22.8. LIGHT EMITTING DIODES (LEDs)

The best known of all optoelectronic devices is the so called LED (lights-emitting diode), which emits a fairly narrow bandwidth of visible (usually red, orange, yellow or green) or invisible (infrared) light when its internal diode junction is stimulated by a forward electric current/voltage (power). LEDs have typical power-to-light energy conversion efficiencies some 10 to 50 times greater than of a simple tungsten lamp and have very fast response times (approximately 0.1 μs compared with tens or hundreds of milliseconds for a tungsten lamp), and are thus widely employed as visual indicators and as moving-light displays.

The operation of light-emitting diode (LED) is based on the phenomenon of electroluminance, which is the emission of light from a semiconductor under the influence of an electrical field. The recombination of charge carriers take place in a forward P-N junction as the electrons cross from the N-region and recombine with holes existing in P-region. Free electrons are in the conduction band of energy levels, while holes are in the valence energy band. Therefore, the electrons are at high energy levels than the holes. For the electrons to recombine with the holes, they must give some of their energy. Typically, these electrons give up energy in the form of heat and light.

In silicon and germanium diodes, most of the electrons give up their energy in the form of heat. However, with GaAsP, and GaP semiconductors, the electrons give up their energy by emitting photons. If the semiconductor is transluscent, the light will be emitted and the junction becomes a source of light, *i.e.* a *light-emitting diode* (LED). LEDs emit no light when *reverse-biased*. In fact, operating LEDs in reverse bias mode will quickly destroy them.

transparent

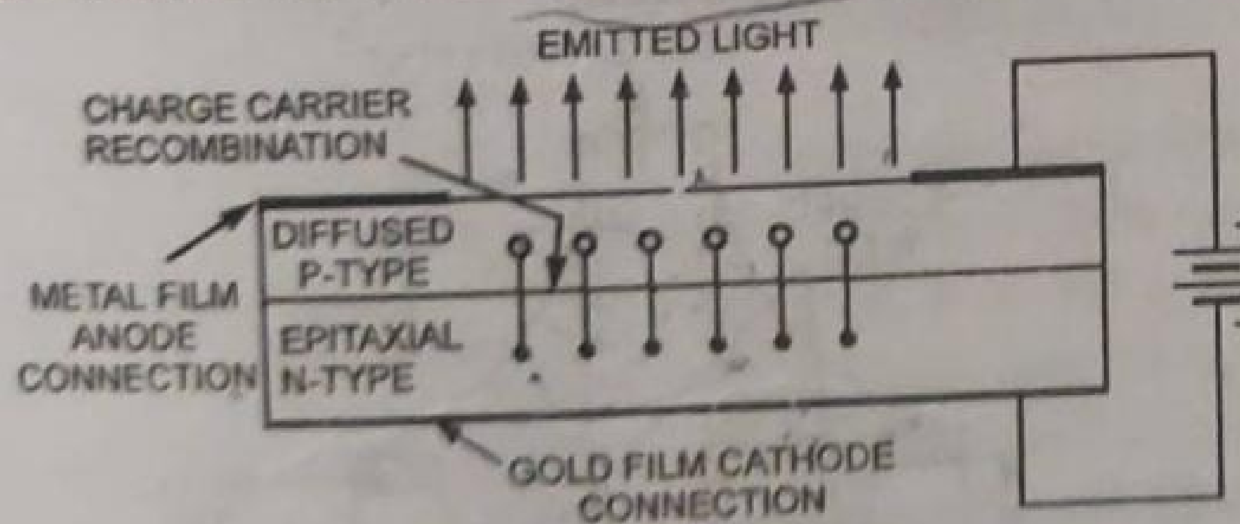
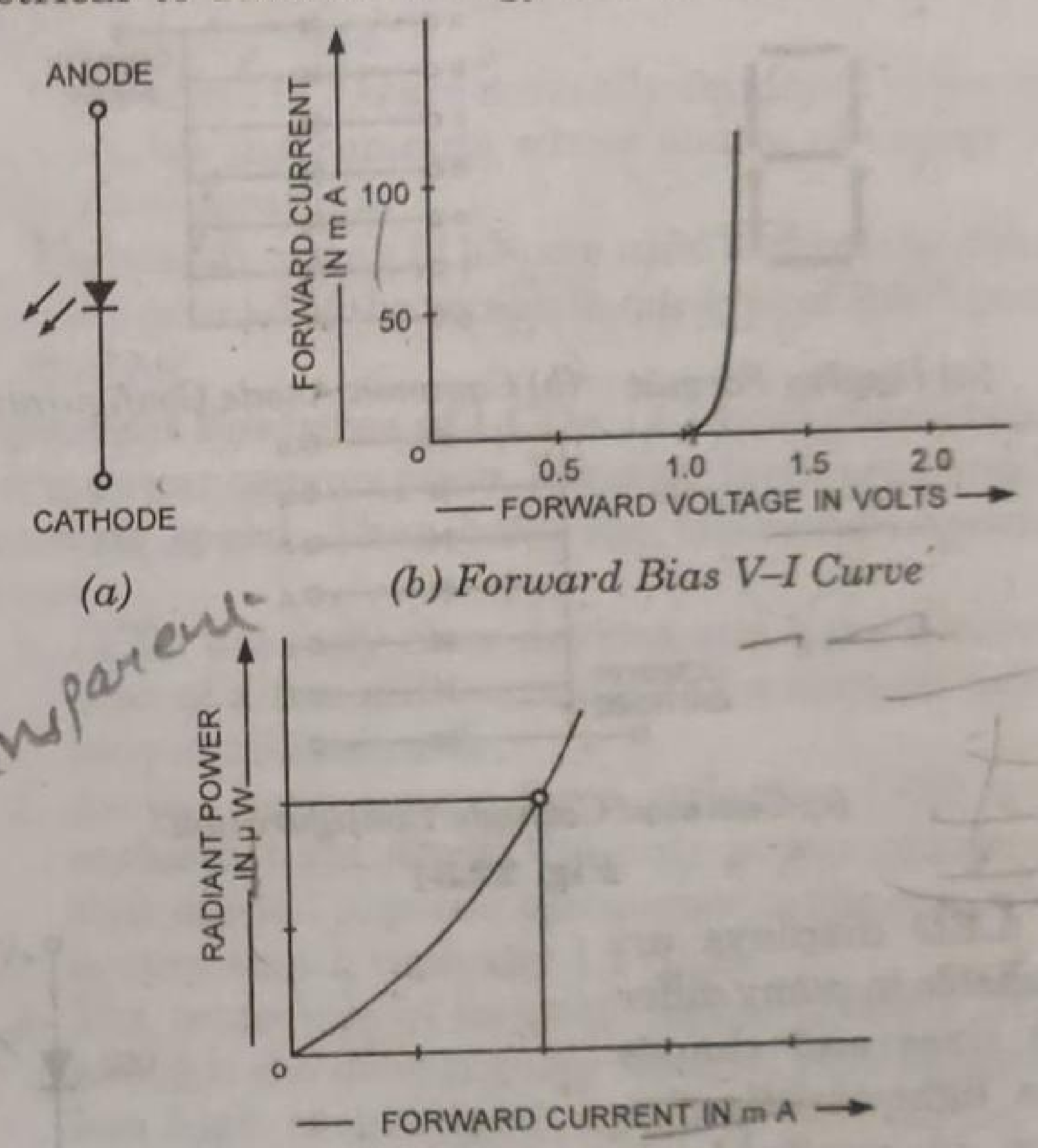


Fig. 22.30. ***LED***

A cross-sectional view of a typically diffused LED is given in Fig. 22.30. The semiconductor material used is gallium arsenide (GaAs), gallium arsenide phosphide (GaAsP) or gallium phosphide (GaP). An N-type epitaxial layer is grown upon a substrate, and the P-region is produced by diffusion. Recombination of charge carriers occur in the P-region so this region is required to be kept at the top. Thus, the P-region becomes the device surface. The metal anode connections are made at the outer edges of P-layer so as to allow more surface area for the light to come out. A gold film is applied to the substrate bottom to reflect as much as possible of the light toward the surface of the device and to provide a cathode connection. LEDs are manufactured with domed lenses so as to reduce the reabsorption problem.

LEDs are always encased in order to protect their delicate wires. LEDs made from GaAs emit invisible infrared light, LEDs constructed of GaAsP tend to emit either red or yellow light. The GaP LEDs give either red or green light.

Figure 22.31 (*a*) shows a circuit symbol for a LED. The arrows indicate radiation emitted by the diode. Figs. 22.31 (*b*) and 22.31 (*c*) give two curves used to determine LED operating characteristics. Figure 22.31 (*b*) is forward bias V-I curve for a typical LED employed in burglar alarms. Forward bias of approximately one volt is required to give significant forward current. Figure 22.31 (*c*) provides radiant power-forward current curve. The radiant output power is rather small and indicates a very low efficiency of electrical to radiant energy conversion.



(*a*) (*b*) *Forward Bias V–I Curve*

(*c*) *Output Characteristic Curve*

Fig. 22.31. ***LED***

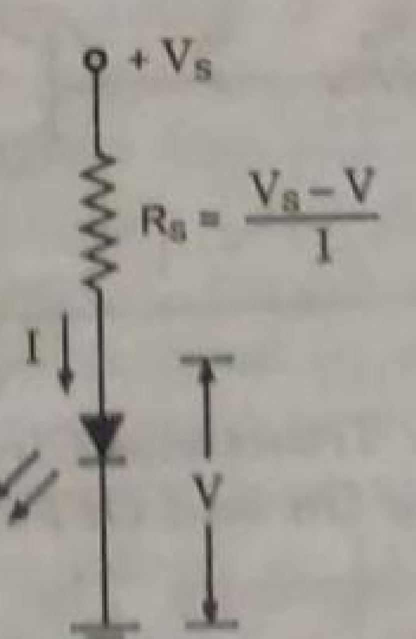


Fig. 22.32. ***LED Circuit***

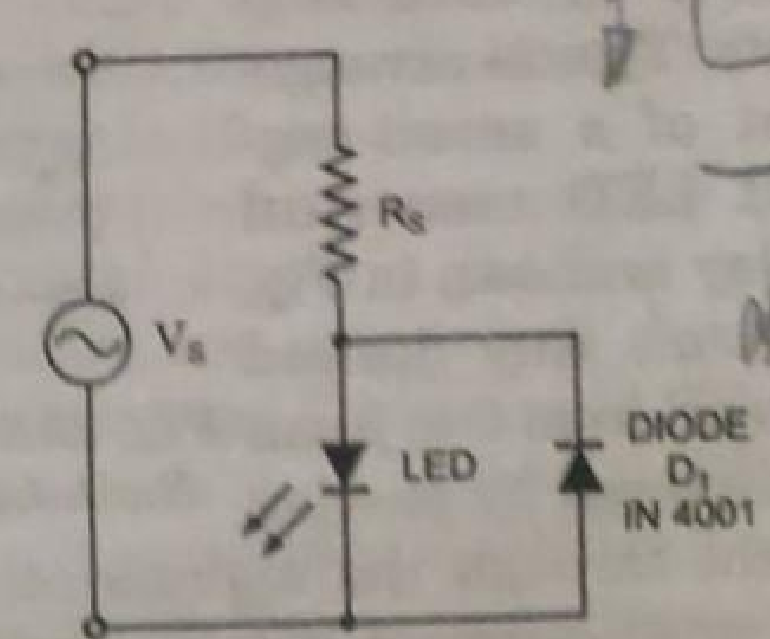


Fig. 22.33. ***LED As An Indicator in AC Circuit***

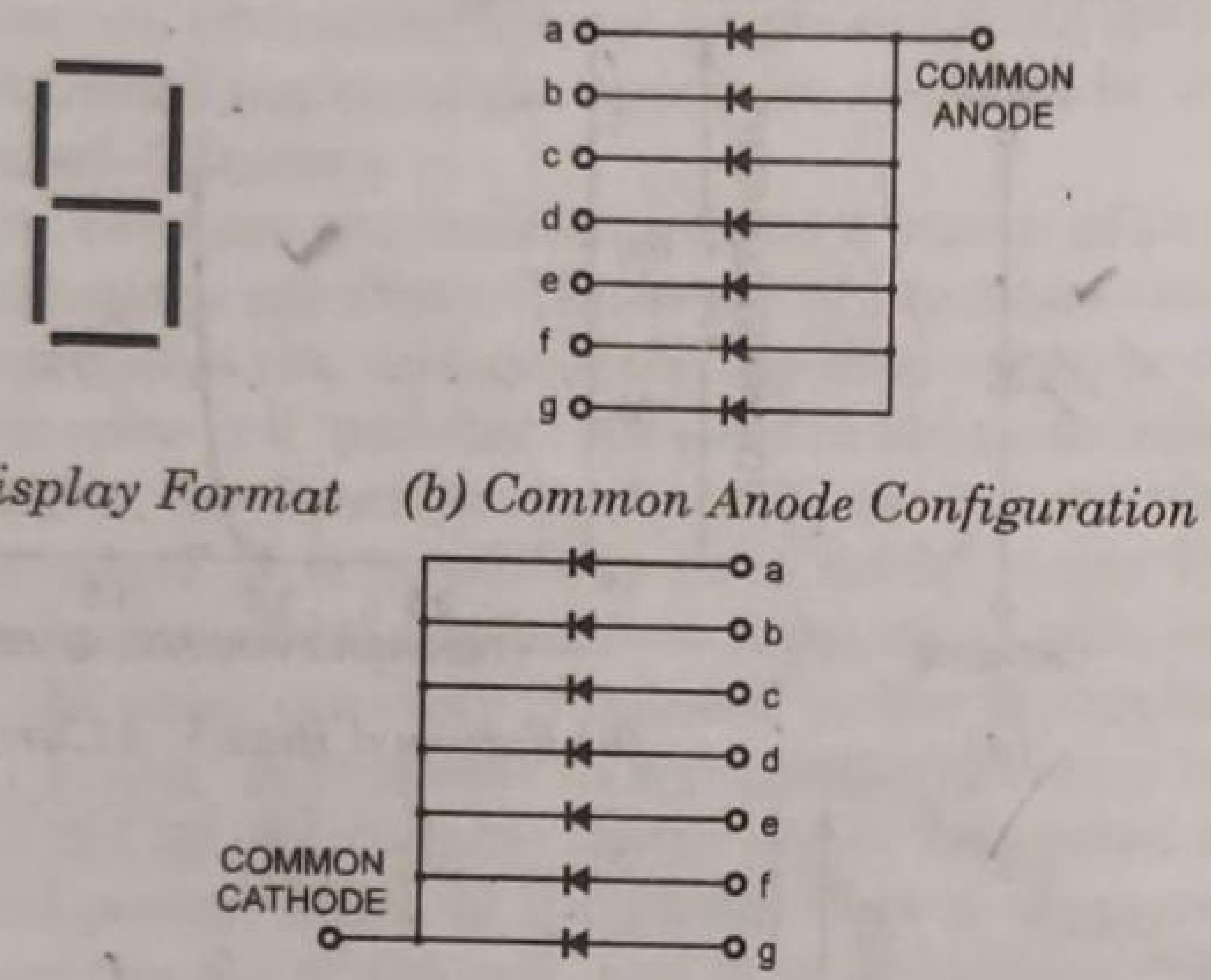
Figure 22.32 shows a source connected to a series resistor R_s and a LED. The outward arrows symbolise the radiated light. The forward resistance of LEDs is very low which means that once the forward bias exceeds, the current through it will increase rapidly for only a very small increase in voltage. Thus it becomes necessary to use an external series current limiting resistor. The value of series resistor R_S can be determined from the following equation

$$R_S = \frac{V_S - V}{I} \quad ...(22.4)$$

where V_S is the supply voltage, V is LED forward bias voltage and I is the desired current.

For most of the commercially available LEDs, the typical voltage drop (diode voltage) is from 1.5–2.5 V for currents between 10 and 50 mA. The exact voltage drop depends on the LED current, colour, tolerance, etc.

A LED can be used as an indicator in ac circuit by wiring it in inverse parallel with a normal diode, as shown in Fig. 22.33, to prevent the LED being reverse biased; for a given brightness, the value of R_s should be halved relative to that of the dc circuit.



(a) Display Format *(b) Common Anode Configuration*

(c) Common Cathode Configuration

Fig. 22.34

LED displays are available in many different sizes and shapes. The light-emitting region is available in lengths from 2.5 to 25 mm. Numbers can be created by such segments. Typical arrangement of a seven-segment LED numerical display is shown in Fig. 22.34 (*a*). Any desired numeral from 0 to 9 can be displayed by passing current through the appropriate segments. The LEDs in a seven-segment display may be connected in common anode or in common-cathode configuration, as illustrated in Figs 22.34 (*b*) and 22.34 (*c*) respectively. LEDs are usually switched on and off by transistor circuit.

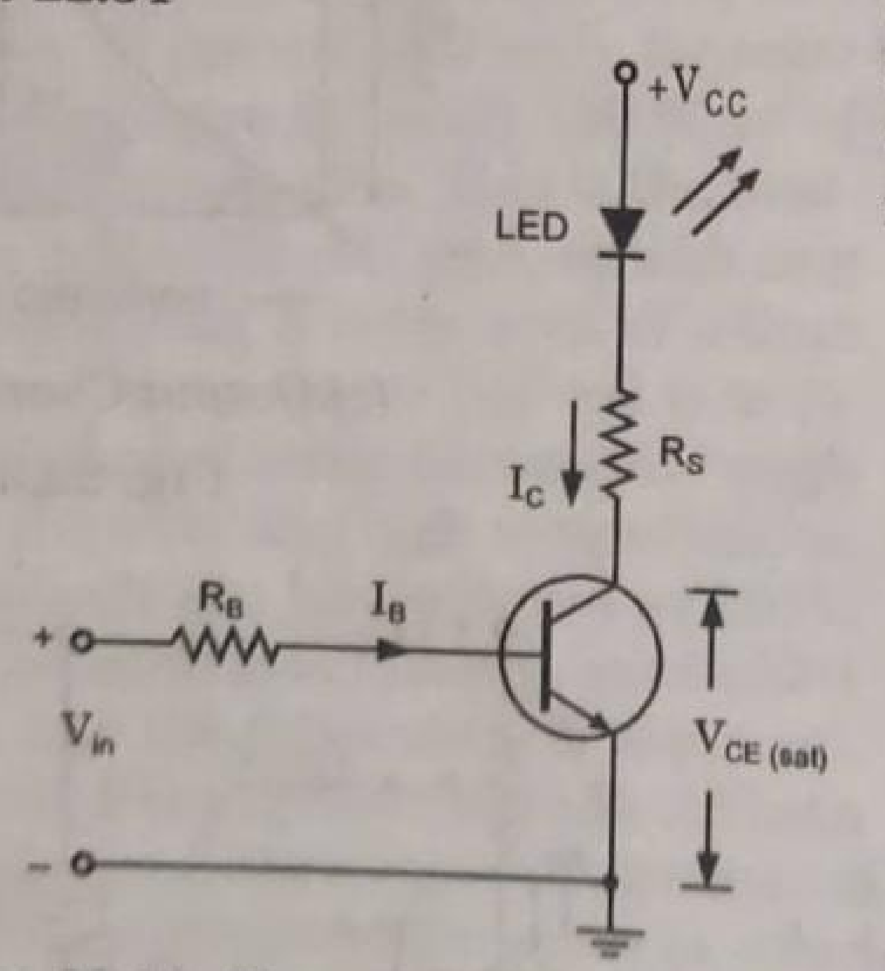


Fig. 22.35. ***Transistor Circuit For Switching On and OFF a LED***

Transistor circuit for switching on and off LEDs is given in Fig. 22.35.

Advantages of LEDs. 1. LEDs are miniature in size and can be stacked together to form numeric and alphanumeric displays in high density matrix.

2. Smooth control of light intensity from an LED because light output from an LED is a function of current flowing through it.
3. LEDs are economical and have a high degree of reliability because they are manufactured with the same type of technology as is used for transistors and ICs.
4. LEDs are rugged and can, therefore, withstand shocks and vibrations.
5. LEDs can be operated over a wide temperature range (0–70°C).
6. The switching time (both on and off) is less than 1 ns. So they are very suitable where dynamic operation of large number of arrays is involved.
7. LEDs are available in different colours like red, yellow, green and amber.
8. They need moderate power. They are used where low dc power is available.
9. They occupy small area.
10. LED devices can be driven by transistor-transistor logic (TTL) whereas gas discharge devices need intermediate transistor stages to allow them to be driven by 5 V TTL.

The *drawbacks of LEDs* are that they may get damaged by overvoltage or overcurrent. They have wide optical bandwidth compared to the LASER ($\simeq$ 10 nm). Their temperature depends on the radiant output power and wavelength. LEDs are not suited for large area displays, primarily because of their high cost. For large displays, devices using gas filled plasma are used.

LEDs that emit visible light are widely used in instrument display panel indicator, digital watches, calculators, multimeters, intercom, telephone switch boards, etc. LEDs that emit invisible infrared light find application in remote control schemes, object detectors, burglar alarm systems; and other areas requiring invisible radiation.

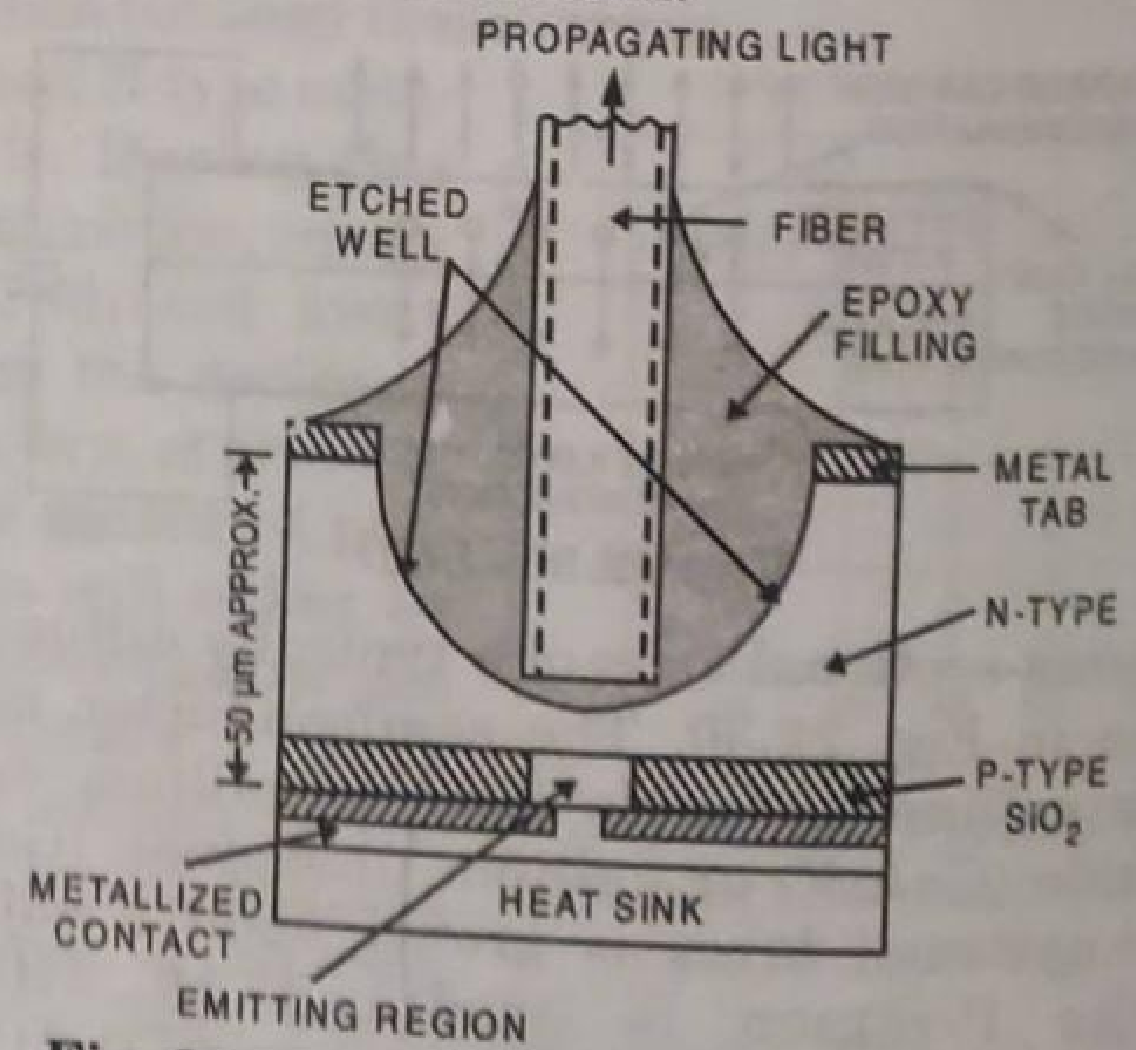


Fig. 22.36. ***LEDs as Source For Fiber Optic System***

The LEDs used for fiber optics are usually of the gallium arsenide (GaAs) type, with various dopants added to shift the center wavelength of the radiation spectrum. Dopants used are phosphorus (P), indium (In), and aluminium (Al). Gallium arsenide phosphide (GaAsP) diodes can be made with bandgaps in the range of 1.5 to 2.0 eV (0.62 – 0.83 μm wavelength). Gallium indium arsenide (GaInAs), indium arsenide phosphide (InAsP), or aluminium indium arsenide (AlInAs) diodes cover the range from 0.5 to 1.5 eV (0.83 to 2.5 μm). Some of these structures may also be used to form laser diodes.

A fiber to the diode coupling is shown in Fig. 22.36. Currently, diode fiber combinations are available in which several hundred microwatts at the most can be produced and injected into an optical fiber.

22.9. LIQUID CRYSTAL DISPLAYS

Another type of displays are liquid crystal displays (LCDs) that are used in similar applications where LEDs are used. The applications of LCDs are display of numeric and alphanumeric characters in segmental and dot matrix displays.

The liquid-crystal display has the distinct advantage of having a low power consumption than the LED. It is typically of the order of microwatts for the display in comparison to the some order of milliwatts for LEDs. Low power consumption requirement has made it compatible with MOS integrated logic circuit. Its other advantages are its low cost and good contrast. The main drawbacks of LCDs are additional requirement of light source, a limited temperature range of operation (between 0 and 60°C), low reliability, short operating life, poor visibility in low ambient lighting, slow speed and the need for an ac drive.

As illustrated in Fig. 22.37, 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.

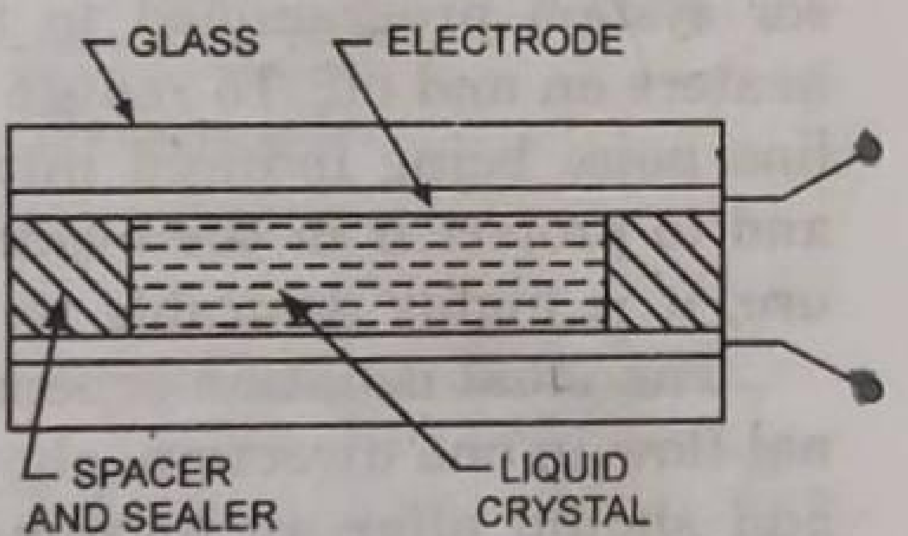


Fig. 22.37

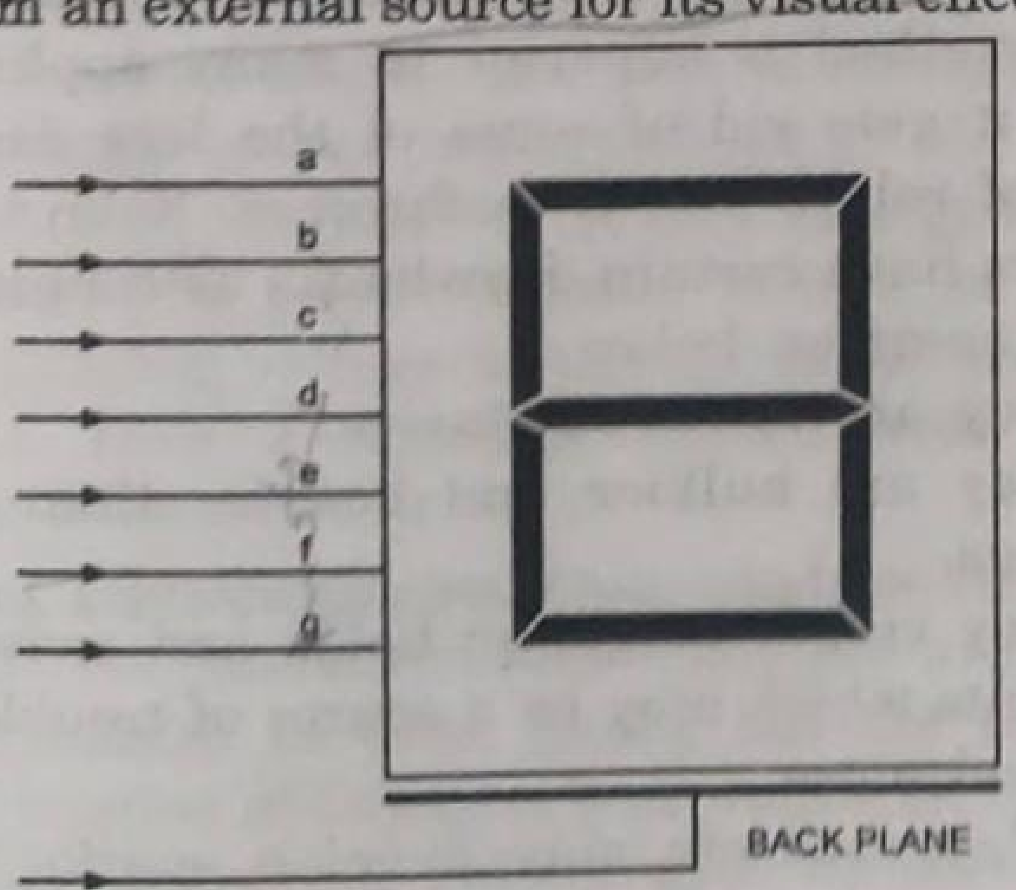


Fig. 22.38. *LCD*

Two types of displays available are dynamic scattering display and field effect 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 unenergized areas remain translucent.

Field effect LCD contains front and back polarizers at right angles to each other. Without electrical excitation, the light coming through the front polarizer is rotated 90° in the fluid, passes through the rear polarizer, and is reflected back by the mirror. When an electrostatic field is applied, the LC fluid molecules rotate 90° so that the light is not rotated 90° and is, therefore, absorbed by the rear polarizer. This causes the appearance of dark digits on a light background.

Most LCDs are prone to premature failure if operated with dc potentials, hence an ac square-wave drive is usually used.

Field-effect LCDs are normally employed in watches and portable instruments where source of energy is a prime consideration.

Thousands of tiny LCDs are used to form the picture elements (pixels) of the screen in one type of B&W pocket TV receiver.

Important Features of LCDs. LCDs are characterised by low power consumption, low cost, large area and low operating speed. They have the following important features.

1. LCDs are very slow devices and have a turn-on time of a few milliseconds, and a turn-off time of tens of milliseconds.
2. As the light source for a reflective LCD is the ambient light itself, the only power required is that needed to cause turbulence in the cell, which is very small, typically 1 μW/cm.
3. The materials of nematic liquid crystals (NLC) which is the most popular liquid crystal structure, has high resistivity (exceeding 10^{10} Ω). So the current requirement for scattering light in an NLC is very marginal (typically 0.1 μA/cm^2).
4. The electric field needed to activate LCDs is typically of the order of 1000 V/mm. This is equivalent to an LCD terminal voltage of 10 V when the NLC layer is 10 μm thick.
5. Unlike LED displays, which are usually quite small, liquid crystal displays (LCDs) can be fabricated in almost any convenient size. The maximum power consumed for a typical LCD used in electronics equipment is about 20 μW per segment, or 140 μW per numeral when all seven segments are energized. Comparing this value to about 400 mW per numeral for a LED display (including series resistor).

22.10. LASER DIODE

Laser is the shortened form of *light amplification by stimulated emission of radiation*. A laser emits radiation of essentially one wavelength, or a very narrowband of wavelengths. This means that the light has a single colour *i.e.*, a monochromatic. Laser light is referred to as *coherent light* as opposed to light made up of a wide band of wavelengths, which is termed *incoherent*.

The recovery rate is much greater in the reverse direction, e.g. going from darkness to illumination level of 300 lux, it takes less than 10 ms to reach a resistance which corresponds with a light level of 400 lux.

LDRs are sensitive, inexpensive, and readily available devices. They have good power and voltage handling capabilities, similar to those of a conventional resistor. Their only significant defect is that they are fairly low acting, taking tens or hundreds of milliseconds to respond to sudden changes in light level. Useful practical applications of LDRs include light and dark-activated switches and alarms, light beam alarms and reflective smoke alarms etc.

An overlight detector is shown in Fig. 22.4. The LDR is a variable resistor whose resistance decreases with the increase in light intensity. When the light falling on an LDR has normal intensity, its resistance is large enough and the voltage across R_1 is insufficient to trigger the SCR. However, when light falling on LDR is of large intensity, the resistance of LDR falls and voltage drop across R_1 becomes large enough to trigger the SCR. Consequently, the buzzer sounds the alarm. It may be noted that if the strong light disappears, the buzzer continues to sound the alarm. It is because once the SCR is fired, the gate loses all control.

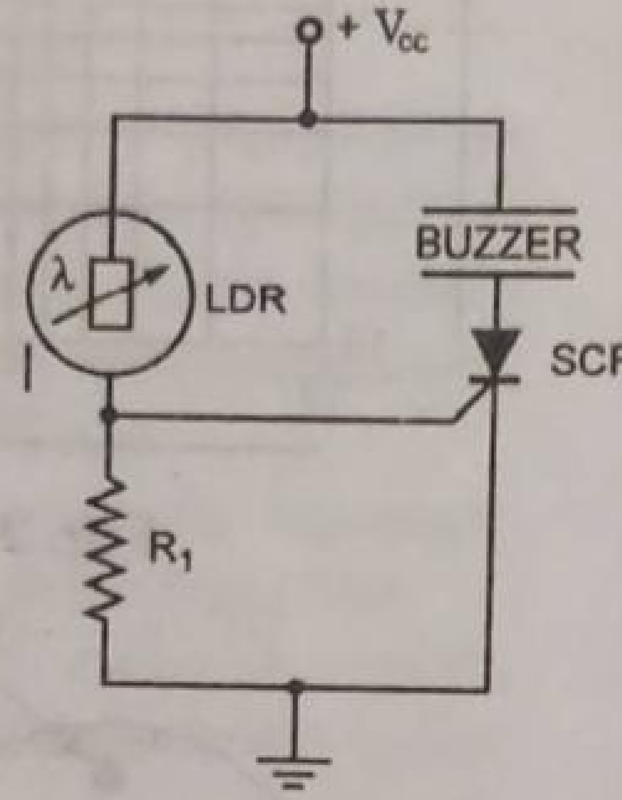


Fig. 22.4. *Overlight Detector*

22.3. PHOTODIODE

Photodiode is a two-terminal semiconductor P-N junction device and is designed to operate with reverse bias. The basic biasing arrangement, construction and symbols for the device are given in Fig. 22.5. It is either mounted in translucent case or has its semiconductor junction mounted beneath an optical lens.

The output voltage is taken from across a series-connected load resistor R. This resistance may be connected between the diode and ground or between the diode and the positive terminal of the supply, as illustrated in Fig. 22.5.

When the P-N junction is reverse-biased, a reverse saturation current flows due to thermally generated holes and electrons being swept across the junction as the minority carriers. With the increase in temperature of the junction more and more hole-electron pairs are

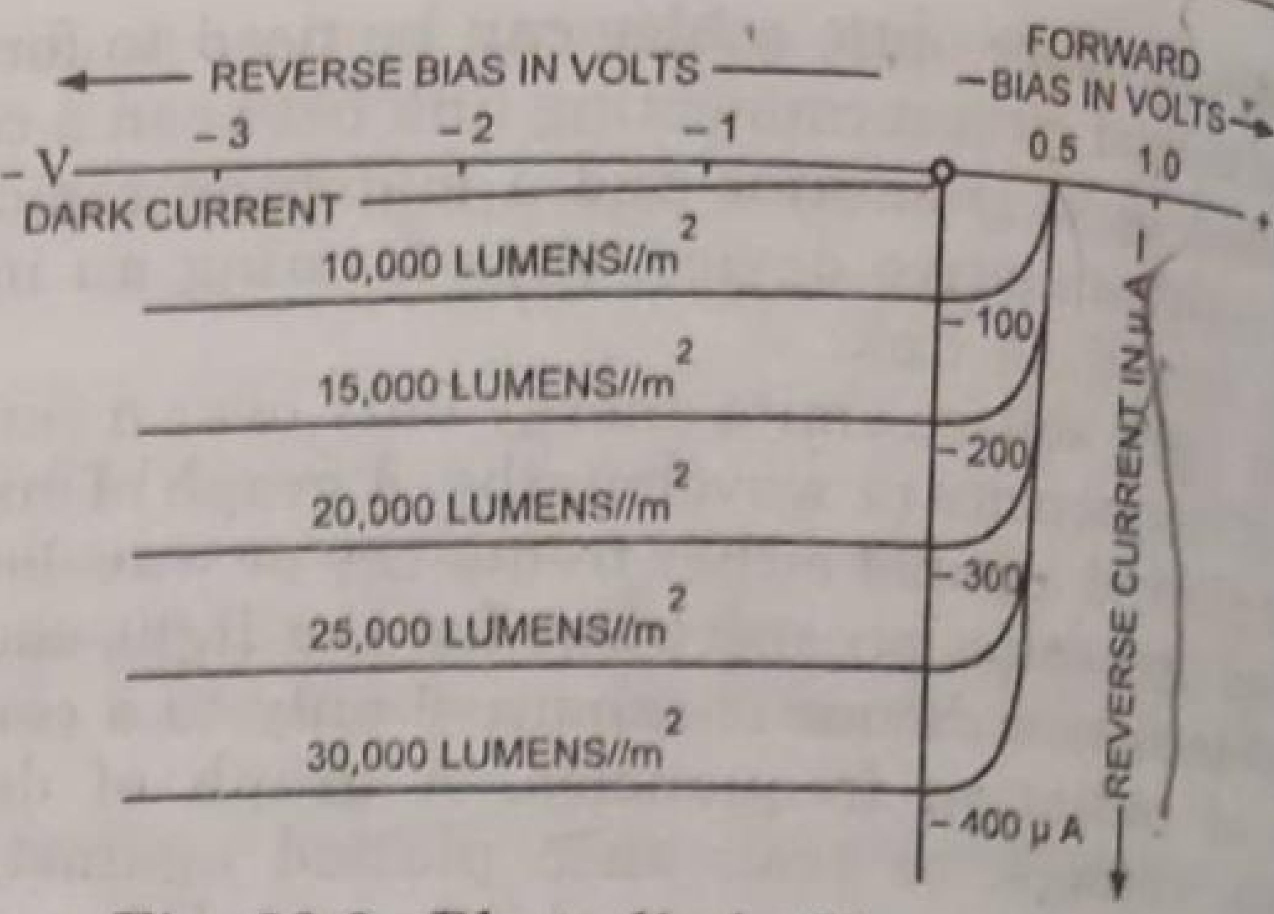


Fig. 22.6. *Photodiode Characteristics*

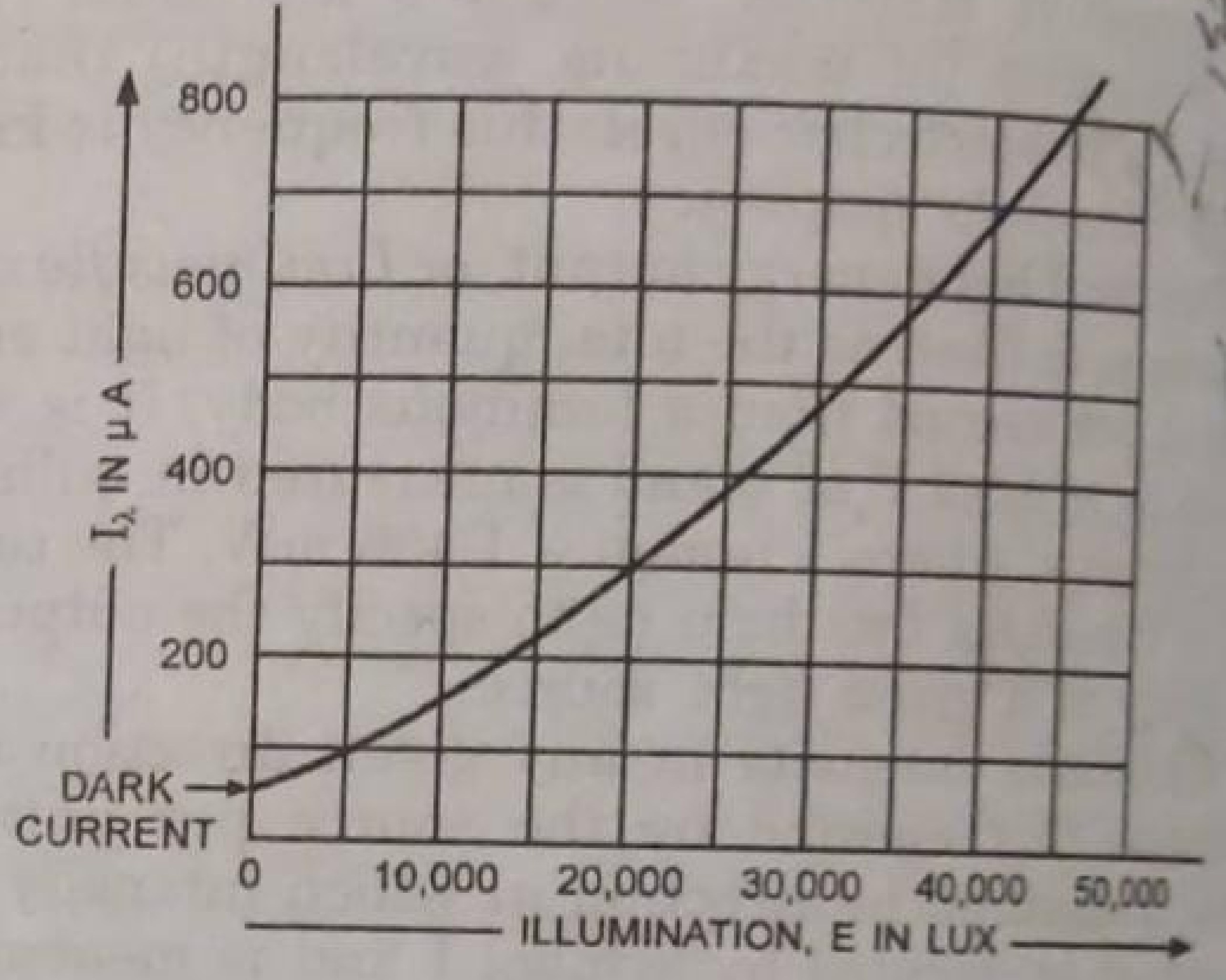
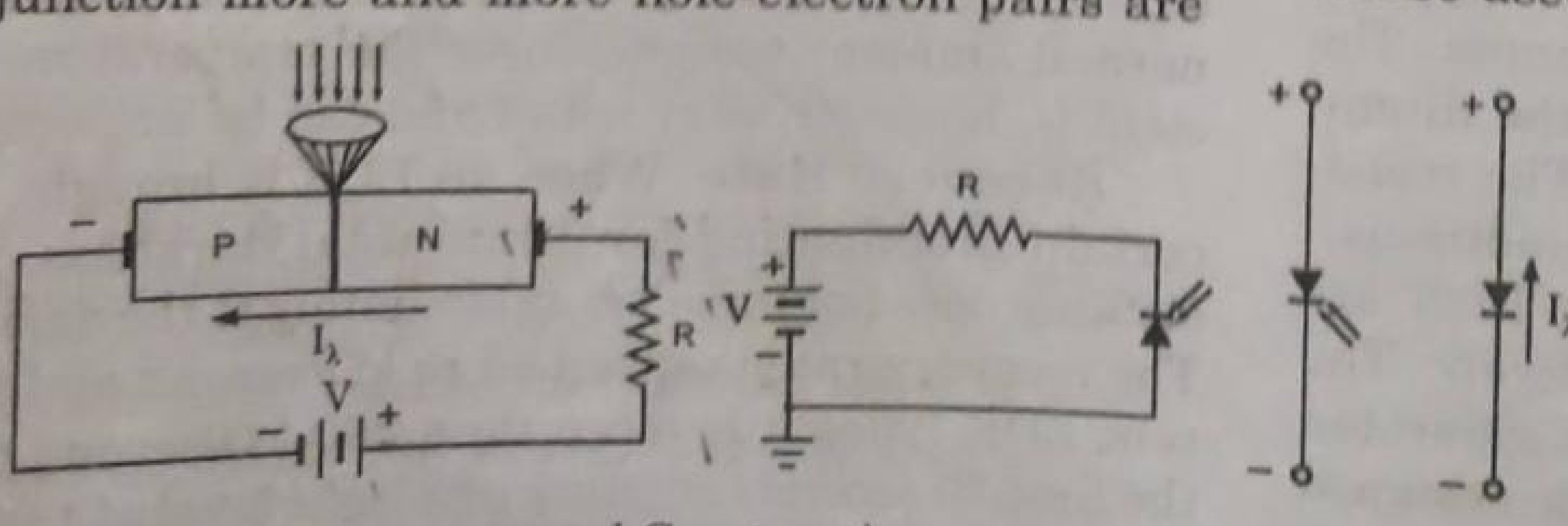


Fig. 22.7

created and so the reverse saturation current I_0 increases. The same effect can be had by illuminating the junction. When light energy bombards a P-N junction, it dislodges valence electrons. The more light striking the junction the larger the reverse current in a diode. It is due to generation of more and more charge carriers with the increase in level of illumination. This is clearly shown in Fig. 22.6 for different intensity levels. The *dark current* is the current that exists when no light is incident. It is to be noted here that current becomes zero only with a positive applied bias equals to V_0. The almost equal spacing between the curves for the same increment in luminous flux reveals that the reverse saturation current I_0 increases linearly with the luminous flux as shown in Fig. 22.7. Increase in reverse voltage does not increase the reverse current significantly, because all available charge carriers are already being swept across the junction. For reducing the reverse saturation current I_0 to zero, it is necessary to forward bias the junction by an amount equal to barrier potential. Thus the photodiode can be used as a *photoconductive device*.

On removal of reverse bias applied across the photodiode, minority charge carriers continue to be swept across the junction while the diode is illuminated. This has the effect of increasing the concentration of holes in the P-side and that of electrons in the N-side. But the barrier potential is negative on the P-side and positive on the N-side, and was created by holes flowing from P to N-side and electrons from N to P-side during fabrication of



(a) Basic Biasing Arrangement and Construction *(b) Symbols*

Fig. 22.5. *Photodiode*

junction. Thus the flow of minority carriers tends to reduce the barrier potential.

When an external circuit is connected across the diode terminals, the minority carriers return to the original side via the external circuit. The electrons which crossed the junction from P to N-side now flow out through the N-terminal and into the P-terminal. This means that the device is behaving as a voltage cell with the N-side being the negative terminal and the P-side the positive terminal. Thus, the photodiode is a *photovoltaic* device as well as *photoconductive* device. When the device is operated with a reverse bias, it operates as a photoconductive device and when operated without the reverse bias, it operates as a photovoltaic device.

Since the rise and fall times (change-of-state parameters) are very small for this device (in the nanosecond range), it can be employed for high-speed counting or switching applications.

Photodiodes have a far lower light sensitivity than cadmium sulphide LDRs, but give a fair quicker response in light level. Generally LDRs are ideal for use in slow acting direct coupled light-level sensing applications, while photodiodes are ideal for use in fast acting ac coupled signalling applications. Typical photodiode applications include detection (both visible and invisible), demodulation, switching, logic circuits that need stability and high speed, character recognition, optical communication equipment, IR remote control circuits, encoders etc.

An alarm system using a photodiode is shown in Fig. 22.8. The reverse current I_λ will continue to flow as long as the light beam is not interrupted. When the light beam gets interrupted, I_λ falls to the dark current level and sounds the alarm.

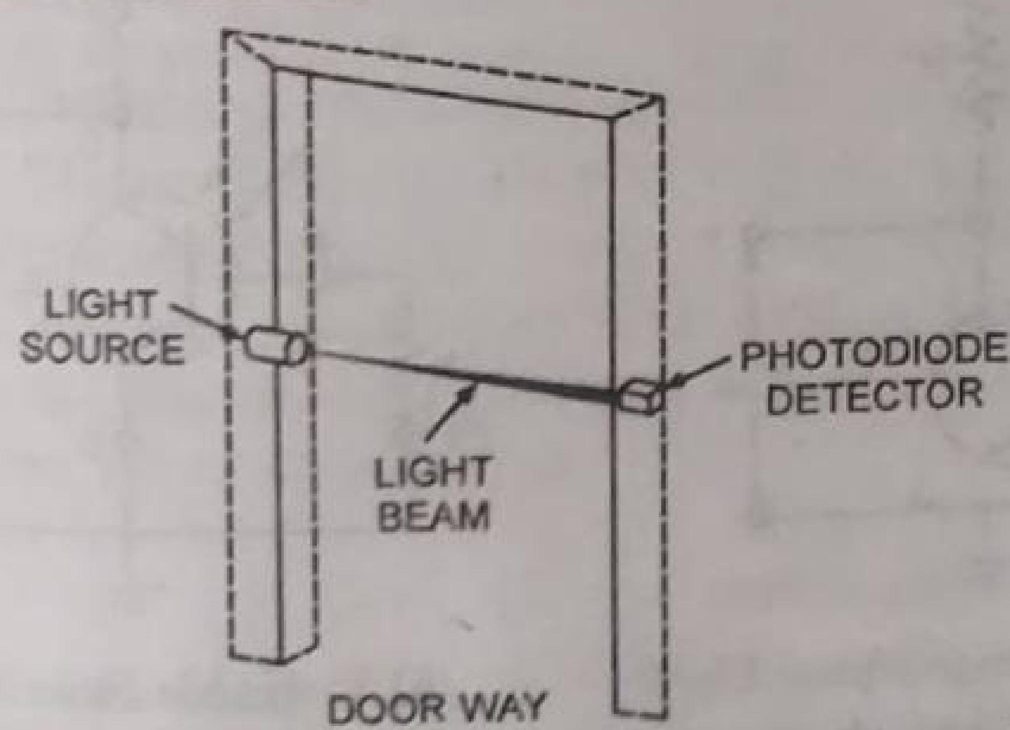


Fig. 22.8. ***Alarm System Using a Photodiode***

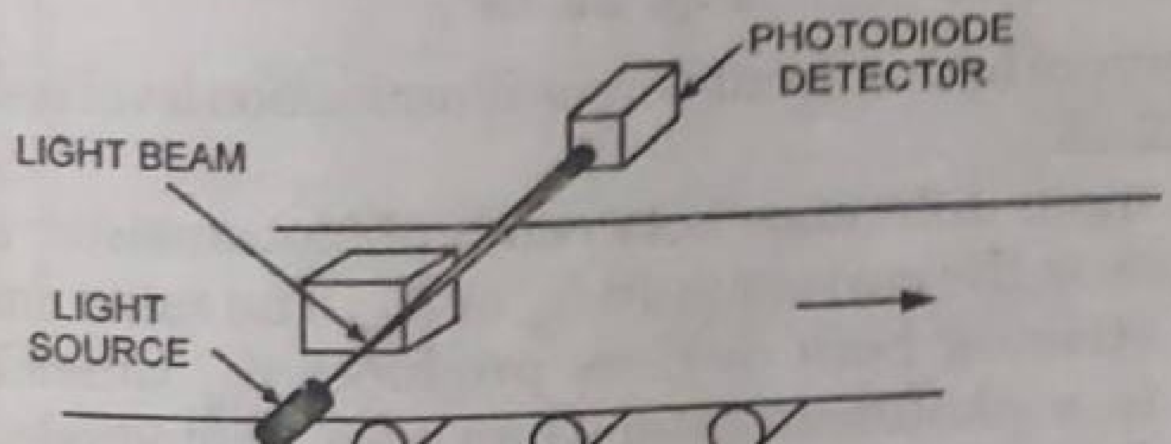
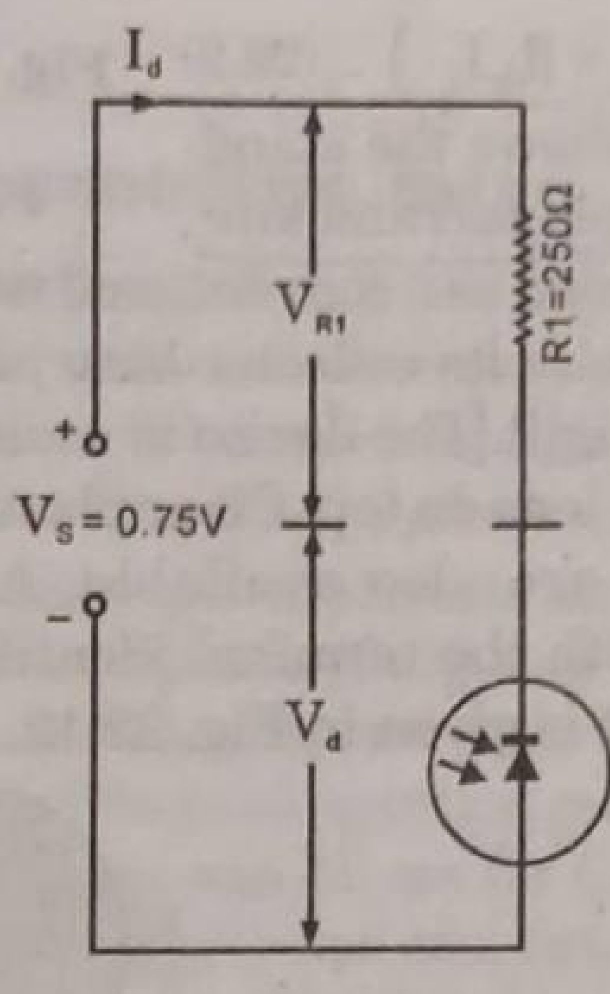


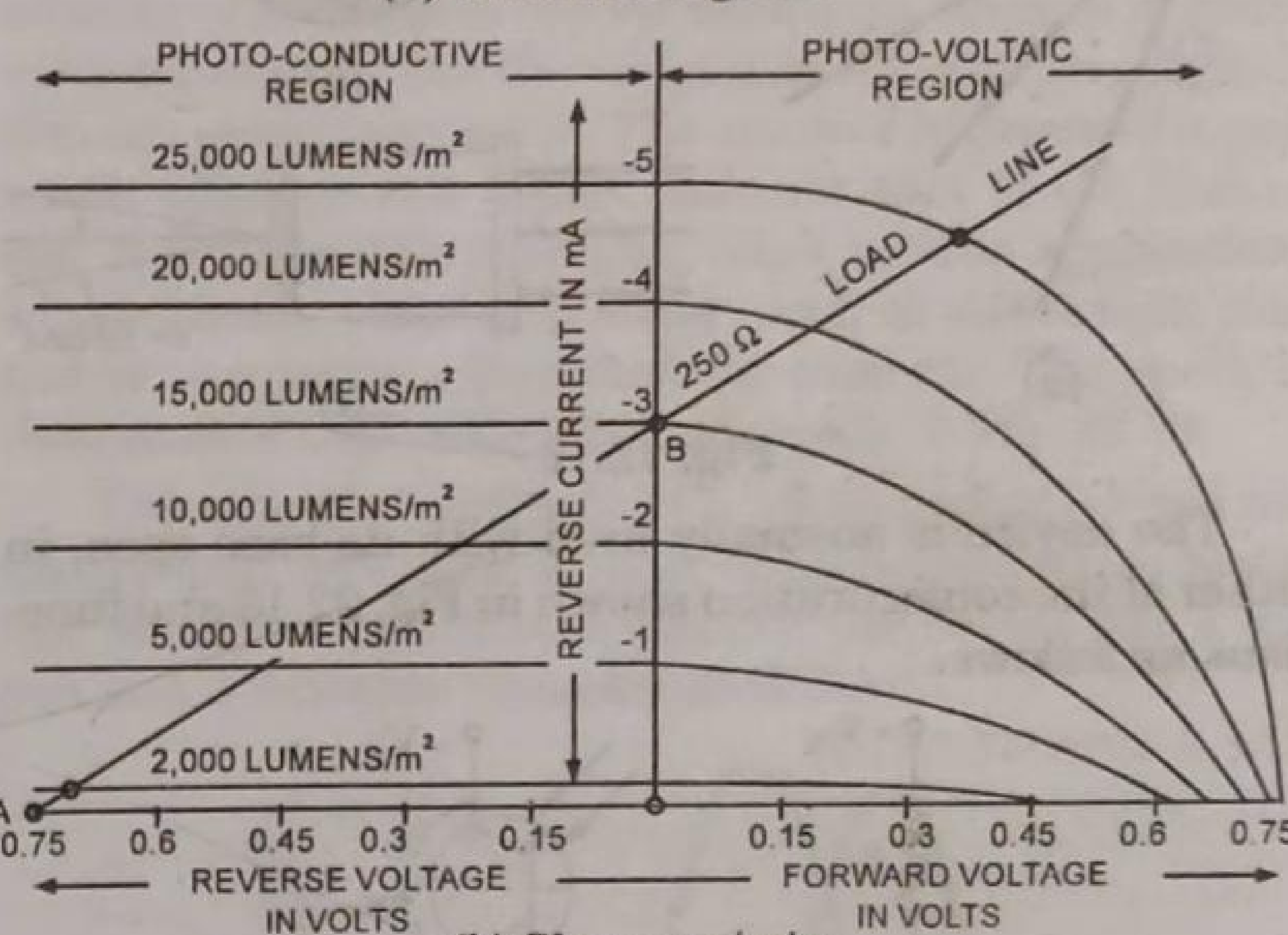
Fig. 22.9. ***Counter Operation Using a Photodiode***

In Fig. 22.9 a photodiode is used to count items on a conveyor belt. As each item passes the light beam is interrupted, I_λ falls to the dark current level and the counter is increased by one count.

Example 22.1. A photodiode is connected in a circuit shown in Fig. 22.10 (*a*). The supply polarity reverse-biases the device. The characteristics of the photodiode are shown in Fig. 22.10 (*b*). Draw the 250 Ω dc load line for the circuit and determine the diode currents and voltages at 2,000 and 25,000 lumens/m² illumination.



(a) Circuit Diagram



(b) Characteristics

Fig. 22.10

Solution: When diode current, $I_d = 0$

Voltage across resistance R_1 (250 Ω) $= V_{R1} = I_d R_1 = 0$

and diode voltage, $V_d = V_S$,

Supply voltage $= -0.75$ V

When diode voltage, $V_d = 0$

Voltage across 250 Ω resistance, $V_{R1} = V_S = -0.75$ V

and diode current, $I_d = \dfrac{V_{R1}}{R_1} = \dfrac{-0.75}{250} = -3.0$ mA

The two points ($V_d = -0.75$ V, $I_d = 0$) and ($V_d = 0$, $I_d = -3.0$ mA) are plotted as points A and B respectively. The straight line joining points A and B is 250 Ω load line. **Ans.**

From the load line we get,

At 2,000 lumens/m² : $I_d = -0.25$ mA; $V_d = -0.69$ V **Ans.**

At 25,000 lumens/m² : $I_d = -4.6$ mA; $V_d = 0.35$ V **Ans.**

It is to be noted that the polarity of the diode, voltage V_d, changes from – ve to + ve at the highest level of illumination.

22.4. PHOTOTRANSISTOR

A phototransistor is similar to an ordinary BJT, except that no base terminal is provided. Instead of a base current, the input to the transistor is in the form of light.