53.1. Fundamentals of Light

According to the Quantum Theory, light consists of discrete packets of energy called photons. The energy contained in a photon depends on the *frequency* of the light and is given by the relation $E = hf$ where h is Plank's constant (6.625×10^{-34} Joule-second). In this equation, energy E is in Joules and frequency f is in hertz (Hz). As seen, photon energy is directly proportional to frequency: higher the frequency, greater the energy. Now, velocity of light is given by $c = f\lambda$ where c is the velocity of the light (3×10^8 m/s) and λ is the wavelength of light in metres. The wavelength of light determines its colour in the visible range and whether it is ultraviolet or infrared outside the visible range.

Now, $\quad E = hf = hc/\lambda \quad$ or $\quad \lambda = hc/E$ metres

$\therefore \quad \lambda = (6.625 \times 10^{-34}) \times (3 \times 10^8)/E = (19.875 \times 10^{-26})/E \qquad$ —E in Joules

If E is in electron-volt (eV), then since $1\text{ eV} = 1.6 \times 10^{-19}$ J

$\therefore \quad \lambda = (19.875 \times 10^{-26})/(E \times 1.6 \times 10^{-19}) = (12.42 \times 10^{-7})/E$ metre

or $\quad \lambda = 1.242\ \mu$m

In a forward-biased P-N junction, electrons and holes both cross the junction. In the process, some electrons and holes recombine with the result that electrons lose energy. The amount of energy lost is equal to the difference in energy between the conduction and valence bands, this being known as the semiconductor energy band gap E_g. The value of E_g for silicon is 1.1 eV, for GaAs is 1.43 eV and for InAs is 0.36 eV. For example, the wavelength of light emitted by silicon P-N junction is $\lambda = 1.242/E_g = 1.242/1.1 = 1.13\ \mu$m.

53.2. Light Emitting Diode (LED)

(a) Theory

As the name indicates, it is a forward-biased P-N junction which emits visible light when energised. As discussed earlier (Art. 53.40), charge carrier recombination takes place when electrons from the N-side cross the junction and recombine with the holes on the P-side.

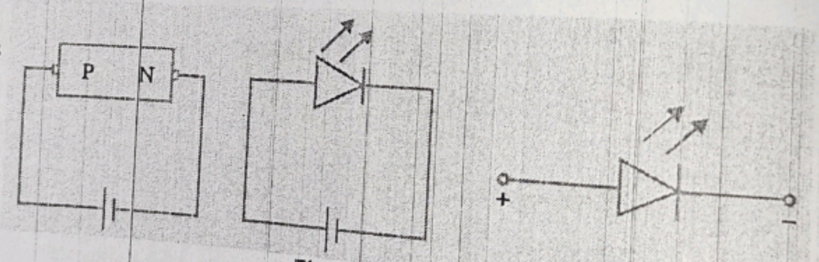
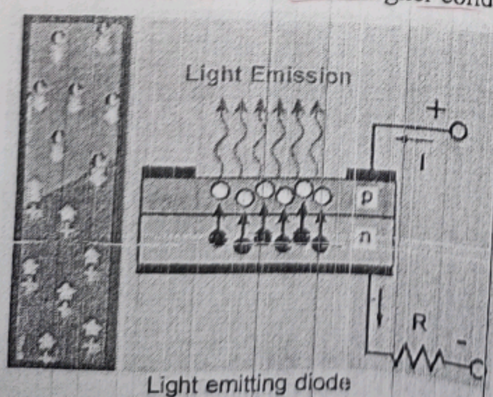
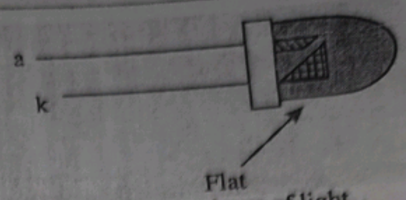


Fig. 53.1

Now, electrons are in the higher conduction band on the N-side whereas holes are in the lower valence band on the P-side. During recombination, some of the energy difference is given up in the form of heat and light (*i.e.* photons). For Si and Ge junctions, greater percentage of this energy is given up in the form of heat so that the amount emitted as light is insignificant. But in the case of other semiconductor materials like gallium arsenide (GaAs), gallium phosphide (GaP) and gallium-arsenide-phosphide (GaAsP), a greater percentage of energy released during recombination is given out in the form of light. If the semiconductor material is translucent, light is emitted and the junction becomes a light source *i.e.* a light-emitting diode (LED) as shown schematically in Fig. 53.1. The colour of the emitted light depends on the type of material used as given on the next page.



1. GaAs — infrared radiation (invisible).
2. GaP — red or green light.
3. GaAsP — red or yellow (amber) light.



LEDs that emit ***blue*** light are also available but red is the most common. LEDs emit no light when reverse-biased. In fact, operating LEDs in reverse direction will quickly destroy them. Fig. 53.1 shows a picture of LEDs that emits different colours of light.

(*b*) Construction

Broadly speaking, the LED structures can be divided into two categories :

1. ***Surface-emitting LEDs*** : These LEDs emit light in a direction **perpendicular** to the *PN* junction plane.
2. ***Edge-emitting LEDs*** : These LEDs emit light in a direction **parallel** to the *PN* junction plane.

Fig. 53.2 shows the construction of a surface-emitting LED. As seen from this figure, an *N*-type layer is grown on a substrate and a *P*-type layer is deposited on it by diffusion. Since carrier recombination takes place in the *P*-layer, it is kept upper most. The metal anode connections are made at the outer edges of the *P*-layer so as to allow more central surface area for the light to escape. LEDs are manufactured with domed lenses in order to lessen the reabsorption problem.

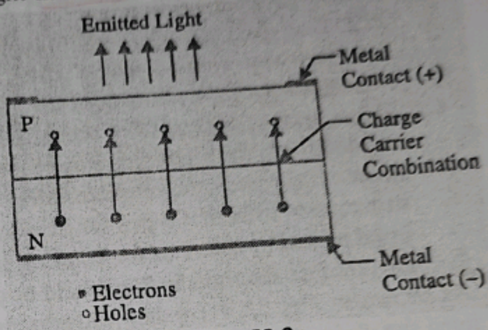


Fig. 53.2

A metal (gold) film is applied to the bottom of the substrate for reflecting as much light as possible to the surface of the device and also to provide cathode connection. LEDs are always encased in order to protect their delicate wires.

Being made of semiconductor material, it is rugged and has a life of more than 10,000 hours.

(*c*) Working

The forward voltage across an LED is considerably greater than for a silicon *PN* junction diode. Typically the maximum forward voltage for LED is between 1.2 V and 3.2 V depending on the device. Reverse breakdown voltage for an LED is of the order of 3 V to 10 V. Fig. 53.3 (*a*) shows a simple circuit to illustrate the working of an LED. The LED emits light in response to a sufficient forward current. The amount of power output translated into light is directly proportional to the forward current as shown in Fig. 53.3 (*b*). It is evident from this figure that greater the forward current, the greater the light output.

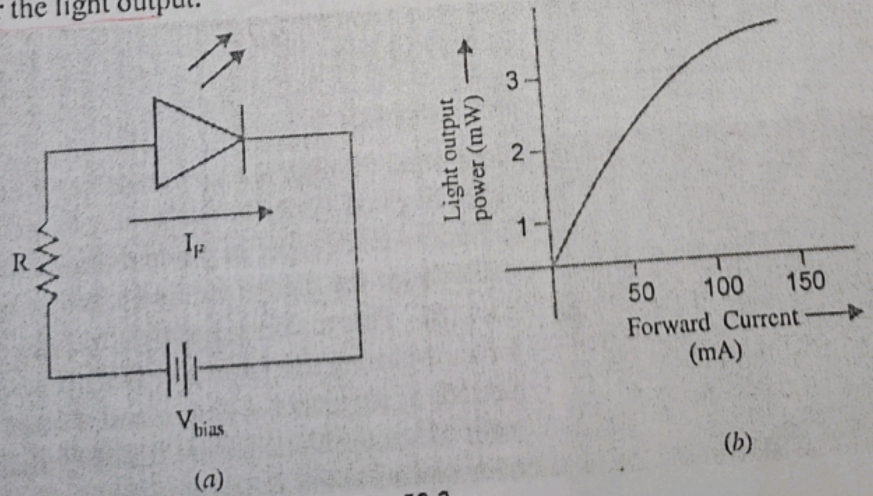


Fig. 53.3

(d) Applications

To chose emitting diodes for a particular application, one or more of the following points have to be considered : wavelength of light emitted, input power required, output power, efficiency, turn-on and turn-off time, mounting arrangement, light intensity and brightness etc.

Since LEDs operate at voltage levels from 1.5 V to 3.3 V, they are highly compatible with solid-state circuitry.

Their uses include the following :

1. LEDs are used in burglar-alarm systems;
2. for solid-state video displays which are rapidly replacing cathode-ray tubes (CRT);
3. in image sensing circuits used for 'picturephone';
4. in the field of optical fibre communication systems where high-radiance GaAs diodes are matched into the silica-fibre optical cable;
5. in data links and remote controllers;
6. in arrays of different types for displaying alphanumeric (letters and numbers) or supplying input power to lasers or for entering information into optical computer memories;
7. for numeric displays in hand-held or pocket calculators.

As shown in Fig. 53.4 (*a*) a seven-segment display consists of seven rectangular LEDs which can form the digits 0 to 9. The seven LED segments are labelled '*a*' to '*g*'. Each of this segments is

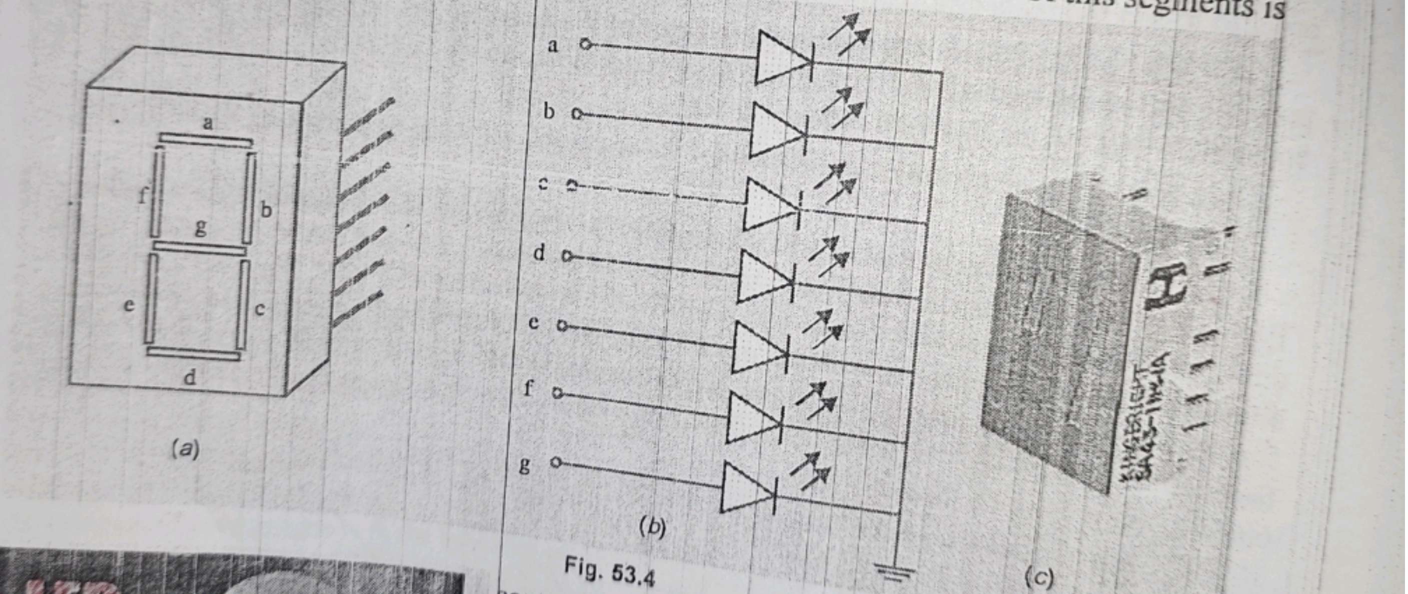
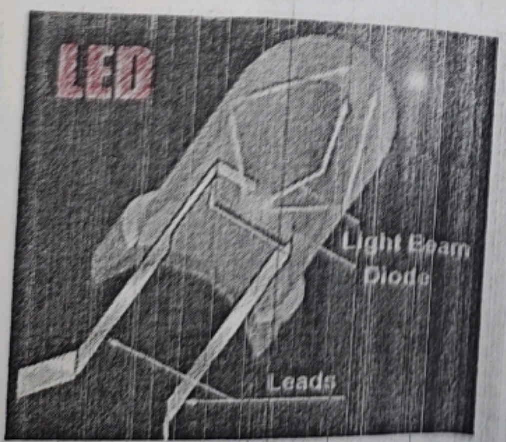


Fig. 53.4



LED

controlled through one of the display LEDs. Seven-segment displays come in two types, common-cathode and common-anode type. In the common-cathode type, all the cathodes of the diodes are tied together as shown in Fig. 53.4 (*b*). This makes it possible to light any segment by forward-biasing that particular LED. For example, to light number 5, segments *a*, *f*, *g*, *c* and *d* must be forward-biased. Since the cathodes are tied to ground, only 5 volt is to be applied to the anode of these segments to light them.

The common-anode seven-segment display has all its anodes tied together to +5 volt and ground is used to light the individual segments. Fig. 53.4(*c*) shows a picture of a seven-segment display.

(c) Multicoloured LEDs

LEDs are available which gives out light in either two or three colours. There are also blinking LEDs. A two-colour LED is a three-terminal device as shown in Fig. 3.5. The longest lead is the cathode and the remaining two leads are the anodes. When leads R and C are forward-biased, the LED emits red light and when leads G and C are forward-biased, LED emits green light. The tricolour LED looks similar to the ordinary LED but emits, red, green or yellow light depending on operating conditions. It has two leads and each of these acts as both anode and cathode. When dc current flows through it in one direction, LED emits red light but when current flows in the opposite direction, LED emits green light. However, with ac current, yellow light is given out.

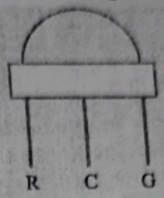
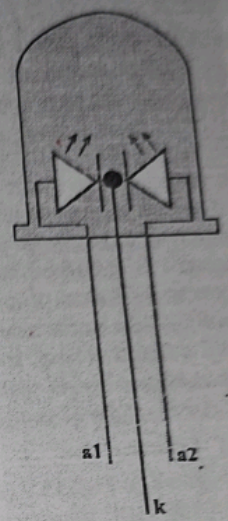


Fig. 53.5



The blinking LED is a combination of an oscillator and a LED in one package. Since it has an anode and a cathode lead, it looks like an ordinary LED. The blinking frequency is usually 3 Hz when the diode forward bias is 5 V. It conducts about 20 mA of current when ON and 0.9 mA when OFF.

53.3. Use of LEDs in Facsimile Machines

Fig. 53.6 shows a simplified schematic diagram of a facsimile (or fax) machine. As seen, the light from the LED array is focussed on the document paper. The light reflected at the paper is focussed on a charge-coupled device (CCD) by a combination of mirror and a lens. This causes the optical information to be converted into electrical information. The electrical information is then sent through the data-processing unit to its destination via telephone line.

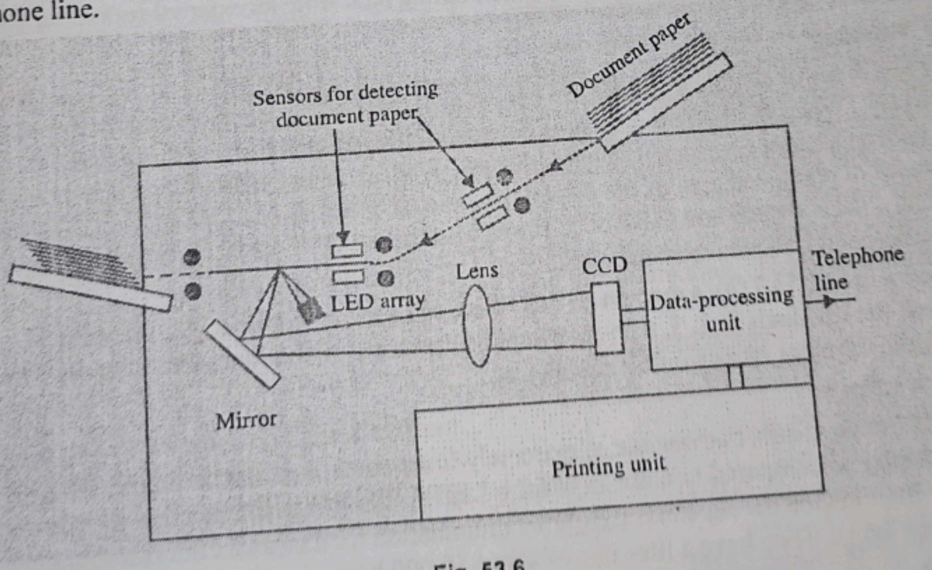


Fig. 53.6

53.4. Liquid Crystals Displays

(a) General

A liquid crystal is a material (usually, an organic compound) which flows like a liquid at room temperature but whose molecular structure has some properties normally associated with solids (examples of such compounds are : cholesteryl nonanoate and p-azoxyanisole). As is well-known, the molecules in ordinary liquids have random orientation but in a liquid crystal they are oriented in a definite crystal pattern. Normally, a thin layer of liquid crystal is transparent to incident light but when an electric field is applied across it, its molecular arrangement is disturbed causing changes in its optical properties. When light falls on an activated layer of a liquid crystal, it is either absorbed or else is scattered by the disoriented molecules.

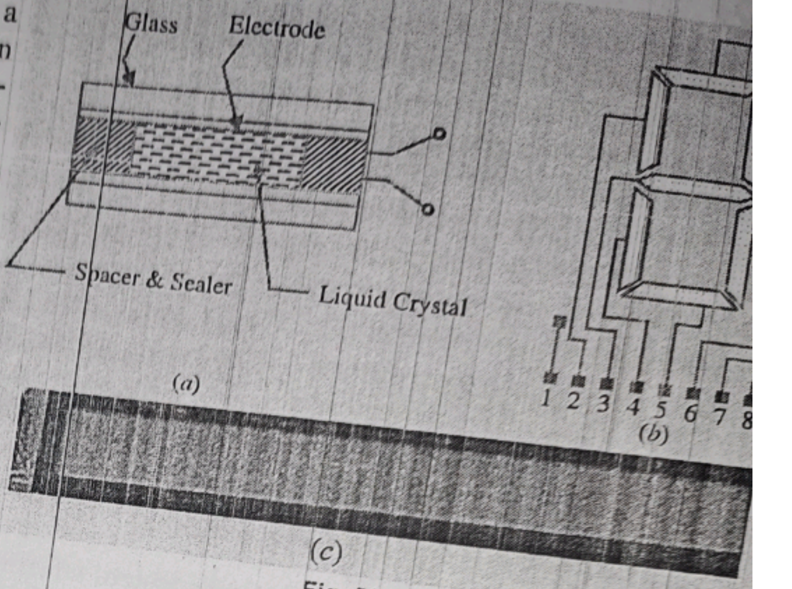


Fig. 53.7

(b) Construction

As shown in Fig. 53.7 (*a*), a liquid crystal 'cell' consists of a thin layer (about 10 μm) of a liquid crystal sandwiched between two glass sheets with transparent electrodes deposited on their inside faces. With both glass sheets transparent, the cell is known as *transmittive* type cell. When one glass is transparent and the other has a reflective coating, the cell is called *reflective* type. The LCD does not produce any illumination of its own. It, in fact, depends entirely on illumination falling on it from an external source for its visual effect.

(c) Working

The two types of display available are known as (*i*) **field-effect display** and (*ii*) **dynamic scattering display.** When field-effect display is energized, the energized areas of the LCD absorb the incident light and, hence give localized black display. When dynamic scattering display is energized, the molecules of energized area of the display become turbulent and scatter light in all directions. Consequently, the activated areas take on a frosted glass appearance resulting in a silver display. Of course, the un-energized areas remain translucent.

As shown in Fig. 53.7 (*b*), a digit on an LCD has a segment appearance. For example, if number 5 is required, the terminals 8, 2, 3, 6 and 5 would be energized so that only these regions would be activated while the other areas would remain clear.

(d) Advantages

An LCD has the distinct advantage of extremely low power requirement (about 10-15 μW per 7-segment display as compared to a few mW for a LED). It is due to the fact that it does not itself generate any illumination but depends on external illumination for its visual effect (colour depending on the incident light). They have a life-time of about 50,000 hours.

(e) Uses

1. Field-effect LCDs are normally used in watches and portable instruments where source of energy is a prime consideration.
2. Thousands of tiny LCDs are used to form the picture elements (pixels) of the screen in one type of B & W pocket TV receiver.
3. Recent desk top LCD monitors.
4. Note book computer display
5. Cellular phone display, to display data on personal digital assistant (PDAs) such as Palm Vx etc.

The liquid crystal display (LCDs) commonly used on notebook computers and handheld PDAs are also appearing on desktop. These flat panel displays promise great clarity at increasingly high resolutions and are available in screen sizes upto 15 inches. The LCD monitor offers benefits and drawbacks. The first benefit is size. Because of the need to house the tube itself, cathode-ray tube (CRT) monitors are big and heavy. LCD monitors are only a few inches deep and they are much lighter in weight. However LCD monitors are expensive than CRTs at present. Another problem is the viewing angle. The optimal viewing angle of an LCD is from straight in front and as you move further to the side the screen becomes harder to read, much more so than with a CRT. Moreover screen resolutions generally reach only as high as 1,024 × 768, which is insufficient for some applications. Fig. 53.7(c) shows the picture of an LCD used in portable instrument.

53.5. P-N Junction Photodiode

It is a two-terminal junction device which is operated by first reverse-biasing the junction and then illuminating it. A reverse-biased *P-N* junction has a small amount of reverse saturation current I_s (or I_0) due to thermally-generated electron-hole pairs. In silicon, I_s is the range of nanoamperes. The number of these minority carriers depends on the intensity of light incident on the junction. When the diode is in glass package, light can reach the junction and thus change the reverse current.

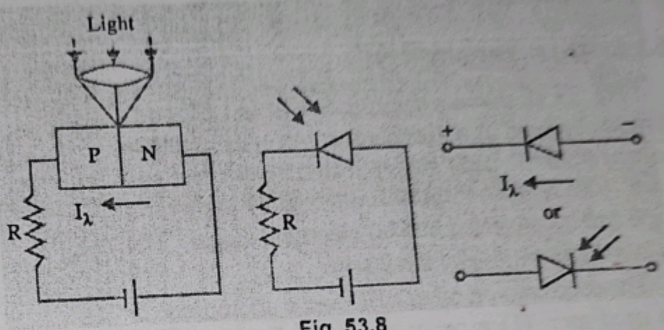
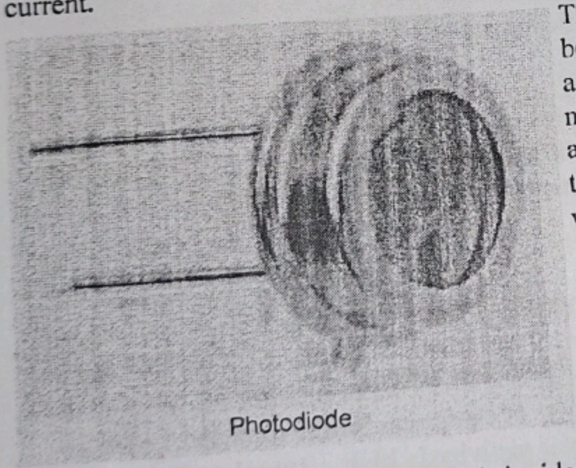


Fig. 53.8



Photodiode

The basic biasing arrangement, construction and symbols of a photodiode are shown in Fig. 53.8. As seen, a lens has been used in the cap of the unit to focus maximum light on the reverse-biased junction. The active diameter of these devices is about 2.5 mm but they are mounted in standard TO-5 packages with a window to allow maximum incident light.

The characteristics of Fig. 53.9 show that for a given reverse voltage, I_λ (or I_s) increases with increase in the level of illumination. The dark current refers to the current that flows when no light is incident. By changing the illumination level, reverse current can be changed. In this way, reverse resistance of the diode can be changed by a factor of nearly 20.

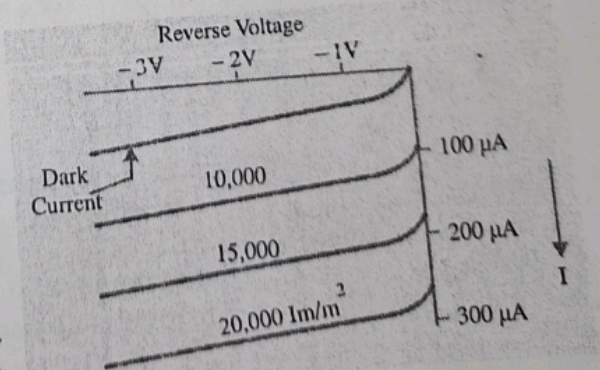


Fig. 53.9

A photodiode can turn its current ON and OFF in nanoseconds. Hence, it is one of the fastest photodetectors. It is used where it is required to switch light ON and OFF at a maximum rate. Applications of a photodiode include