7

Special-Purpose Diodes

INTRODUCTION

The most common application of diodes is rectification. The rectifier diodes are used in power supplies to convert a.c. voltage into d.c. voltage. But rectification is not all that a diode can do. A number of specific types of diodes are manufactured for specific applications in this fast developing world. Some of the more common special-purpose diodes are (*i*) Zener diode (*ii*) Light-emitting diode (LED) (*iii*) Photo-diode (*iv*) Tunnel diode (*v*) Varactor diode and (*vi*) Shockley diode.

7.1 Zener Diode

A zener diode is a special type of diode that is designed to operate in the reverse breakdown region. An ordinary diode operated in this region will usually be destroyed due to excessive current. This is not the case for the zener diode.

A zener diode is heavily doped to reduce the reverse breakdown voltage. This causes a very thin depletion layer. As a result, a zener diode has a sharp reverse breakdown voltage V_Z. This is clear from the reverse characteristic of zener diode shown in Fig. 7.1. Note that the reverse characteristic drops in an almost vertical manner at reverse voltage V_Z. As the curve reveals, two things happen when V_Z is reached :

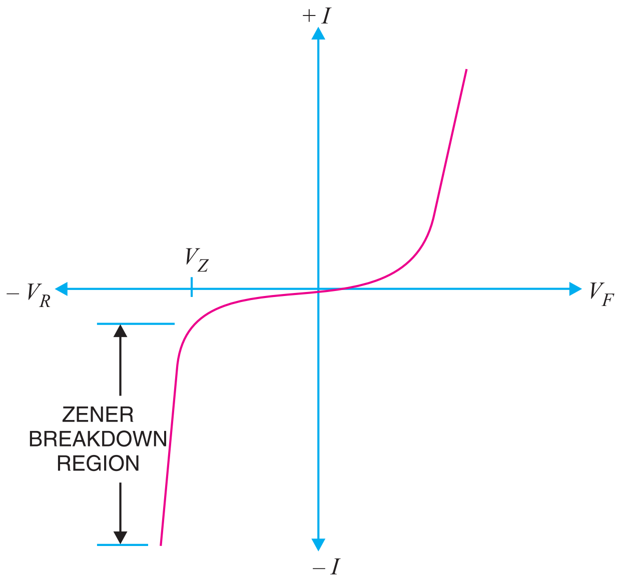


Fig. 7.1

(*i*) The diode current increases rapidly.

(*ii*) The reverse voltage V_Z across the diode remains almost constant.

In other words, *the zener diode operated in this region will have a relatively constant voltage across it, regardless of the value of current through the device.* This permits the zener diode to be used as a *voltage regulator.* For detailed discussion on zener diode, the reader may refer to chapter 6 of this book.

7.2 Light-Emitting Diode (LED)

A **light-emitting diode (LED)** *is a diode that gives off visible light when forward biased.*

Light-emitting diodes are not made from silicon or germanium but are made by using elements like gallium, phosphorus and arsenic. By varying the quantities of these elements, it is possible to produce light of different wavelengths with colours that include red, green, yellow and blue. For example, when a LED is manufactured using gallium arsenide, it will produce a red light. If the LED is made with gallium phosphide, it will produce a green light.

Light-emitting diode

Theory. When light-emitting diode (LED) is forward biased as shown in Fig. 7.2 (*i*), the electrons from the *n*-type material cross the *pn* junction and recombine with holes in the *p*-type material. Recall that these free electrons are in the conduction band and at a higher energy level than the holes in the valence band. When recombination takes place, the recombining electrons release energy in the form of heat and light. In germanium and silicon diodes, almost the entire energy is given up in the form of heat and emitted light is insignificant. However, in materials like gallium arsenide, the number of photons of light energy is sufficient to produce quite intense visible light.

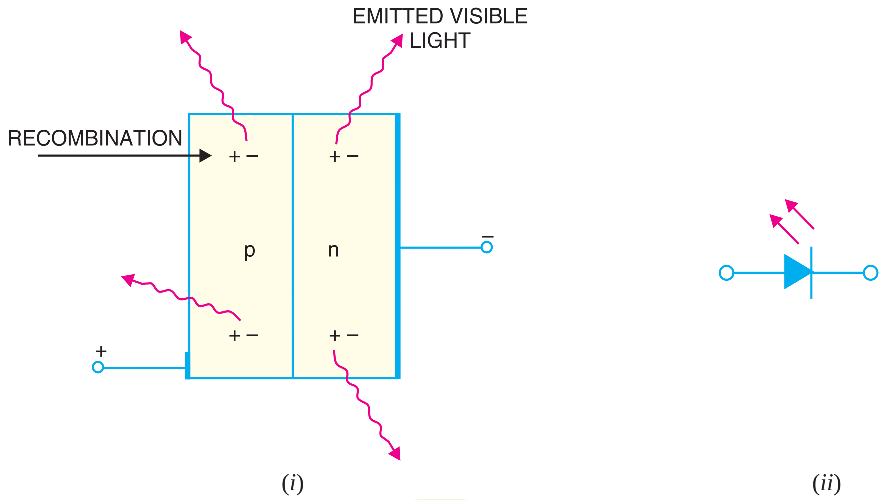


Fig. 7.2

Fig. 7.2 (*ii*) shows the schematic symbol for a LED. The arrows are shown as pointing away from the diode, indicating that light is being emitted by the device when forward biased. Although LEDs are available in several colours (red, green, yellow and orange are the most common), the schematic symbol is the same for all LEDs. There is nothing in the symbol to indicate the colour of a particular LED. Fig. 7.3 shows the graph between radiated light and the forward current of the LED. It is clear from the graph that the intensity of radiated light is directly proportional to the forward current of LED.

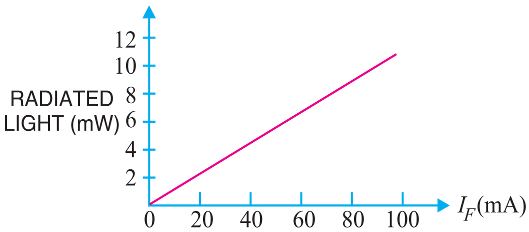


Fig. 7.3

7.3 LED Voltage and Current

The forward voltage ratings of most LEDs is from 1V to 3V and forward current ratings range from 20 mA to 100 mA. In order that current through the LED does not exceed the safe value, a resistor R_S is connected in series with it as shown in Fig. 7.4. The input voltage is V_S and the voltage across LED is V_D.

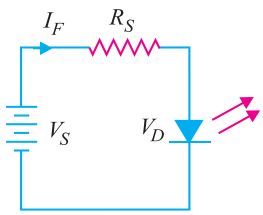


Fig. 7.4

∴ Voltage across $R_S = V_S - V_D$

∴ Circuit current, $I_F = \dfrac{V_S - V_D}{R_S}$

Example 7.1. *What value of series resistor is required to limit the current through a LED to 20 mA with a forward voltage drop of 1.6 V when connected to a 10V supply ?*

Solution.

Series resistor, $R_S = \dfrac{V_S - V_D}{I_F}$

Here V_S = 10 V; V_D = 1.6 V; I_F = 20 mA = 20×10^{-3} A

$\therefore \quad R_S = \dfrac{10 - 1.6}{20 \times 10^{-3}} = \mathbf{420\ \Omega}$

Note that resistor R_S is also called *current-limiting resistor.*

Example 7.2. *What is current through the LED in the circuit shown in Fig. 7.5 ? Assume that voltage drop across the LED is 2 V.*

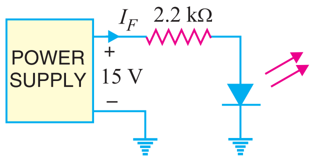


Fig. 7.5

Solution.

Current through LED, $I_F = \dfrac{V_S - V_D}{R_S}$

Here $V_S = 15$ V; $V_D = 2$ V; $R_S = 2.2\ \text{k}\Omega = 2.2 \times 10^3\ \Omega$

$\therefore \quad I_F = \dfrac{15 - 2}{2.2 \times 10^3} = 5.91 \times 10^{-3}\ \text{A} = \mathbf{5.91\ mA}$

7.4 Advantages of LED

The light-emitting diode (LED) is a solid-state light source. LEDs have replaced incandescent lamps in many applications because they have the following advantages :

(*i*) Low voltage

(*ii*) Longer life (more than 20 years)

(*iii*) Fast on-off switching

Protecting LED against reverse bias. The LEDs have low reverse voltage ratings. For example, a typical LED may have a maximum reverse voltage rating of 3V. This means that if a reverse voltage greater than 3 V is applied to the LED, the LED may be destroyed. Therefore, one must be careful not to use LEDs with a high level of reverse bias. One way to protect a LED is to connect a rectifier diode in parallel with LED as shown in Fig. 7.6. If reverse voltage greater than the reverse voltage rating of LED is accidentally applied, the rectifier diode will be turned on. This protects the LED from damage.

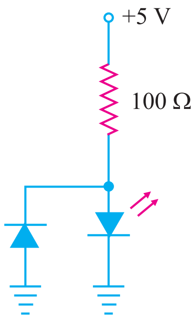


Fig. 7.6

7.5 Multicolour LEDs

A LED that emits one colour when forward biased and another colour when reverse biased is called a **multicolour LED.**

One commonly used schematic symbol for these LEDs is shown in Fig. 7.7. Multicolour LEDs

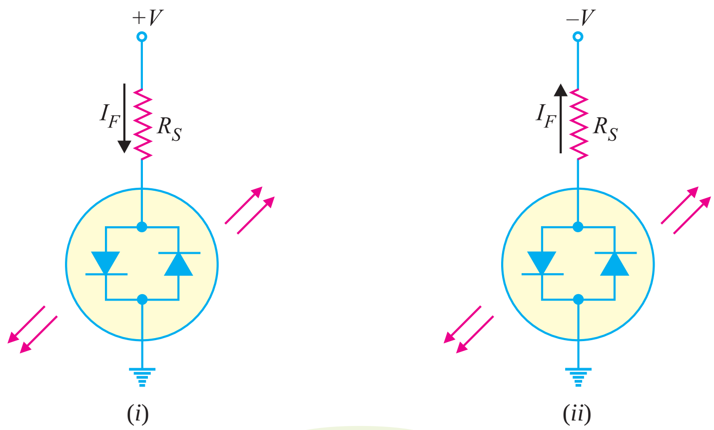


Fig. 7.7

actually contain two *pn* junctions that are connected in *reverse-parallel i.e.* they are in parallel with anode of one being connected to the cathode of the other. If positive potential is applied to the top terminal as shown in Fig. 7.7 (*i*), the *pn* junction on the **left** will light. Note that the device current passes through the left *pn* junction. If the polarity of the voltage source is reversed as shown in Fig. 7.7 (*ii*), the *pn* junction on the **right** will light. Note that the direction of device current has reversed and is now passing through the right *pn* junction.

Multicolour LEDs are typically *red* when biased in one direction and *green* when biased in the other. If a multicolour LED is switched fast enough between two polarities, the LED will produce a *third* colour. A red/green LED will produce a *yellow* light when rapidly switched back and forth between biasing polarities.

7.6 Applications of LEDs

The LED is a low-power device. The power rating of a LED is of the order of milliwatts. This means that it is useful as an indicator but not good for illumination. Probably the two most common applications for visible LEDs are (*i*) as a power indicator (*ii*) seven-segment display.

(*i*) As a power indicator. A LED can be used to indicate whether the power is on or not. Fig. 7.8 shows the simple use of the LED as a power indicator. When the switch *S* is closed, power is applied to the load. At the same time current also flows through the LED which lights, indicating power is on. The resistor R_S in series with the LED ensures that current rating of the LED is not exceeded.

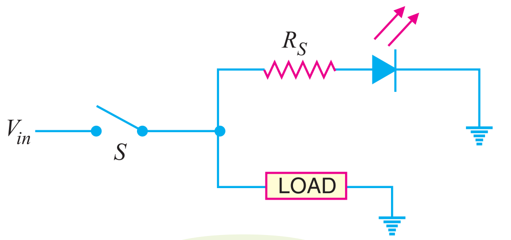


Fig. 7.8

(*ii*) Seven-segment display. LEDs are often grouped to form seven-segment display. Fig. 7.9 (*i*) shows the front of a seven segment display. It contains seven LEDs (*A, B, C, D, E, F* and *G*) shaped in a figure of *8. Each LED is called a **segment. If a particular LED is forward biased, that LED or segment will light and produces a bar of light. By forward biasing various combinations of seven LEDs, it is possible to display any number from 0 to 9. For example, if LEDs *A, B, C, D* and *G* are lit (by forward biasing them), the display will show the number 3. Similarly, if LEDs *C, D, E, F, A* and *G* are lit, the display will show the number *6*. To get the number 0, all segments except *G* are lit.

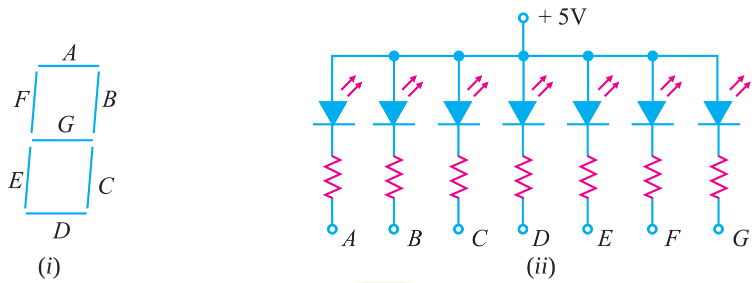


Fig. 7.9

Fig. 7.9 (*ii*) shows the schematic diagram of seven-segment display. External series resistors are included to limit currents to safe levels. Note that the anodes of all seven LEDs are connected to a

* Note that LEDs *A, B, C, D, E* and *F* are arranged clockwise from the top with LED *G* in the middle.

** Each LED is called a segment because it forms part of the character being displayed.

common positive voltage source of +5 V. This arrangement is known as **common-anode type*. In order to light a particular LED, say *A*, we ground the point *A* in Fig. 7.9 (*ii*). It forward biases the LED *A* which will be lit.

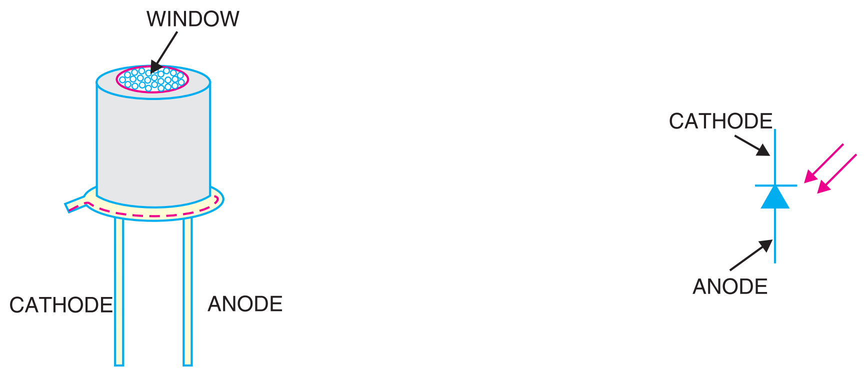
7.7 Photo-diode

A **photo-diode** *is a reverse-biased silicon or germanium pn junction in which reverse current increases when the junction is exposed to light.*

The reverse current in a photo-diode is directly proportional to the intensity of light falling on its *pn* junction. This means that greater the intensity of light falling on the *pn* junction of photo-diode, the greater will be the reverse current.

Principle. When a rectifier diode is reverse biased, it has a very small reverse leakage current. The same is true for a photo-diode. The reverse current is produced by thermally generated electron-hole pairs which are swept across the junction by the electric field created by the reverse voltage. In a rectifier diode, the reverse current increases with temperature due to an increase in the number of electron-hole pairs. *A photo-diode differs from a rectifier diode in that when its pn junction is exposed to light, the reverse current increases with the increase in light intensity and vice-versa*. This is explained as follows. When light (photons) falls on the ***pn* junction, the energy is imparted by the photons to the atoms in the junction. This will create more free electrons (and more holes). These additional free electrons will increase the reverse current. As the intensity of light incident on the *pn* junction increases, the reverse current also increases. In other words, as the incident light intensity increases, the resistance of the device (photo-diode) ***decreases.

Photo-diode package. Fig. 7.10 (*i*) shows a typical photo-diode package. It consists of a *pn* junction mounted on an insulated substrate and sealed inside a metal case. A glass window is mounted on top of the case to allow light to enter and strike the *pn* junction. The two leads extending from the case are labelled anode and cathode. The cathode is typically identified by a tab extending from the side of the case.



(*i*) (*ii*)

Fig. 7.10

Fig. 7.10 (*ii*) shows the schematic symbol of a photo-diode. The inward arrows represent the incoming light.

* Also available is the *common-cathode type* where all cathodes are connected together.

** This is true only if the light energy is applied at the junction. If it is applied to the crystal at some distance from the junction, the free electrons and holes will recombine (thus neutralising each other) before they can join the flow of reverse current.

*** It is for this reason that semiconductor devices such as diodes and transistors are usually enclosed in opaque case to protect them from light. Those diodes or transistors which are used for light-detecting, on the other hand, must be encased in transparent plastic or glass so that light may fall on them.

7.8 Photo-diode Operation

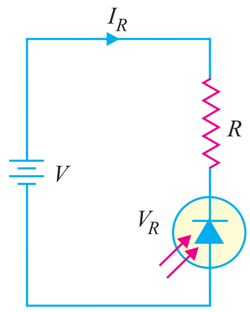


Fig. 7.11

Fig. 7.11 shows the basic photo-diode circuit. The circuit has reverse-biased photo-diode, resistor R and d.c. supply. The operation of the photo-diode is as under :

(i) When no light is incident on the *pn* junction of photo-diode, the reverse current I_r is extremely small. This is called **dark current.**

The resistance of photo-diode with no incident light is called *dark resistance* (R_R).

$$\text{Dark resistance of photo-diode, } R_R = \frac{V_R}{\text{Dark current}}$$

(ii) When light is incident on the *pn* junction of the photo-diode, there is a transfer of energy from the incident light (photons) to the atoms in the junction. This will create more free electrons (and more holes). These additional free electrons will increase the reverse current.

(iii) As the intensity of light increases, the reverse current I_R goes on increasing till it becomes maximum. This is called **saturation current.**


Calibrated Photo-Diode

7.9 Characteristics of Photo-diode

There are two important characteristics of photo-diode.

***(i)* Reverse current-Illumination curve.** Fig. 7.12 shows the graph between reverse current (I_R) and illumination (E) of a photo-diode. The reverse current is shown on the vertical axis and is measured in μA. The illumination is indicated on the horizontal axis and is measured in mW/cm^2. Note that graph is a straight line passing through the origin.

$$\therefore \quad I_R = m\,E$$

where m = slope of the straight line

The quantity m is called the *sensitivity* of the photo-diode.

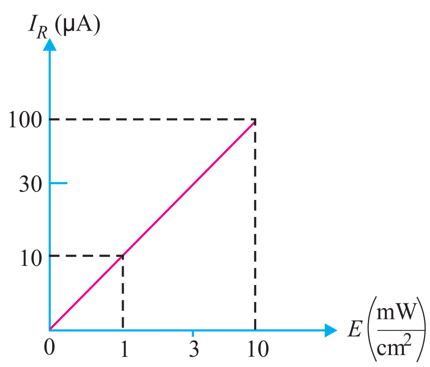


Fig. 7.12

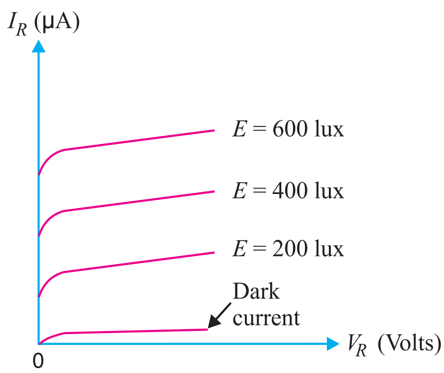


Fig. 7.13

***(ii)* Reverse voltage-Reverse current curve.** Fig. 7.13 shows the graph between reverse current (I_R) and reverse voltage (V_R) for various illumination levels. It is clear that for a given reverse-biased voltage V_R, the reverse current I_R increases as the illumination (E) on the *pn* junction of photo-diode is increased.

7.10 Applications of Photo-diodes

There are a large number of applications of photo-diodes. However, we shall give two applications of photo-diodes by way of illustration.

***(i)* Alarm circuit using photo-diode.** Fig. 7.14 shows the use of photo-diode in an alarm system. Light from a light source is allowed to fall on a photo-diode fitted in the doorway. The reverse current I_R will continue to flow so long as the light beam is not broken. If a person passes through the door, light beam is broken and the reverse current drops to the dark current level. As a result, an alarm is sounded.

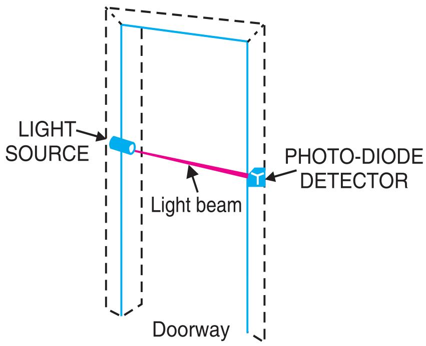


Fig. 7.14

***(ii)* Counter circuit using photo-diode.** A photo-diode may be used to count items on a conveyor belt. Fig. 7.15 shows a photo-diode circuit used in a system that counts objects as they pass by on a conveyor. In this circuit, a source of light sends a concentrated beam of light across a conveyor to a photo-diode. As the object passes, the light beam is broken, I_R drops to the dark current level and the count is increased by one.

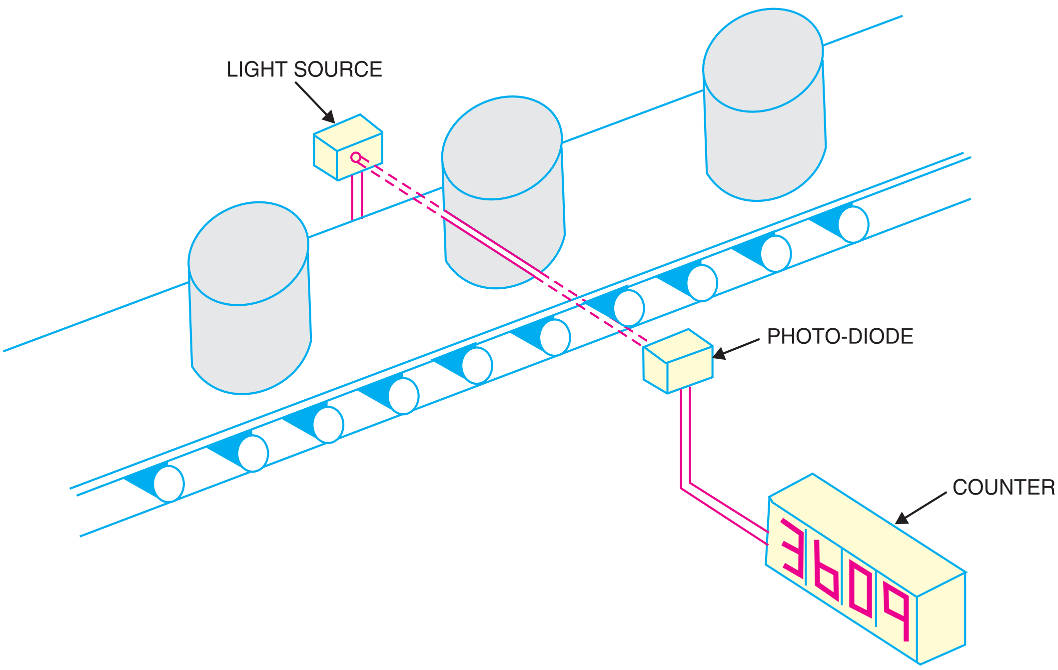


Fig. 7.15

Example 7.3. *From the reverse current-Illumination curve for a photo-diode shown in Fig. 7.16, determine the dark resistance. Assume a reverse-biased voltage of 10 V.*

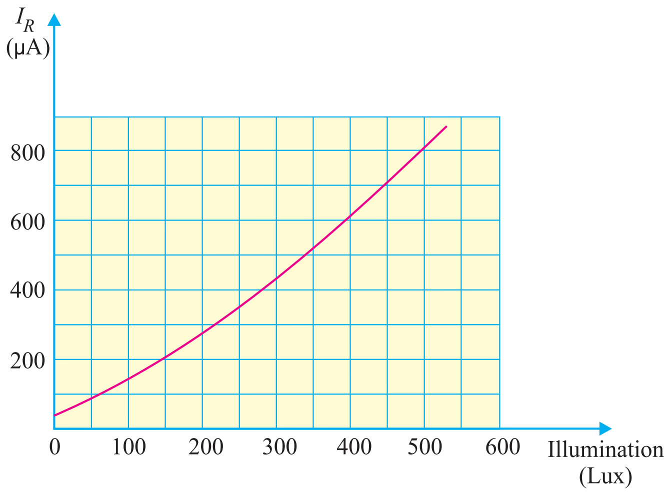


Fig. 7.16

Solution.

The current that flows when the incident light is removed from the photo-diode is called *dark current*. The resistance of a photo-diode corresponding to dark current is called *dark resistance*. From the curve shown in Fig. 7.16, it is clear that for zero illumination, the reverse current is 50 μA.

$\therefore$ Dark current, $I_r = 50\ \mu A = 50 \times 10^{-6}$ A

Reverse voltage, $V_R = 10$ V

$\therefore$ Dark resistance, $R_R = \frac{V_R}{I_r} = \frac{10}{50 \times 10^{-6}} = 200 \times 10^3\ \Omega =$ **200 kΩ**

Example 7.4. *A photo-diode is exposed to light with an illumination of 2.5 mW/cm^2. If the sensitivity of the photo-diode for the given conditions is 37.4 μA/mW/cm^2, find the reverse current through the device.*

Solution.

Reverse current = Sensitivity × Illumination

or $I_R = m \times E = 37.4 \times 2.5 =$ **93.5 μA**

7.11 Optoisolator

An ***optoisolator*** *(also called optocoupler) is a device that uses light to couple a signal from its input (a photoemitter e.g., a LED) to its output (a photodetector e.g., a photo-diode).*

Fig. 7.17 shows a LED-photo diode optoisolator. The LED is on the left and the photo-diode is on the right. The arrangement shown in Fig. 7.17 is referred to as *optocoupling* because the output from the LED circuit is coupled via light to the photo-diode circuit. When the LED is energised, current flows through the LED. The light from the LED hits the photo diode and sets up a reverse current through resistor R_2. The voltage across the photo-diode is given by :

$$V_{out} = V_{SS} - I\,R_2$$

The output voltage depends on how large the reverse current is. If we vary the LED supply, the amount of light changes and this causes the photo diode current to change. As a result, V_{out} changes. The key advantage of an optoisolator is the electrical isolation between the input and output circuits; the only contact between the input and output circuits is the stream of light.

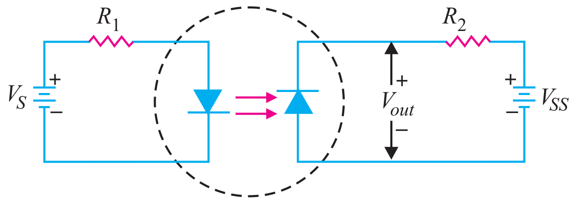


Fig. 7.17

7.12 Tunnel Diode

A **tunnel diode** *is a pn junction that exhibits negative resistance between two values of forward voltage (i.e., between peak-point voltage and valley-point voltage).*

A conventional diode exhibits *positive resistance when it is forward biased or reverse biased. However, if a semiconductor junction diode is heavily doped with impurities, it exhibits negative resistance (*i.e.* current decreases as the voltage is increased) in certain regions in the forward direction. Such a diode is called *tunnel diode*.

Theory. The tunnel diode is basically a *pn* junction with heavy doping of *p*-type and *n*-type semiconductor materials. In fact, a tunnel diode is doped approximately 1000 times as heavily as a conventional diode. This heavy doping results in a large number of majority carriers. Because of the large number of carriers, most are not used during the initial recombination that produces the depletion layer. As a result, the *depletion layer is very narrow.* In comparison with conventional diode, the depletion layer of a tunnel diode is 100 times narrower. The operation of a tunnel diode depends upon the *tunneling effect* and hence the name.

Tunneling effect. The heavy doping provides a large number of majority carriers. Because of the large number of carriers, there is much drift activity in *p* and *n* sections. This causes many valence electrons to have their energy levels raised closer to the conduction region. Therefore, it takes only a very small applied forward voltage to cause conduction.

The movement of valence electrons from the valence energy band to the conduction band with little or no applied forward voltage is called **tunneling.** *Valence electrons seem to tunnel through the forbidden energy band.*

As the forward voltage is first *increased*, the diode current rises rapidly due to tunneling effect. Soon the tunneling effect is reduced and current flow starts to *decrease* as the forward voltage across the diode is increased. The tunnel diode is said to have entered the negative resistance region. As the voltage is further increased, the tunneling effect plays less and less part until a valley-point is reached. From now onwards, the tunnel diode behaves as ordinary diode *i.e.*, diode current increases with the increase in forward voltage.

V-I Characteristic. Fig. 7.18 (*i*) shows the V-I characteristic of a typical tunnel diode.

(*i*) As the forward voltage across the tunnel diode is increased from zero, electrons from the *n*-region "tunnel" through the potential barrier to the *p*-region. As the forward voltage increases, the diode current also increases until the *peak-point P* is reached. The diode current has now reached peak current I_P (= 2.2 mA) at about peak-point voltage V_P (= 0.07 V). Until now the diode has exhibited positive resistance.

(*ii*) As the voltage is increased beyond V_P, the tunneling action starts decreasing and the diode current decreases as the forward voltage is increased until *valley-point V* is reached at valley-point voltage V_V (= 0.7V). In the region between peak-point and valley-point (*i.e.*, between points *P* and

* If current flowing through a circuit or device increases as the applied voltage is increased, we say that the circuit or device has positive resistance.

V), the diode exhibits negative resistance *i.e.*, as the forward bias is increased, the current decreases. This suggests that tunnel diode, when operated in the negative resistance region, can be used as an oscillator or a switch.

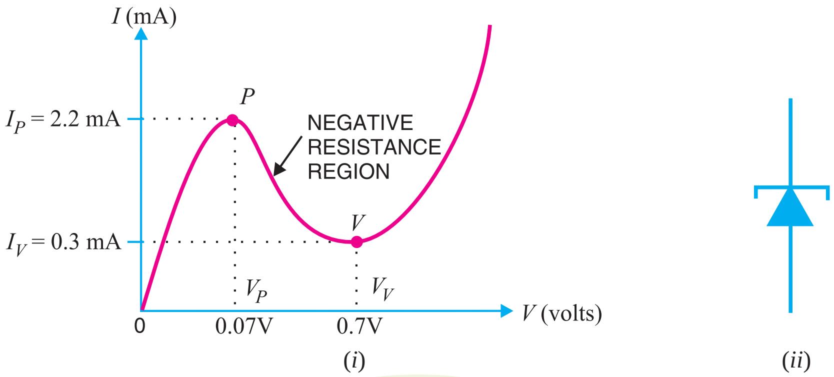


Fig. 7.18

(iii) When forward bias is increased beyond valley-point voltage V_V (= 0.7 V), the tunnel diode behaves as a normal diode. In other words, from point V onwards, the diode current increases with the increase in forward voltage *i.e.*, the diode exhibits positive resistance once again. Fig. 7.18. (*ii*) shows the symbol of tunnel diode. It may be noted that a tunnel diode has a high reverse current but operation under this condition is not generally used.

7.13 Tunnel Diode Oscillator

A tunnel diode is always operated in the negative resistance region. When operated in this region, it works very well in an oscillator. Fig. 7.19 (*i*) shows a parallel resonant circuit. Note that R_P is the parallel equivalent of the series winding resistance of the coil. When the tank circuit is set into oscillations by applying voltage as shown in Fig. 7.19. (*ii*), damped oscillations are produced. It is because energy is lost in the resistance R_P of the tank circuit.

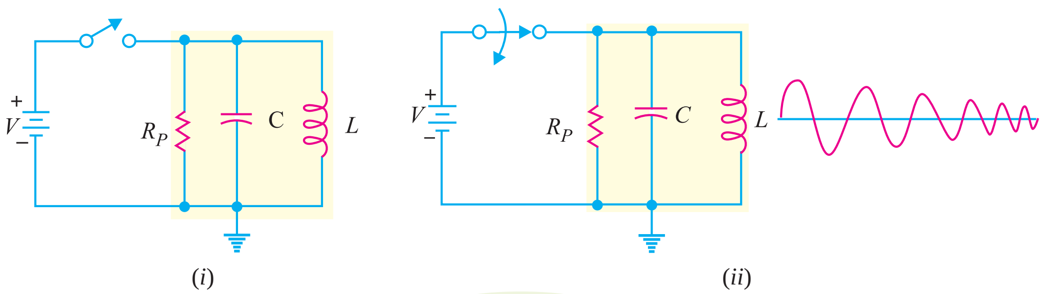


Fig. 7.19

If a tunnel diode is placed in series with the tank circuit and biased at the centre of the negative-resistance portion of its characteristic as shown in Fig. 7.20, undamped oscillations are produced at the output. It is because the negative-resistance characteristic of the tunnel diode counteracts the positive-resistance characteristic of the tank circuit.

The circuit shown in Fig. 7.20 is called *tunnel diode oscillator* or *negative resistance oscillator.* The negative resistance oscillator has one major drawback. While the circuit works very well at extreme high frequencies (upper mega hertz range), it cannot be used efficiently at low frequencies. Low-frequency oscillators generally use transistors.

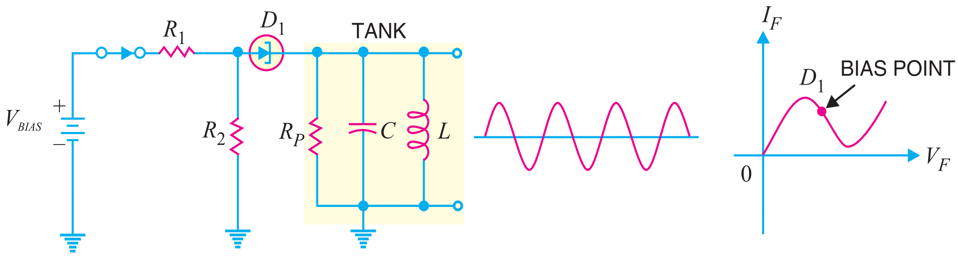
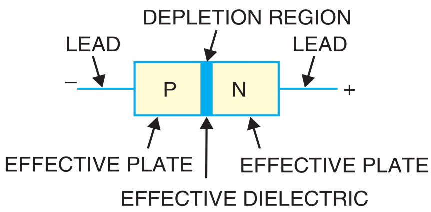


Fig. 7.20

7.14 Varactor Diode

A junction diode which acts as a variable capacitor under changing reverse bias is known as a ***varactor diode.***

When a *pn* junction is formed, depletion layer is created in the junction area. Since there are no charge carriers within the depletion zone, the zone acts as an insulator. The *p*-type material with holes (considered positive) as majority carriers and *n*-type material with electrons (–ve charge) as majority carriers act as charged plates. Thus the diode may be considered as a capacitor with *n*-region and *p*-region forming oppositely charged plates and with depletion zone between them acting as a dielectric. This is illustrated in Fig. 7.21 (*i*). A varactor diode is specially constructed to have high capacitance under reverse bias. Fig. 7.21 (*ii*) shows the symbol of varactor diode. The values of capacitance of varactor diodes are in the picofarad (10^{-12} F) range.



(*i*) (*ii*)

Fig. 7.21

Theory. For normal operation, a *varactor diode is always *reverse biased.* The capacitance of varactor diode is found as :

$$C_T = \varepsilon \frac{A}{W_d}$$

where C_T = Total capacitance of the junction

ε = Permittivity of the semiconductor material

A = Cross-sectional area of the junction

W_d = Width of the depletion layer

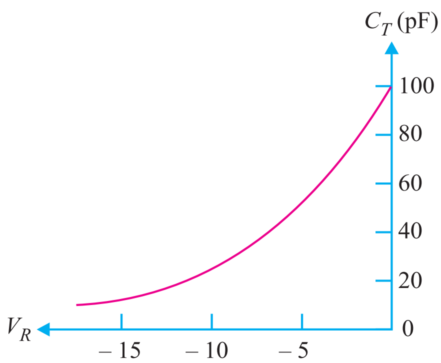


Fig. 7.22

When reverse voltage across a varactor diode is increased, the width W_d of the depletion layer increases. Therefore, the total junction capacitance C_T of the junction decreases. On the other hand, if the reverse voltage across the diode is lowered, the width W_d of the depletion layer decreases. Consequently, the total junction capacitance C_T increases.

* A forward biased varactor diode would serve no useful purpose.

Fig. 7.22 shows the curve between reverse bias voltage V_R across varactor diode and total junction capacitance C_T. Note that C_T can be changed simply by changing the voltage V_R. For this reason, a varactor diode is sometimes called **voltage-controlled capacitor.**

7.15 Application of Varactor Diode

We have discussed that we can increase or decrease the junction capacitance of varactor diode simply by changing the reverse bias on the diode. This makes a varactor diode ideal for use in circuits that require voltage-controlled tuning. Fig. 7.23 shows the use of varactor diode in a tuned circuit. Note that the capacitance of the varactor is in *parallel* with the inductor. The varactor and the inductor form a parallel *LC* circuit. *For normal operation, a varactor diode is always operated under reverse bias.* In fact, this condition is met in the circuit shown in Fig. 7.23. The resistance R_W in the circuit is the *winding resistance* of the inductor. This winding resistance is in series with the potentiometer R_1. Thus R_1 and R_W form a voltage divider that is used to determine the amount of reverse bias across the varactor diode D_1 and therefore its capacitance. By adjusting the setting of R_1, we can vary the diode capacitance. This, in turn, varies the resonant frequency of the *LC* circuit. The resonant frequency f_r of the *LC* circuit is given by;

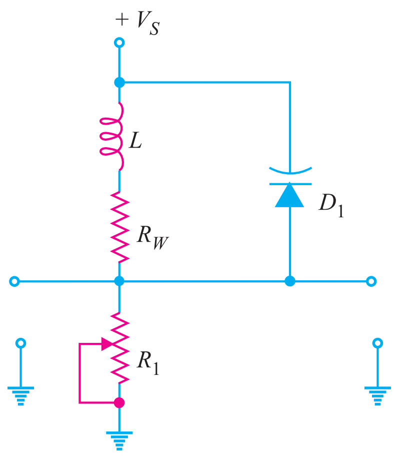


Fig. 7.23

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

If the amount of varactor reverse bias is *decreased*, the value of *C* of the varactor *increases.* The increase in *C* will cause the resonant frequency of the circuit to *decrease.* Thus, *a decrease in reverse bias causes a decrease in resonant frequency and vice-versa.*

Example 7.5. *The LC tank circuit shown in Fig. 7.23 has a 1 mH inductor. The varactor has capacitance of 100 pF when reverse bias is 5V d.c. Determine the resonant frequency of the circuit for this reverse bias.*

Solution.

$$\text{Resonant frequency, } f_r = \frac{1}{2\pi\sqrt{LC}}$$

Here, $L = 1\text{mH} = 1 \times 10^{-3}$ H; $C = 100 \text{ pF} = 100 \times 10^{-12}$ F

$$\therefore \quad f_r = \frac{1}{2\pi\sqrt{1\times10^{-3}\times100\times10^{-12}}} = 503.3 \times 10^3 \text{ Hz} = \textbf{503.3 kHz}$$

7.16 Shockley Diode

Named after its inventor, a Shockley diode is a *PNPN* device having two terminals as shown in Fig. 7.24 (*i*). This *device acts as a switch and consists of four alternate *P*-type and *N*-type layers in a single crystal. The various layers are labelled as P_1, N_1, P_2 and N_2 for identification. Since a *P*-region adjacent to an N-region may be considered a junction diode, the Shockley diode is equivalent to three junction diodes connected in series as shown in Fig. 7.24 (*ii*). The symbol of Shockley diode is shown in Fig. 7.24 (*iii*).

* Note that if we remove the gate terminal of an SCR, the resulting device is Shockley diode.

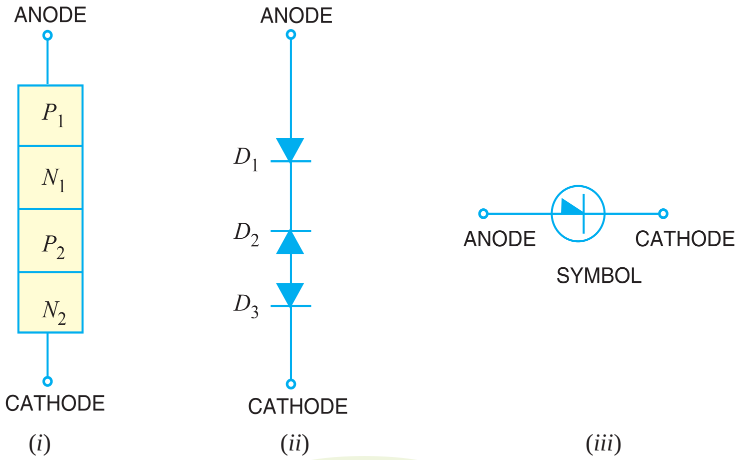


Fig. 7.24

Working

(i) When Shockley diode is forward biased (*i.e.*, anode is positive w.r.t. cathode), diodes D_1 and D_3 would be forward-biased while diode D_2 would be reverse-biased. Since diode D_2 offers very high resistance (being reverse biased) and the three diodes are in series, the Shockley diode presents a very high resistance. As the *forward voltage increases, the reverse bias across D_2 is also increased. At some forward voltage (called *breakover voltage* V_{BO}), reverse breakdown of D_2 occurs. Since this breakdown results in reduced resistance, the Shockley diode presents a very low resistance. From now onwards, the Shockley diode behaves as a conventional forward-biased diode; the forward current being determined by the applied voltage and external load resistance. This behaviour of Shockley diode is indicated on its *V-I* characteristic in Fig. 7.25.

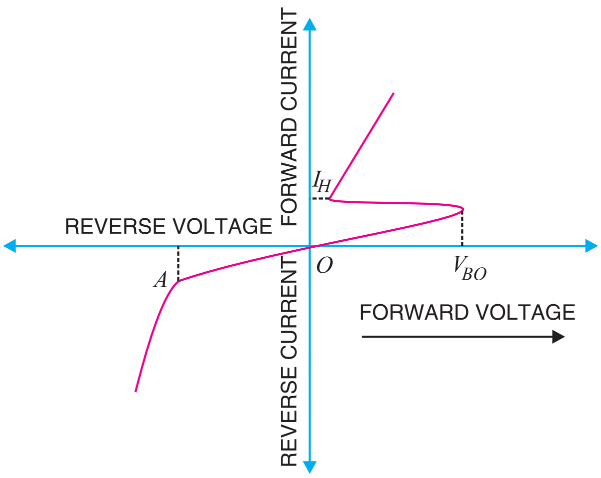


Fig. 7.25

(ii) When Shockley diode is reverse biased (*i.e.*, anode is negative *w.r.t.* cathode), diodes D_1 and D_3 would be reverse-biased while diode D_2 would be forward-biased. If reverse voltage is increased sufficiently, the reverse voltage breakdown (point *A* in Fig. 7.25) of Shockley diode is reached. At this point, diodes D_1 and D_3 would go into reverse-voltage breakdown, the reverse current flowing

* Since D_1 and D_3 offer very low resistance (being forward biased), the entire applied voltage appears as reverse voltage across D_2.

through them would rise rapidly and the heat produced by this current flow could ruin the entire device. For this reason, *Shockley diode should never be operated with a reverse voltage sufficient to reach the reverse-voltage breakdown point.*

Conclusion. The above discussion reveals that Shockley diode behaves like a switch. So long as the forward voltage is less than breakover voltage, Shockley diode offers very high resistance (*i.e.*, switch is open) and practically conducts no current. At voltages above the break-over value, Shockley diode presents a very low resistance (*i.e.* switch is closed) and Shockley diode conducts heavily. It may be noted that Shockley diode is also known as *PNPN diode* or *four layer diode* or *reverse-blocking diode thyristor.*

Note. Once Shockley diode is turned ON (*i.e.*, it starts conducting), the only way to turn it OFF is to reduce the applied voltage to such a value so that current flowing through Shockley diode drops below its *holding current* (I_H) *value*. Diode D_2 then comes out of its reverse-breakdown state and its high-resistance value is restored. This, in turn, causes the entire Shockley diode to revert to its high-resistance (switch open) state.

MULTIPLE-CHOICE QUESTIONS

1. Zener diodes are used primarily as
(*i*) amplifiers (*ii*) voltage regulators
(*iii*) rectifiers (*iv*) oscillators

2. A *pn* junction that radiates energy as light instead of as heat is called a
(*i*) LED (*ii*) photo-diode
(*iii*) photocell (*iv*) Zener diode

3. The capacitance of a varactor diode increases when reverse voltage across it
(*i*) decreases (*ii*) increases
(*iii*) breaks down (*iv*) stores charge

4. To display the digit 8 in a seven-segment indicator
(*i*) C must be lighted
(*ii*) G must be off
(*iii*) F must be on
(*iv*) All segments must be lighted

5. A photo-diode is normally
(*i*) forward-biased
(*ii*) reverse-biased
(*iii*) Neither forward nor reverse biased
(*iv*) Emitting light

6. When the reverse voltage increases, the junction capacitance
(*i*) decreases (*ii*) stays the same
(*iii*) increases (*iv*) has more bandwidth

7. The device associated with voltage-controlled capacitance is a
(*i*) LED (*ii*) photo-diode
(*iii*) varactor diode (*iv*) Zener diode

8. The varactor is usually
(*i*) forward-biased
(*ii*) reverse-biased
(*iii*) unbiased
(*iv*) in the breakdown region

9. When the light increases, the reverse current in a photo-diode
(*i*) increases (*ii*) decreases
(*iii*) is unaffected (*iv*) none of the above

10. To display the digit 0 in a seven segment display
(*i*) A must be lighted
(*ii*) F must be off
(*iii*) G must be on
(*iv*) all segments except G should be lighted

Answers to Multiple-Choice Questions

1. (*ii*)	**2.** (*i*)	**3.** (*i*)	**4.** (*iv*)	**5.** (*ii*)
6. (*i*)	**7.** (*iii*)	**8.** (*ii*)	**9.** (*i*)	**10.** (*iv*)

Chapter Review Topics

1. What is a LED ?
2. Explain the working of a LED.
3. Give two applications of LEDs.
4. Why do LEDs need series current-limiting resistors ?
5. How does LED differ from an ordinary diode ?
6. What is a photo-diode ?
7. How does photo-diode work ?
8. Give two applications of photo-diodes.
9. What is an optoisolator ?
10. What is a tunnel diode ?
11. Explain the V-I characteristics of a tunnel diode.
12. Explain the working of tunnel diode oscillator.
13. What is a varactor diode ?
14. Explain the working of varactor diode.
15. Give one application of varactor diode.
16. Explain the working of Shockley diode.

Discussion Questions

1. Why is LED not made of silicon or germanium ?
2. Where do we use seven-segment display ?
3. How do we protect LED from large reverse voltage ?
4. How does photo-diode differ from an ordinary diode ?
5. What is dark resistance of photo-diode ?
6. What do you mean by the sensitivity of photo-diode ?
7. What is the use of optoisolator ?
8. How does the width of depletion layer change the capacitance of a varactor ?

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