16. Semiconductor Devices

Can you recall?

1. What is a p-n junction diode?
2. What is breakdown voltage and knee voltage?
3. What is a forward and reverse biased diode?

16.1 Introduction

In XI th Std. we have studied a p-n junction diode. When the diode is forward biased, it behaves as a closed switch and current flows in the diode circuit. When the diode is reverse biased, it behaves as an open switch and no current flows in the diode circuit. This switching action of a diode allows it to be used as a rectifier.

Generation of AC at a power station is more cost effective than producing DC power. The transmission of AC power is also more economic than transmitting DC power. This AC voltage varies sinusoidally. In India, it is 230 V and has a frequency of 50 Hz. There are many electronic gadgets such as a TV, or a mobile charger which require a DC supply. Therefore, it is necessary to convert AC voltage into a DC voltage. The AC mains voltage is rectified by using junction diodes to obtain a DC voltage. In this chapter, we will study the use of diode as a rectifier and also different types of rectifiers. We will also study filters which remove the AC component from the rectified voltage and voltage regulators which provide the required DC voltage.

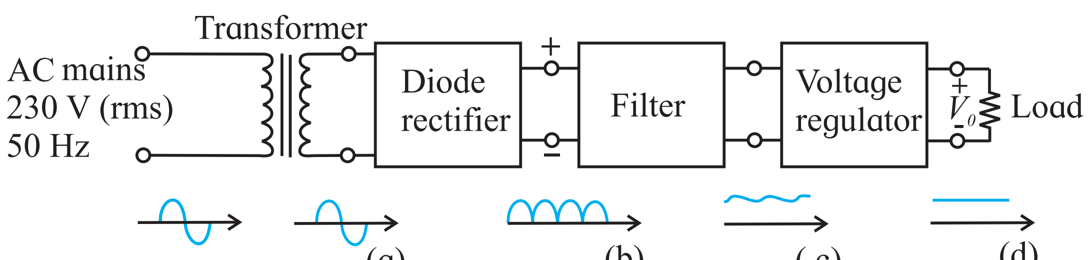
Working of a simple rectifier circuit is shown in Fig. 16.1. The AC mains supply is connected to the primary of a transformer and its secondary is connected to a rectifier circuit. The AC voltage shown as a sinusoidal wave from the secondary of the transformer is converted into a DC voltage by a diode rectifier. This is shown next as a pulsating wave (b). The output of the rectifier contains some AC component. This AC component in the DC output of a rectifier is called *ripple* and is shown at the output of the rectifier. It is removed by using a *filter circuit*. The output of the filter circuit is almost a pure DC. (It can still contain some ripple). The *voltage regulator circuit* shown after the filter restricts the output voltage to the desired value. The output voltage at this stage is a across pure DC (d).

16.2 p-n Junction Diode as a Rectifier

An AC voltage varies sinusoidally, i.e. its value and direction changes in one cycle. A rectifier converts this bidirectional voltage or current into a unidirectional voltage or current. *The conversion of AC voltage into a DC voltage is called rectification*. An electronic circuit which rectifies AC voltage is called rectifier. There are two types of rectifier circuits, 1) half wave rectifier and 2) full wave rectifier.

16.2.1 Half Wave Rectifier

A simple half wave rectifier circuit using only one diode is shown in Fig. 16.2.



16.1: Block diagram simple rectifier circuit with respective output wave form. Describe the wave forms.

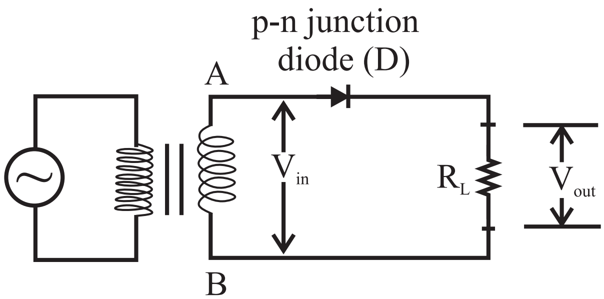


Fig. 16.2: Circuit diagram of a half wave rectifier.

The secondary coil AB of a transformer is connected in series with a diode D and the load resistance R_L. The use of transformer has two advantages. First, it allows us to step up or step down the AC input voltage as per the requirement of the circuit, and second it isolates the rectifier circuit from the mains supply to reduce the risk of electric shock. The AC voltage across the secondary coil AB changes its polarities after every half cycle. When the positive half cycle begins, the voltage at the point A is at higher potential with respect to that at the point B, therefore, the diode (D) is forward biased. It conducts (works as a closed switch) and current flows through the circuit. When the negative half cycle begins, the potential at the point A is lower with respect to that at the point B and the diode is reverse biased, therefore, it does not conduct (works as an open switch). No current passes through the circuit. Hence, the diode conducts only in the positive half cycles of the AC input. It blocks the current during the negative half cycles. The waveform for input and output voltages are shown in Fig. 16.3. In this way, current always flows through the load R_L in the same direction for alternate positive half cycles.

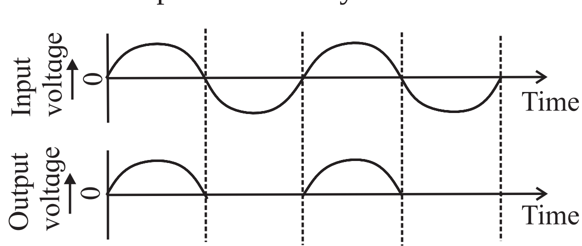


Fig. 16.3: Waveform of input and output signals for half wave rectifier.

Hence a DC output voltage obtained across R_L is in the form of alternate pulses.

16.2.2 Full Wave Rectifier:

As discussed in the previous section, the output of a half wave rectifier is available only in alternate positive half cycles of the AC input. All negative half cycles are lost and the efficiency of a half wave rectifier is very poor. Therefore, a rectifier circuit using two diodes is more useful.

In a full wave rectifier, current flows through the load in the same direction during both the half cycles of input AC voltage. This is because, the full wave rectifier circuit consists of two diodes conducting alternately. Figure 16.4 shows typical circuit of a full wave rectifier. The circuit consists of a centre tapped transformer and diodes D_1 and D_2.

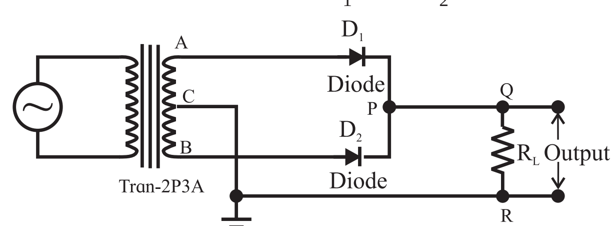


Fig. 16.4: Circuit diagram for full wave rectifier.

The diodes D_1 and D_2 are connected such that D_1 conducts in the positive half cycle and D_2 conducts in the negative half cycle of the input voltage. During the positive half cycle of the input voltage, the point A is at a higher potential than that of the point B and the diode D_1 conducts. The current through the load resistance R_L follows the path APQRC as shown in Fig. 16.4. During the negative half cycle of the input voltage, point B is at higher potential than point A and the diode D_2 conducts. The current through the load resistance R_L follows the path BPQRC. Thus, the current flowing through the load resistance is in the same direction during both the cycles.

The input and output waveforms of a full wave rectifier are shown in Fig. 16.5. First waveform is input AC. The second wave form shows the output when the diode D1 conducts and the third waveform shows the output when diode D_2 conducts. The fourth waveform shows the total output waveform of the full wave rectifier.

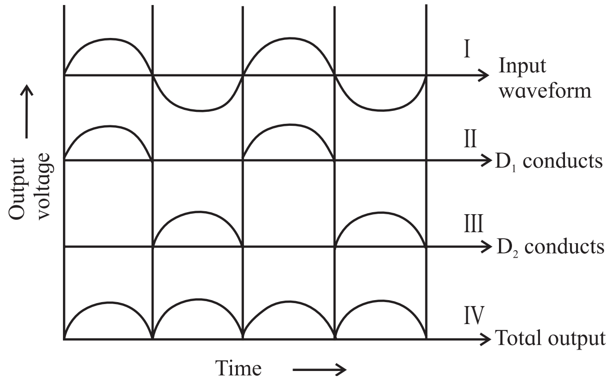


Fig 16.5: Waveforms of input and output signals for a full wave rectifier.

Remember this

A full wave rectifier utilises both half cycles of AC input voltage to produce the DC output

Do you know?

The maximum efficiency of a full wave rectifier is 81.2% and the maximum efficiency of a half wave rectifier is 40.6%. It is observed that the maximum efficiency of a full wave rectifier is twice that of half wave rectifier.

Advantages of a full wave rectifier

1) Rectification takes place in both the cycles of the AC input.
2) Efficiency of a full wave rectifier is higher than that of a half wave rectifier.
3) The ripple in a full wave rectifier is less than that in a half wave rectifier.

Example 16.1 : If the frequency of the input voltage50 Hz is applied to a (a) half wave rectifier and (b) full wave rectifier, what is the output frequency in both cases?

Solution:

(a) The output frequency is 50 Hz because for one AC input pulsating we get one cycle of DC.

(b) The output frequency is 100Hz because for one input ac cycle we get two cycles of pulsating DC.

16.2.3 Ripple Factor:

The output of a rectifier consists of a small fraction of an A C component along with DC called the ripple. This ripple is undesirable and is responsible for the fluctuations in the rectifier output. Figure 16.6 (a) shows the ripple in the output of a rectifier.

The effectiveness of a rectifier depends upon the magnitude of the ripple component in its output. A smaller ripple means that the rectifier is more effective.

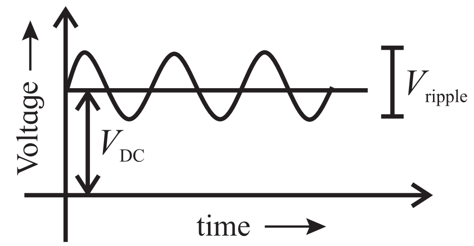


Fig. 16.6 (a): Ripple in the output of a DC output.

The ratio of root mean square (rms) value of the AC component to the value of the DC component in the rectifier output is known as the ripple factor, i.e.,

$$Ripple\ factor = \frac{r.m.s. value\ of\ AC\ component}{value\ of\ DC\ component}$$

16.2.4 Filter circuits:

The output of a rectifier is in the form of pulses as shown in the fourth waveform in Fig 16.5.The output is unidirectional but the output does not have a steady value. It keeps fluctuating due to the ripple component present in it. A filter circuit is used to remove the ripple from the output of a rectifier.

A filter circuit is a circuit which removes the AC component or the ripple from a rectifier output and allows only the DC component.

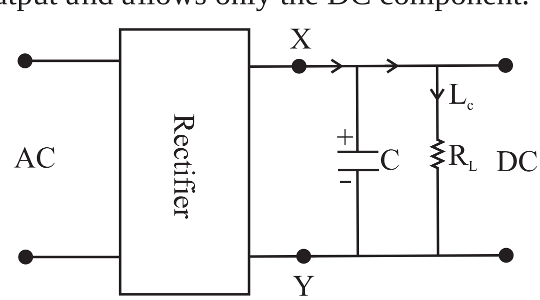


Fig. 16.6 (b): Filter circuit with capacitor.

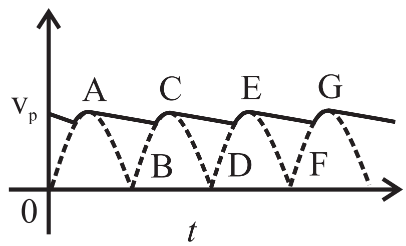


Fig. 16.6 (c): Output wave form ofter filtration.

A capacitor filter:

As shown in Fig. 16.6 (b), the pulsating DC voltage of a rectifier output is applied across the capacitor. As the voltage across the capacitor rises, capacitor gets charged to point A and supplies current to the load resistance. At the end of quarter cycle, the capacitor gets charged to the peak voltage shown as Vp in Fig. 16.7 (c) of the rectified output voltage. Now, the rectifier voltage begins to decrease, so that the capacitor starts discharging through the load resistance and the voltage across it begins to drop. Voltage across the load decreases only slightly, up to the point B, because the next voltage peak recharges the capacitor immediately. This process is repeated again and again and the output voltage waveform takes the form shown in Fig 16.6 (c). This output is unregulated DC wave form. Voltage, regulator circuits are used to obtain regulated DC supply The capacitor filter circuit is widely used because of its low cost, small size and light weight. This type of filter is preferred for small load currents. It is commonly used in battery eliminators.

When a power supply is connected to a load, it is noticed that there is a drop in the output voltage. A power supply whose output changes when a load is connected across it is called *unregulated power supply*. When the output of a power supply remains steady even after connecting a load across it, it is called a *regulated power supply*. There are many ways in which a power supply can be regulated. A commonly used voltage regulator circuit uses a Zener diode. We will now discuss a Zener diode first and then try to understand how it can be used as a voltage regulator.

16.3 Special Purpose Junction Diodes:

In this section we will study some of the common special purpose junction diodes such as,

1) Zener diode, 2) Photo diode, 3) Solar cell, 4) Light Emitting Diode (LED).

16.3.1 Zener Diode:

A Zener diode works on the principle of junction breakdown. The other diodes mentioned above make use of photosensitivity, a very important and useful property of semiconductors.

16.3 : Junction Break Down:

In XIth Std. we have studied that when reverse bias voltage of an ordinary junction diode is increased beyond a critical voltage, the reverse current increases sharply to a high value. This critical voltage is called *reverse breakdown voltage*. The diode is damaged at this stage. We will now discuss what happens when there is a junction breakdown.

Electrical break down of any material (metal, semiconductor or even insulator) can be due to **1) Avalanche breakdown** or **2) Zener breakdown.** We will discuss only the Zener breakdown in some details.

Zener Breakdown :

When the reverse voltage across a p-n junction diode is increased, the electric field across the junction increases. This results in a force of attraction on the negatively charged electrons at the junction. Covalent bonds which hold the semiconductor together are broken due to this force and electrons are removed from the bonds. These free electrons are then available for electrical conduction and result in a large current. When the applied voltage is increased, the electric field across the junction also increases and more and more electrons are removed from their covalent bonds. Thus, a net current is developed which increases rapidly with increase in the applied voltage.

Zener breakdown occurs in diodes which are heavily doped. The depletion layer is narrow in such diodes. Zener breakdown does not result in damage of a diode.

Zener Diode Characteristic:

A Zener diode is a p-n junction diode designed to work in the breakdown region. It is used as a voltage regulator or a voltage stabiliser. Figure 16.7 (a) shows the circuit symbol of a Zener diode. Its I-V characteristic is shown in Fig. 16.7 (b).

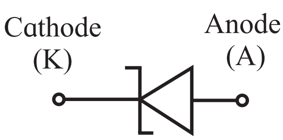


Fig 16.7 (a): circuit symbol of a Zener diode.

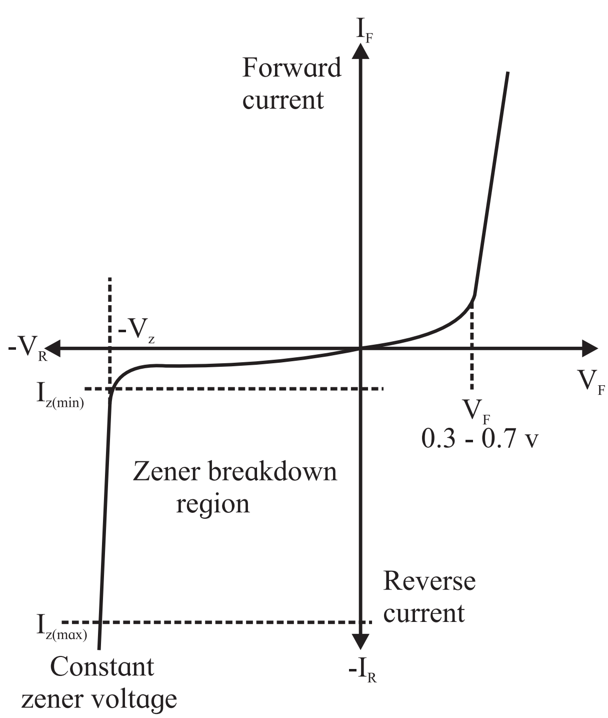


Fig 16.7: (b) I-V Characteristic curve for Zener Diode.

As can be seen from the characteristic, a Zener diode behaves like a normal diode when forward biased. When reverse biased, it shows a breakdown. This breakdown discussed previously occurs at a voltage called the Zener voltage V_z. The current suddenly increases if the applied voltage is increased beyond the Zener voltage. It is interesting to note that the voltage remains constant at V_Z, for increasing current, once the Zener breakdown occurs. This property of the Zener diode is used in a voltage regulator. The Zener voltage V_Z depends upon the amount of doping. For a heavily doped diode, the depletion layer is thin and the breakdown occurs at a lower reverse voltage. A lightly doped diode has higher breakdown voltage. The Zener diodes with breakdown voltage of less than 6 V, operate mainly at Zener breakdown region. Those with voltage greater the 6 V operate mainly in avalanche breakdown region (not discussed here) but both are called Zener diode.

Zener diode as a voltage regulator:

When a Zener diode is operated in the breakdown region, voltage across it remains almost constant even if the current through it changes by a large amount. A voltage regulator maintains a constant voltage across a load regardless of variations in the applied input voltage and variations in the load current. Figure 16.8 shows a typical circuit diagram of a voltage regulator using a Zener diode.

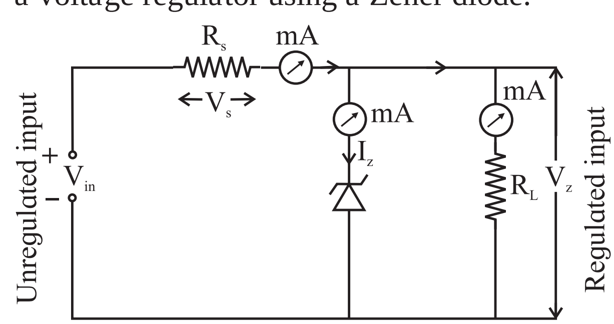


Fig. 16.8: Voltage regulator using a Zener diode.

A Zener diode of break down voltage V_Z is connected in reverse bias to an input voltage source V_i. The resistor, R_S connected in series with the Zener diode limits the current flow through the diode. The load resistance R_L is connected in parallel with the Zener diode, so that the voltage across R_L is always the same as the Zener voltage, ($V_R = V_Z$). We will try to understand how voltage is regulated using such circuit.

(a) If the input voltage increases, the current through R_s and the Zener diode also increases. This results in an increase in the voltage across the resistance R_s, but the voltage across the Zener diode does not change. The series resistance R_s absorbs the output voltage fluctuations and maintains a constant voltage across the load resistance. This is because the Zener voltage remains constant even through the current through the Zener diode changes when it is in the breakdown region.

When the input voltage increases, the voltage across the series resistance R_s also increases. This causes an increase in the current through the Zener diode and the current through the load resistance remains constant. Hence the output voltage remains constant irrespective of the change in the input voltage.

(b) When the input voltage is constant but the load resistance R_L decreases, the load current increases. This extra current cannot come from the source because the drop across R_s will not change as the Zener is within its regulating range. The additional load current is due to a decrease in the Zener current I_Z.

(c) When there is no load in the circuit, the load current will be zero, ($I_L = 0$) and all the circuit current passes through the Zener diode. This results in maximum dissipation of power across the Zener diode. Similarly, a small value of the series resistor R_S results in a larger diode current when the load resistance R_L of a large value is connected across it. This will increases the power dissipation requirement of the diode. The value of the series resistance R_S is so selected that the maximum power rating of the Zener diode is not exceeded when there is no load or when the load is very high.

The voltage across the Zener diode remains constant at its break down voltage V_Z for all the values of Zener current I_Z as long as the current persists in the break down region. Hence, a regulated DC output voltage $V_O = V_Z$ is obtained across R_L whenever the input voltage remains within a minimum and maximum voltage.

Do you know?

The voltage stabilization is effective when there is a minimum Zener current. The Zener diode must be always operated within its breakdown region when there is a load connected in the circuit. Similarly, the supply voltage V_S must be greater than V_Z.

Working of a Zener Regulator:

Let $I_{Z(min)}$, $I_{Z(max)}$ be the minimum and maximum Zener currents respectively and V_Z be the Zener voltage.

Let V_S, be the voltage across R_S when the current is minimum, therefore, $V_S = (I_{Z(min)} R_S)$. Eq. (16.1).

From the Fig. 16.8, we have,

$V_{in} = (V_S + V_Z)$. Thus, the lower value of the input voltage is,

$$V_{in(low)} = (V_S + V_Z).$$

$$\therefore V_{in(low)} = I_{Z(min)} R_S + V_Z \qquad \text{--- (16.2)}$$

Similarly, the voltage across R_S when the current is maximum will be, $V_S = (I_{Z(max)} R_S)$ and

$$V_{in(high)} = (V_S + V_Z) = (I_{Z(max)} R) + V_Z$$

The maximum power rating (P_Z) of a Zener diode is given by, $P_Z = (I_{Z(max)} V_Z)$.

While designing a Zener regulator, the value of series resistance is determined by considering the specification of the Zener diode.

Similarly, if the input voltage (V_i) decreases, the current through R_s and the Zener diode also decreases. Therefore, V_S, the voltage drop across R_S also decreases without any change in the voltage V_Z, across the Zener diode. Hence, any change in the input voltage does not change the voltage across the Zener diode. Thus, a Zener diode gives constant output voltage (V_O) across R_L. The limitation of this regulator is that the current through a Zener diode should never exceed the $I_{Z(max)}$ value. If the current exceeds this value, the

Zener diode gets damaged due to heating. The $I_{Z(max)}$ value is provided by manufacturer.

Remember this

Zener effect occurs only if the diode is heavily doped, because when the depletion layer is thin, breakdown occurs at low reverse voltage and the field strength will be approximately $3x10^7$ V/m. It causes an increase in the flow of free carriers and increase in the reverse current.

Applications of Zener Diode: The Zener diode is used when a constant voltage is required. It has a number of applications such as: Voltage regulator, Fixed reference voltage provider in transistor biasing circuits, Peak clipper or limiter in a wave shaping circuit, Protector against meter damage from accidental fluctuations, etc.

Example 16. 2

A 5.0V stabilized power supply is required to be desinged using a 12V DC power supply as input source. The maximum power rating P_Z of the Zener diode is 2.0 W. Using the Zener regulator circuit described in Fig. 16.8, calculate,

a)The maximum current flowing through the Zener diode. b) The minimum value of the series resistor, R_S. c) The load current IL if a load resistor of 1kΩ is connected across the Zener diode. d)The Zener current I_Z at full load.

Solution:

a) Maximum current I_Z = Power/Voltage =

P_Z /Vo = 2.0/5.0 = 0.4 A = 400 mA.

b) $R_S = (V_s - V_Z)/ I_Z$ = (12.0 – 5.0) 400

= 17.5 Ω.

c) $I_L = V_Z/ R_L$ = 5.0/1000 = 0.005 A = 5.0 mA

d) $I_Z = I_S - I_L$ = (400 – 5) = 395 mA.

Can you tell?

1. How does a cell phone charger produce a voltage of 5.0 V form the line voltage of 230V?
2. Why is a resistance connected in series with a Zener diode when used in a circuit?

Do you know?

The voltage across a Zener diode does not remain strictly constant with the changes in the Zener current. This is due to R_Z, the Zener impedance, or the internal resistance of the Zener diode. R_Z acts like a small resistance in series with the Zener. Changes in I_Z cause small changes in V_Z .

16.3.2 Photo Diode :

A photodiode is a special type of a p-n junction diode which converts light energy into electrical energy. It generates current when exposed to light. It is also called as *photodetector or a photosensor*. It operates in reverse biased mode. Figure 16.9 (a) shows the

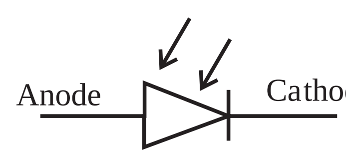


Fig. 16.9 (a) : Circuit symbol of photodiode.

circuit symbol of a photodiode. *Only mionority current flows through a photodiode*. Figure 16.9 (b) shows schematic of the structure of a photodiode.

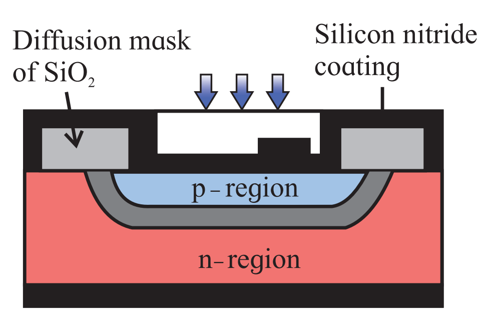


Fig. 16.9 (b) : Schematic of the structure of a photodiode.

The p-n junction of a photodiode is placed inside a glass material so that only the junction of a photodiode is exposed to light. Other part of the diode is generally painted with an opaque colour or covered. Figure 16.9 (c) shows a typical photodiode.

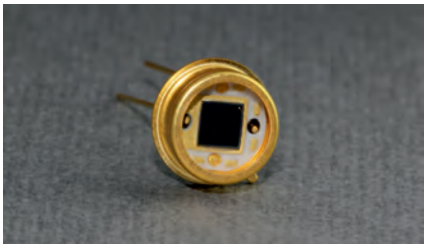


Fig. 16.9 (c) : A typical photodiode.

Working Principle of Photodiode:

When a p-n junction diode is reverse biased, a reverse saturation current flows through the junction. The magnitude of this current is constant for a certain range of reverse bias voltages. This current is due to the minority carriers on its either side.(Electrons are minority carriers in the p-region and the holes are minority carriers in the p-region of a diode). *The reverse current depends only on the concentration of the minority carriers and not on the applied voltage*. This current is called the dark currant in a photodiode because it flows even when the photodiode is not illuminated. Figure 16.10 schematically shows working of a photodiode.

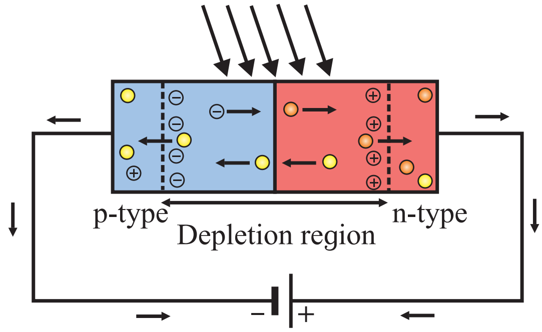


Figure 16.10: schematically shows working of a photodiode.

When a p-n junction is illuminated, electron-hole pairs are generated in the depletion region. The energy of the incident photons should be larger than the band gap of the semiconductor material used to fabricate the photodiode. The electrons and the holes are separated due to the intrinsic electric field present in the depletion region. The electrons are attracted towards the anode and the holes are attracted towards the cathode. More carriers are available for conduction and the reverse current is increased. *The reverse current of a photodiode depends on the intensity of the incident light*. Thus, the reverse current can be controlled by controlling the concentration of the minority carriers in the junction. Figure 16.11 shows the I-V characteristic of a photodiode. It clearly shows the relation between intensity of illumination and the reverse current of a photodiode.

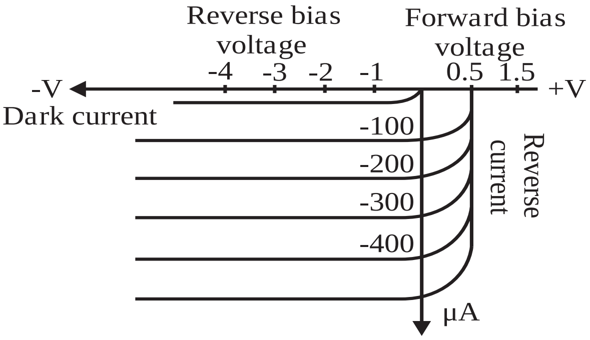


Fig. 16.11: The I-V characteristic of a photodiode.

The total current passing through a photodiode is the sum of the photocurrent and the dark current. Figure 16.12 shows the graphical relation between the reverse current of a photodiode and the intensity of illumination incident on the photodiode. The sensitivity of the device can be increased by minimizing the dark current.

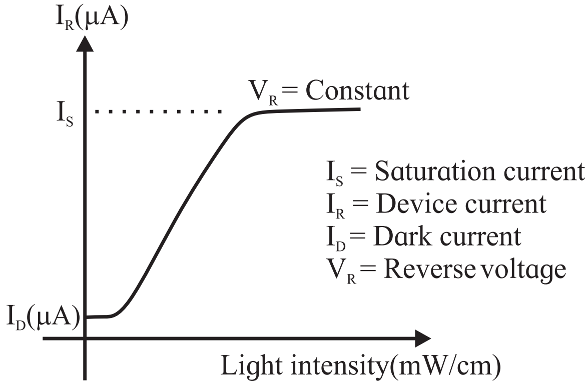


Fig. 16.12: Relation between the reverse current of a photodiode and the intensity of illumination

As you can see from the curve, reverse current increases initially with increase in the intensity of illumination. It reaches a constant value after certain voltage is reached. *This constant value is called the saturation current of the photodiode*. One more term associated with a photodiode is its dark resistance R_d. It is the resistance of a photodiode when it is not illuminated. Dark resistance of a photodiode (R_d) is defined as the ratio of the maximum reverse voltage and its dark current.

$$R_d = \frac{Maximum\ reverse\ voltage}{Dark\ current}$$

Advantages of photodiode

1) Quick response when exposed to light.
2) Linear response. The reverse current is linearly proportional to intensity of incident light.
3) High speed of operations.
4) Light weight and compact size.
5) Wide spectral response. For example, photodiodes made from Si respond to radiation of wavelengths from 190 nm (UV) to 1100 nm (IR).
6) Relatively low cost.

Disadvantages of photodiode

1) Its properties are temperature dependent, similar to many other semiconductor devices.
2) Low reverse current for low illumination levels.

Applications of photodiode

A photodiode has many applications in a number of fields ranging from domestic applications to industrial applications due to its linear response. The basic concept used in almost all these devices/applications is that a photodiode conducts whenever light strikes it and it stops conducting the moment light stops. Some applications of a photodiode are:

1) Counters and switches.
2) Burglar alarm systems.
3) Detection of visible and invisible radiations.
4) Circuits in which fast switching and high-speed operations are required.
5) Fiber optic communication systems.
6) Optocouplers, used to provide an electric isolation between two electronic circuits.
7) Photo sensors/detectors, for accurate measurement of light intensity.
8) Safety electronics like fire and smoke detectors

Try this

Study the relation between intensity of the incident light and the reverse current of a photodiode.

16.3.3 Solar Cell or Photovoltaic Cell:

Solar energy can be used in many ways. It pollution freez and available free of cost. Two major types of devices converting solar energy in usable form are, a) *Photo thermal devices* which convert the solar energy into heat energy. These are mostly used for providing hot water. and b) *Photo voltaic devices* which convert solar energy into electrical energy using solar cells. We will discuss the solar cells in some details. It is also known as photovoltaic cell. Light incident on a solar cell produces both a current and a voltage to generate electric power. A solar cell thus works as a source of DC power. Solar cells can supply power for electric equipment at remote place on earth or aboard a satellite or a space station.

Structure of a Solar Cell:

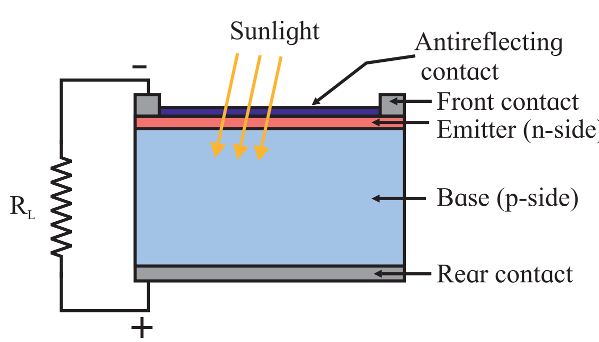


Fig.16.13: (a) Schematic structure of a solar cell.

Figure 16.13 (a) shows the schematic structure of a solar cell. It consists of a p-n junction. The n-side of the junction faces the solar radiation. The p-side is relatively thick and is at the back of the solar cell. Both the p-side and the n-side are coated with a conducting material. The n-side is coated with antireflection coating which allows visible light to pass through it. The main function of this coating is to reflect the IR (heat) radiations and protect the solar cell from heat. This is necessary, because the electronic properties of semiconductors are sensitive to fluctuations in temperature. This coating works as the electrical contact of the solar cell. The contact on the n-side is called the front contact and that at the p-side is called the back contact or the rear contact. The n-side of a solar cell is thin so that the light incident on it reaches the depletion region where the electron-hole pairs are generated.

Material used for fabricating a solar cell should fulfil two important requirements. Firstly, it must be photosensitive material which absorbs light and raises electrons to a higher energy state. Secondly, the higher energy electrons thus generated should be taken from the solar cell into an external circuit. The electrons then dissipate their energy while passing through the external circuit and return to the solar cell. Almost all photovoltaic devices use semiconductor materials in the form of a p-n junction.

Working of a solar cell:

When light is incident on a solar cell, the following sequence of events takes place.

1) Electron-hole pairs are generated in the depletion region of the p-n junction. These are photo-generated carriers.
2) The electrons and holes are separated and collected at the cathode and the anode respectively.
3) The carriers are accumulated and generate a voltage across the solar cell.
4) Power thus produced is dissipated (utilised) in the load resistance or in the circuit connected across the solar cell.

Current produced in a in a solar cell is called the ‘light-generated current’, or ‘photo-generated current’. This is a two-step process. The first step is the absorption of incident photons to generate electron-hole pairs. Electron-hole pairs will be generated in the solar cell provided that the incident photon has energy greater than that of the band gap. Normally, the electrons and holes thus produced recombine and will be lost. There will be no generation of current or power. However, the photo-generated electrons (in the p-type material), and the photo-generated holes (in the n-type material) are spatially separated and prevented from recombination in a solar cell.

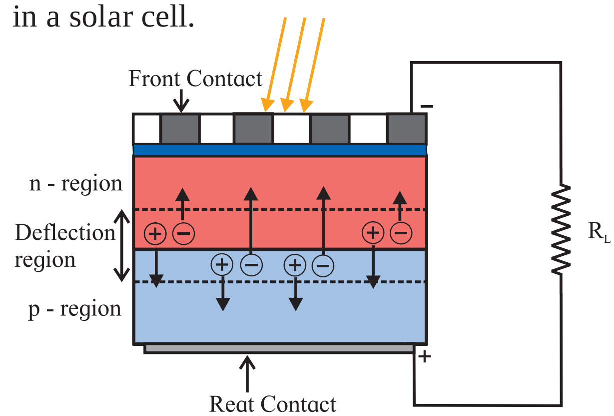


Fig. 16.13: (b) Separation of carriers in a solar cell.

This separation of carriers is possible due to the intrinsic electric field of the depletion region. Figure 16. 13 (b) shows this schematically. When the light-generated electron in the in the p-type region reaches the p-n junction, it is swept across the junction by the electric field at the junction. It reaches the n-type region where it is now a majority carrier. Similarly, the light generated hole reaches the p-type region and becomes a majority carrier in it. The positive and negative charges are thus accumulated on the p-region and the n-region of the solar cell which can be used as a voltage source. When the solar cell is connected to an external circuit, the light-generated carriers flow through the external circuit.

V-I Characteristic of solar Cell or Photovoltaic cell:

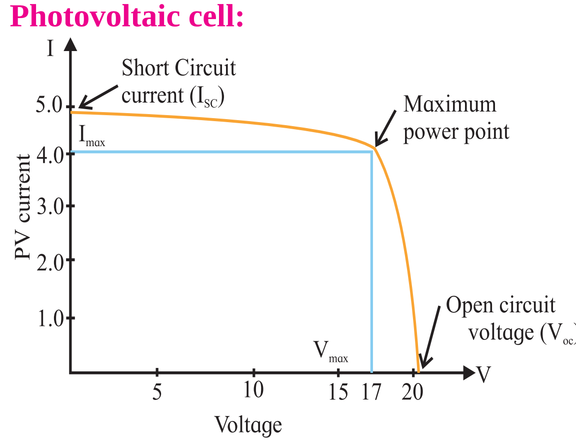


Fig. 16.14 :V-I Characteristic of solar Cell or Photovoltaic cell

Figure 16.14 shows the I-V characteristic of solar cell when illuminated. This is drawn in the fourth quadrant because a solar cell supplies current to the load. The power delivered to the load is zero when the load is short-circuited. The intersection of the curve with the I-axis is the short-circuit current, I_{sc}, corresponding to a given light intensity. The intersection of the curve with the V- axis is the open circuit voltage, V_{oc}, corresponding to given light intensity. Again, power delivered to the load is zero when the load is open. However, there is a point on the curve where power delivered $P_L = (V_{oL} . I_{sc})$ is maximum.

Criteria for selection of material for solar cell:

1) Its band gap should be between 1.0 eV to 1.8 eV.
2) It should have high optical absorption (conversion of light into electrical energy).
3) It should have good electrical conductivity.
4) Material should be easily available.

Most materials used for fabrication of solar cells are have a band gap of about 1.5 eV. These include: Si (*Eg* = 1.1 eV), GaAs (*Eg* =1.43 eV), CdTe(*Eg* = 1.45 eV), CuInSe (*Eg* =1.04 eV). Solar cells used in domestic and space applications are mostly Si based solar cells. Solar cells are non-polluting, they require less maintenance and last longer. They have a higher cost of installation, are low in efficiency.

Use of Solar cell:

Solar cells are used for charging batteries during day time so that batteries can supply power during night. They are useful at remote places, for supplying power to various electronic equipment from calculators to satellites and space stations, to supply power to traffic signals, in communication stations, and in Lux meter to measure intensity of light.

Can you tell?

What is the difference between a photo diode and a solar cell?

When the intensity of light incident on a photo diode increases, how is the reverse current affected?

16.3.4 Light Emitting Diode / LED:

The Light Emitting Diode or LED as it is more commonly called is a *diode which emits light when large forward current passes through it.*

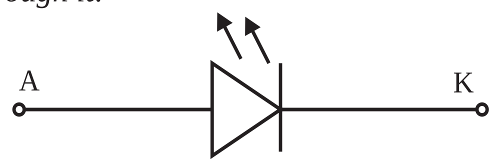


Fig. 16.15 (a): Circuit symbol of LED.

Figure 16.15 (a) shows the circuit symbol of LED and the Fig. 16.15 (b) shows a schematic construction of a typical LED. The construction of a LED is different from that of a normal diode. The n-region is heavily doped than the p-region of the p-n junction. The LED p-n junction is encased in a dome-shaped transparent case so that light is emitted uniformly in all directions and internal reflections are minimized. Metal electrodes attached on either side of the p-n junction serve as contacts for external electrical connection. The larger leg of a LED is the positive electrode or anode. LEDs with more than 2 pins are also available such as 3, 4 and 6 pin configurations to obtain multi-colours in the same LED package. Surface mounted LED displays are available that can be mounted on PCBs.

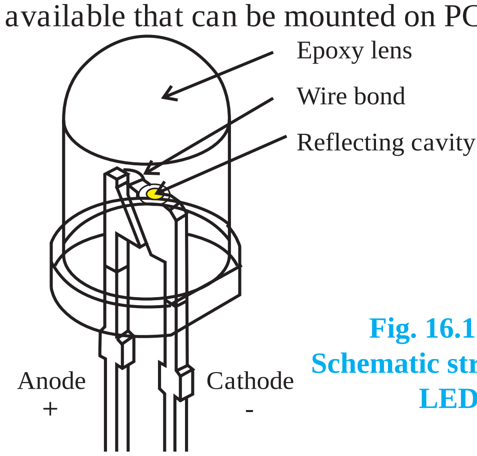


Fig. 16.15 (b): Schematic structure of LED.

LED is fabricated in such a way that light emitted is not reabsorbed into the material. It is ensured that the electron-hole recombination takes place on the surface for maximum light output.

Do you know?

LED junction does not actually emit that much light so the epoxy resin body is constructed in such a way that the photons emitted by the junction are reflected away from the surrounding substrate base to which the diode is attached and are focused upwards through the domed top of the LED, which itself acts like a lens concentrating the light. This is why the emitted light appears to be brightest at the top of the LED.

Working of a LED:

Figure 16.16 schematically shows the emission of light when electron-hole pair combines. When the diode is forward biased, electrons from the semiconductor's conduction band recombine with holes from the valence band releasing sufficient energy to produce photons which emit a monochromatic (single colour) light. Because of the thin layer, a reasonable number of these photons can leave the junction and emit coloured light. The amount of light output is directly proportional to the forward current. Thus, higher the forward current, higher is the light output.

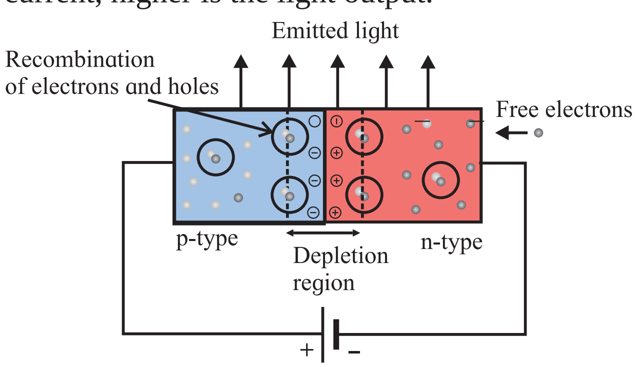


Fig. 16.16: Emission of light from LED

LEDs are fabricated by using compound semiconductors made with elements such as gallium, phosphorus and arsenic. By varying the proportions of these elements in the semiconducting materials, it is possible to produce light of different wavelengths. For example, when LED is manufactured using aluminium gallium arsenide (AlGaAs), it emits infrared radiations. LED made using gallium arsenic phosphide (GaAsP) produces either red or yellow light, whereas LED made by using aluminium gallium phosphide (AlGaP) emits red or green light and zinc selenide (ZnSe) produce blue light.

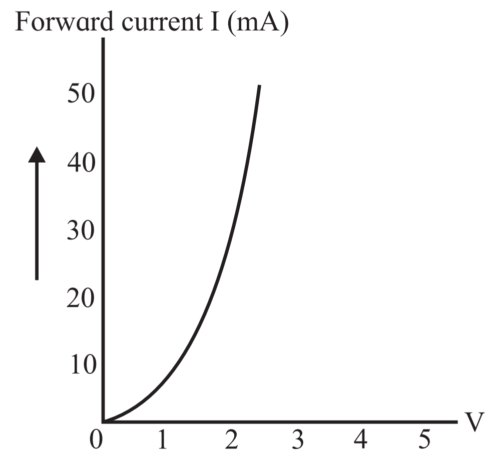


Fig.16.17: Light Emitting Diode (LED) I-V Characteristic Curves showing different colours available.

I-V Characteristics Light Emitting Diodes:

Figure 16.17 shows the I-V characteristic of LED. It is similar to the forward characteristic of an ordinary diode.

Remember this

The current rating of LED is of a few tens of milli-amps. Hence it is necessary to connect a high resistance in series with it. The forward voltage drop of an LED is much larger than an ordinary diode and is around 1.5 to 3.5 volts.

Advantages of LED:

LED is a solid state light source.

1. Energy efficient: More light output for lesser electrical power. LEDs are now capable of producing 135 lumens/watt
2. Long Lifetime: 50,000 hours or more if properly manufactured.
3. Rugged: LEDs are also called Solid State Lights (SSL) as they are made of solid material with no filament or tube or bulb to break.