSe cells. Another important difference between the two materials is their temperature sensitivity. There is large change in the resistance of a cadmium selenide cell with changes in ambient temperature, but the resistance of cadmium sulphide remains relatively stable. The *spectral response* of a cadmium sulphide cell closely matches that of the human eye, and the cell is therefore often used in applications where human vision is a factor, such as street light control or automatic iris control for cameras.

The essential elements of a photoconductive cell are the ceramic substrate, a layer of photoconductive material, metallic electrodes to connect the device into a circuit and a moisture resistant enclosure.

The circuit symbol and construction of a typical photoconductive cell are shown Fig 6.14 A and B.

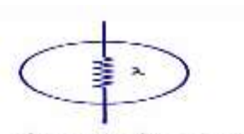


Fig 6.14 A & B Photo-conductive-cell-circuit-symbol

Photo-conductive-cell-construction

Light sensitive material is arranged in the form of a long strip, zigzagged across a disc shaped base with protective sides. For added protection, a glass or plastic cover may be included. The two ends of the strip are brought out to connecting pins below the base.

Photoconductive cell circuit:

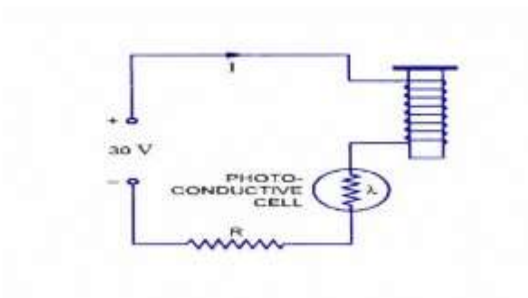


Fig 6.15 Photo-conductive-cell-circuit

Characteristics of a Photoconductive cell:

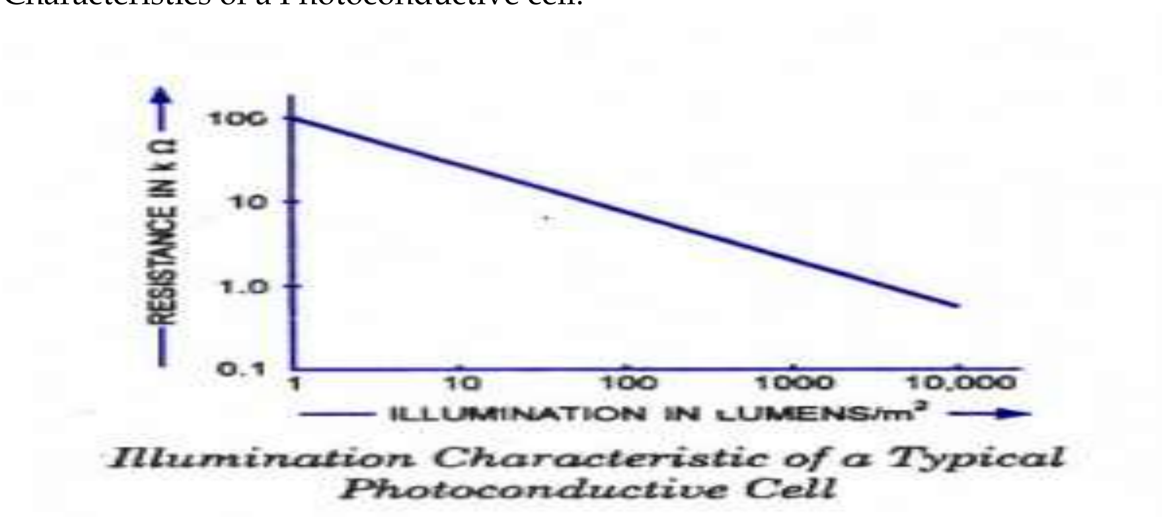


Fig 6.16 Photo-conductive-cell-characteristics

The illumination characteristics of a typical photoconductive cell are shown from which it is obvious that when the cell is not illuminated its resistance may be more than 1 00 kilo ohms. This resistance is called the *dark resistance*. When the cell is illuminated, the resistance may fall to a few hundred ohms. Note that the scales on the illumination characteristic are logarithmic to cover a wide ranges of resistance and illumination that are possible.

The major drawback of the photoconductive cells is that temperature variations cause substantial variations in resistance for a substantial variations in resistance for a particular light intensity. Therefore such a cell is unsuitable for analog applications.

What is a Solar Cell?

A solar cell (also known as a photovoltaic cell or PV cell) is defined as an electrical device that converts light energy into electrical energy through the photovoltaic effect. A solar cell is basically a p-n junction diode. Solar cells are a form of photoelectric cell, defined as a device whose electrical characteristics – such as current, voltage, or resistance – vary when exposed to light.

Individual solar cells can be combined to form modules commonly known as solar panels. The common single junction silicon solar cell can produce a maximum open-circuit voltage of approximately 0.5 to 0.6 volts. By itself this isn't much – but remember these solar cells are tiny. When combined into a large solar panel, considerable amounts of renewable energy can be generated.

Construction of Solar Cell

A solar cell is basically a junction diode, although its construction it is little bit different from conventional p-n junction diodes. A very thin layer of p-type semiconductor is grown on a relatively thicker n-type semiconductor. We then apply a 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. 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 through it.

V-I Characteristics of a Photovoltaic Cell

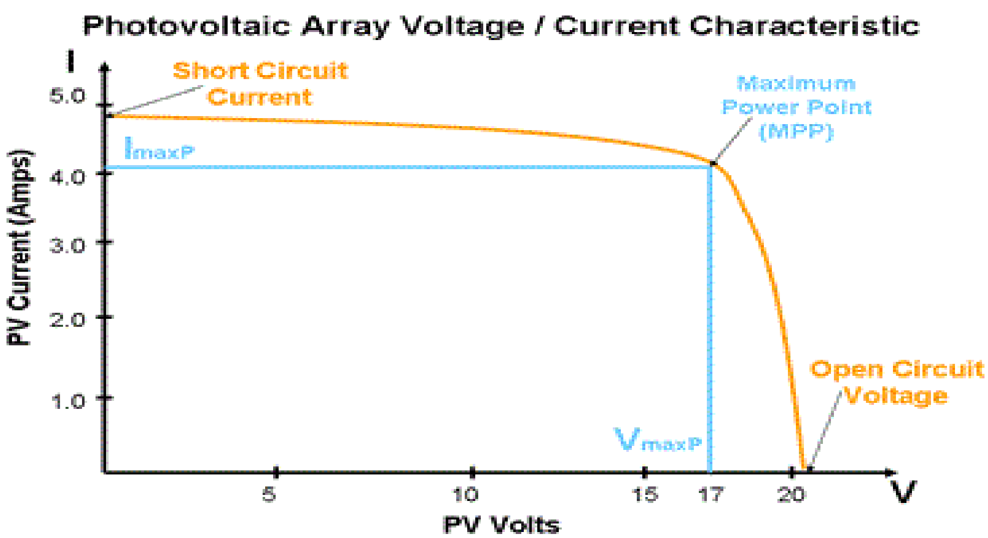


Fig 6.17 V-I characteristics of a Photovoltaic Cell

Criteria for 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.

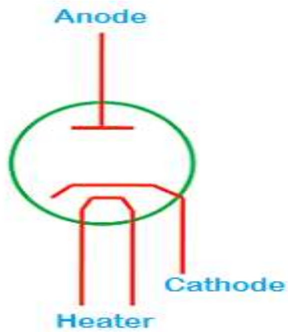
Conclusion: Though solar cell has some disadvantage associated it, but the disadvantages are expected to overcome as the technology advances, since the technology is advancing, the cost of solar plates, as well as the installation cost, will decrease down so that everybody can effort to install the system. Furthermore, the government is laying much emphasis on the solar energy so after some years we may expect that every household and also every electrical system is powered by solar or the renewable energy source.

What is vacuum tube

Generally, vacuum refers to a space where charged particles such as electrons, protons, neutrons and all other matter are absent. In other words, vacuum is nothing but the empty space.

Vacuum tube is an electronic device that controls the flow of electrons in a vacuum. It is also called as electron tube or valve. John Ambrose Fleming developed the first vacuum tube in 1904.

A vacuum tube consists of cathode (also called as filament), anode (also called as plate), and electrode (also called as grid). Cathode is an electron emitter that emits the free electrons whereas anode is an electron collector that collects the free electrons.



Grid or electrode controls the electric current or flow of electrons between anode and cathode. The free electrons that are emitted by the cathode are attracted towards the anode or plate. These free electrons carry the electric current while moving from cathode to anode.

Advantages and disadvantages of vacuum tubes

Advantages of vacuum tubes

1. Vacuum tubes are replaced easily.
2. Vacuum tubes can works at high temperature without any damage.
3. Vacuum tubes produce superior sound quality.

Disadvantages of vacuum tubes

1. Vacuum tubes are huge compared to the semiconductor devices such as diodes, transistors, and integrated circuits.
2. Vacuum tubes generate more heat.
3. High voltages are required to operate the vacuum tubes.
4. Vacuum tubes consume more power.
5. High cost.
6. Failure rate is high.
7. Vacuum tubes occupy more space than the transistors.

https://www.electronics-tutorials.ws/diode/diode_8.html

https://www.electrical4u.com/solar-cell/

https://www.physics-and-radio-electronics.com/electronic-devices-and-circuits/vacuum-tubes/whatisvacuumtube.html