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CHAPTER 53

OPTO-ELECTRONIC DEVICES

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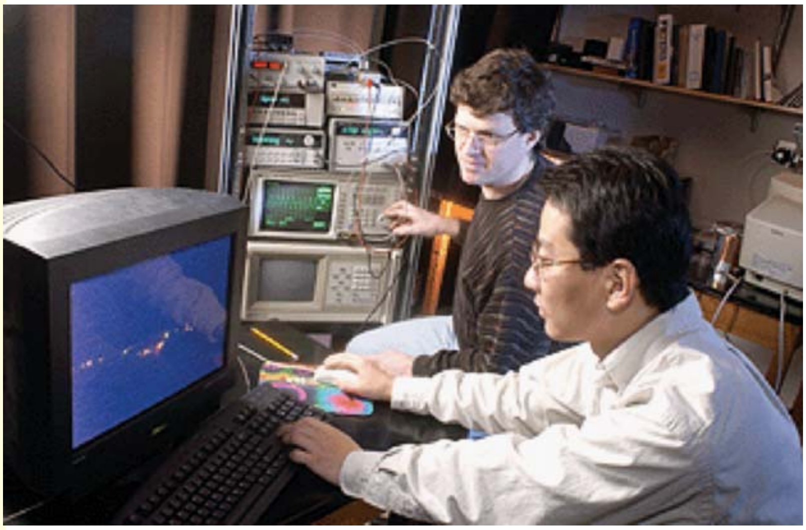

Researchers have demonstrated a new type of nanometer scale optoelectronic device that performs addition and other complex logic operations

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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, $$E = hf = hc/\lambda \quad \text{or} \quad \lambda = hc/E \text{ metres}$$

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

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

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

or $$\lambda = 1.242 \ \mu\text{m}$$

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 $\lambda = 1.242/E_g = 1.242/1.1 = 1.13$ µm.

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 re-combination takes place when electrons from the N-side cross the junction and recombine with the holes on the P-side.

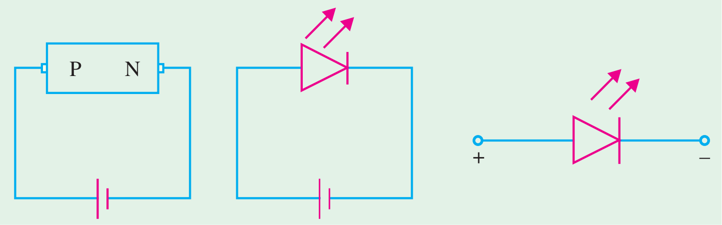
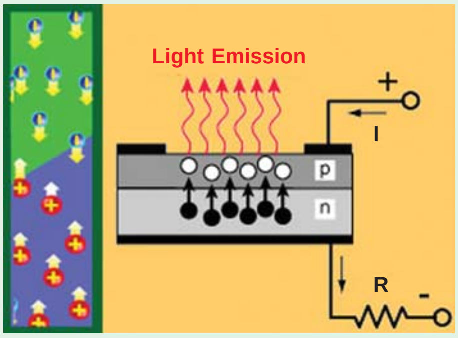
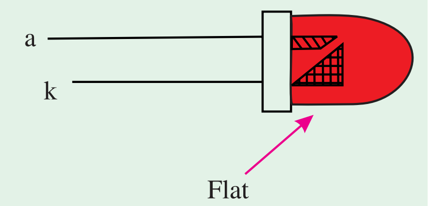


Fig. 53.1

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.



Light emitting diode



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.

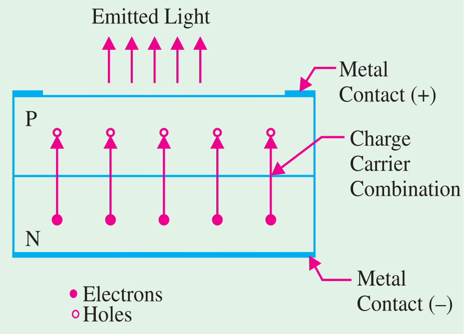


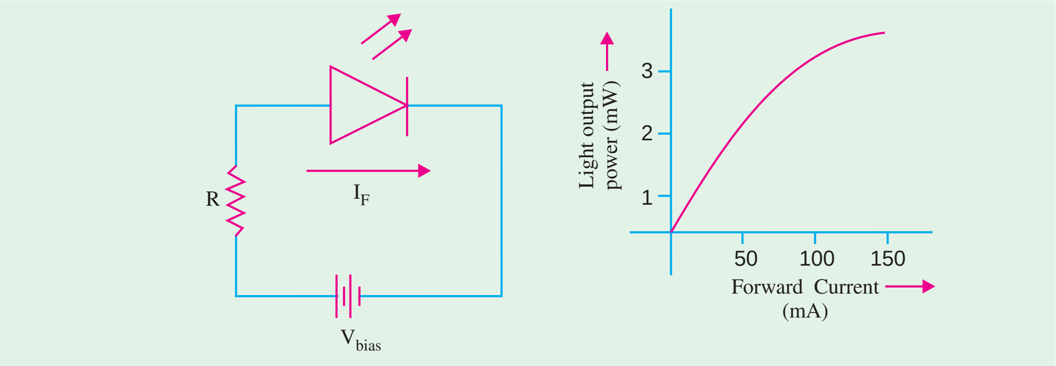
Fig. 53.2

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.



(*a*) (*b*)

Fig. 53.3

(*d*) Applications

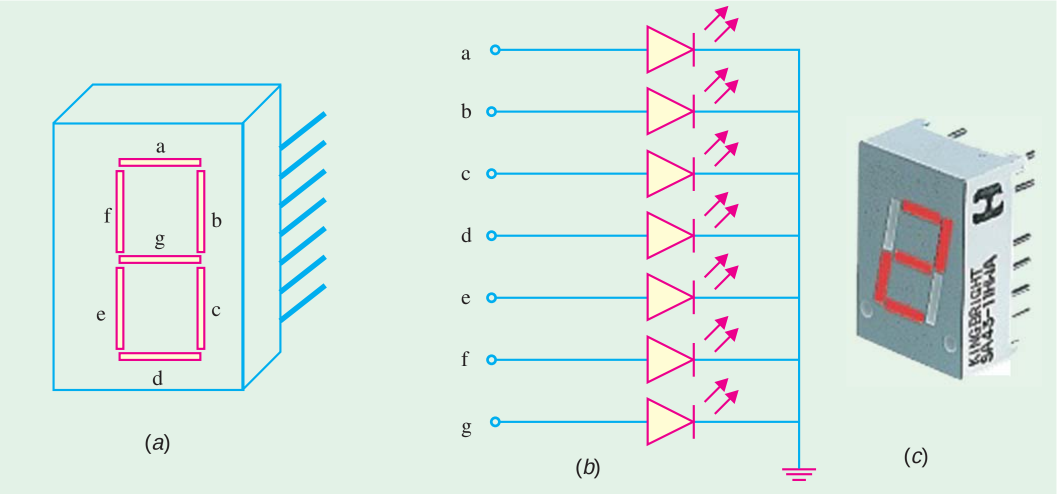
To chose emitting diodes for a particular application, one or more of the following points have to be considered : wavelength of light emitted, input power required, output power, efficiency, turn-on and turn-off time, mounting arrangement, light intensity and brightness etc.

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 :

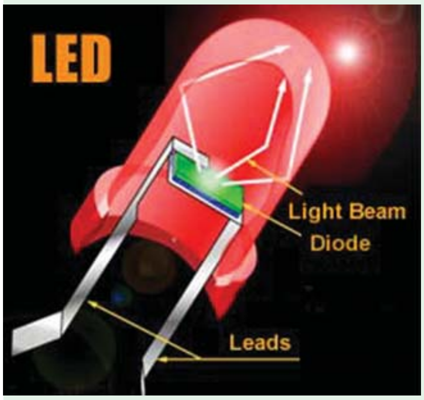
1. LEDs are used in burglar-alarm systems;
2. for solid-state video displays which are rapidly replacing cathode-ray tubes (CRT);
3. in image sensing circuits used for 'picturephone';
4. in the field of optical fibre communication systems where high-radiance GaAs diodes are matched into the silica-fibre 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 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.



(*a*) (*b*) (*c*)

Fig. 53.4



LED

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.

(*e*) 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.

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.

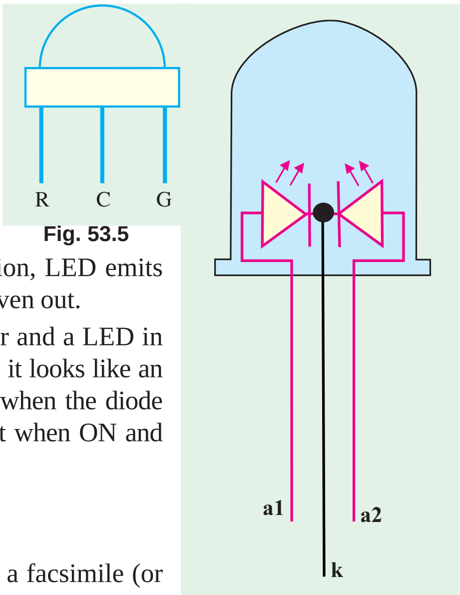


Fig. 53.5

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.

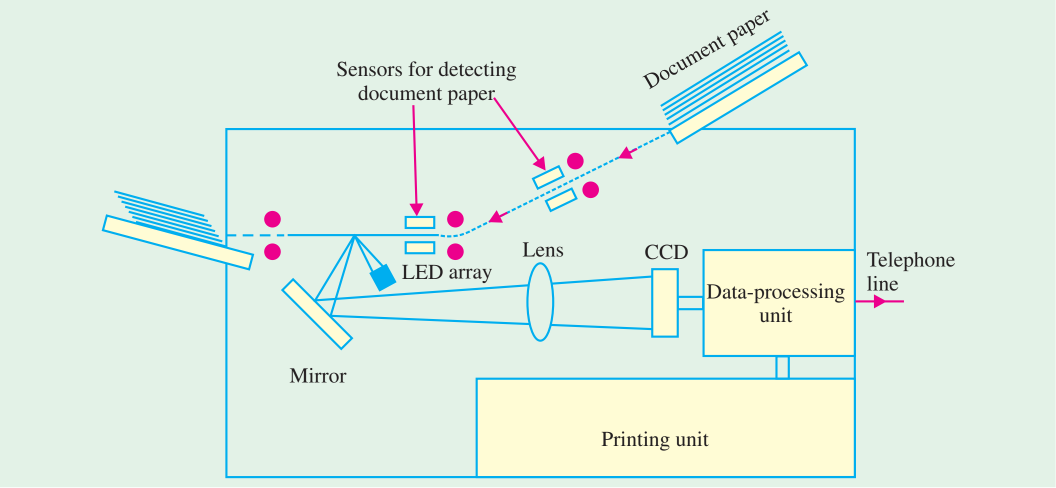
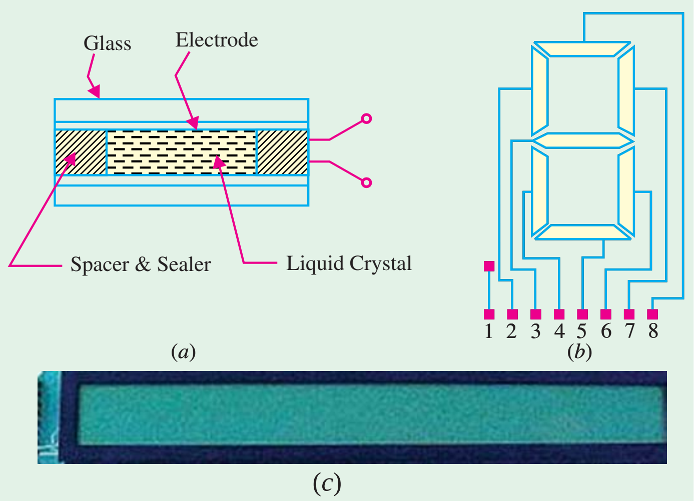


Fig. 53.6

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,



(*a*) (*b*)

(*c*)

Fig. 53.7

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.

(*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 V*x* 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.

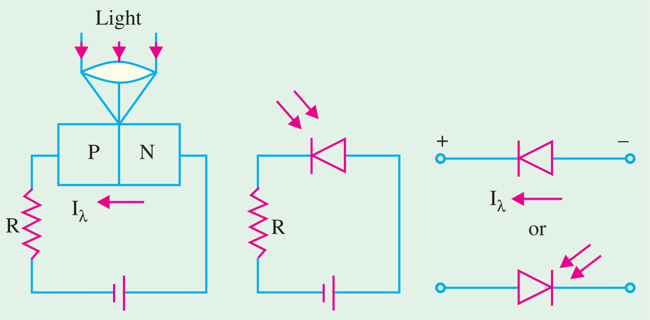
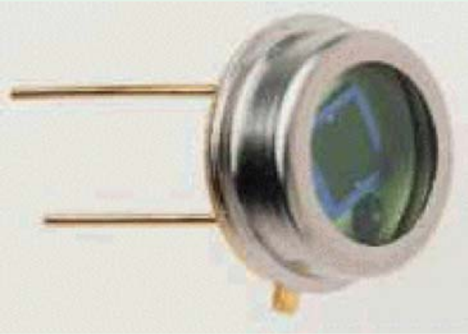


Fig. 53.8



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.

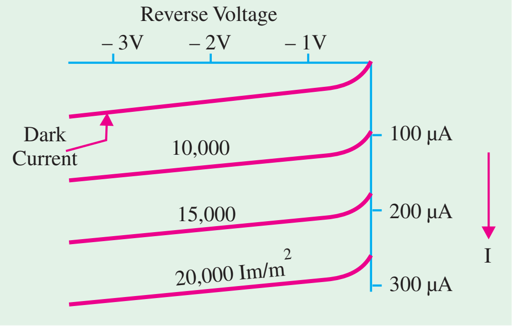


Fig. 53.9

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

1. detection, both visible and invisible ;
2. demodulation ;
3. switching ;
4. logic circuit that require stability and high speed ;
5. character recognition ;
6. optical communication equipment ;
7. encoders etc.

53.6. Dust Sensor

Fig. 53.10 shows a combination of an LED and a photodiode used as a dust sensor. As seen, the light emitted from the LED gets reflected by the dust particles. The reflected light is collected by the photodiode and is converted into an electrical signal. The dust sensor is employed in cleaners.

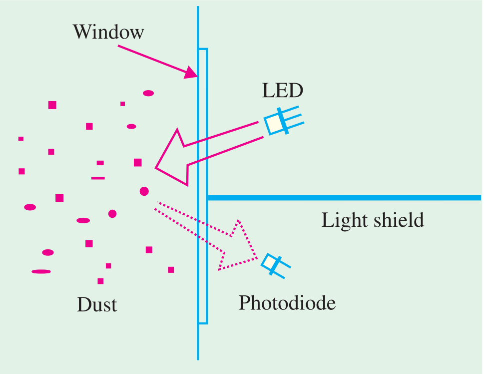
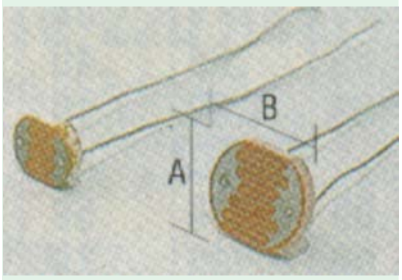


Fig. 53.10

The combination of an LED and a photodiode is also used as : **(1)** a paper sensor in facsimile machines, **(2)** as a tape-end sensor in videotape recorders/players, and **(3)** as a dirt detector for rinsing in washing machines.



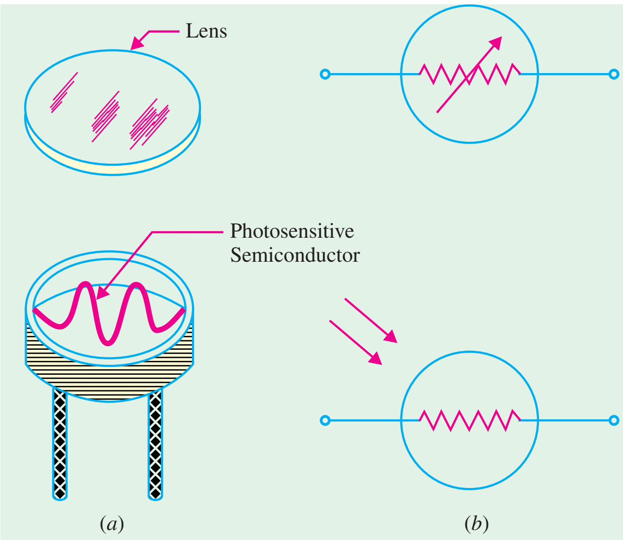
CdS photo sensitive detectors

53.7. Photoconductive Cell

It is a semiconductor device whose resistance varies inversely with the intensity of light that falls upon it. It is also known as ***photoresistive*** cell or ***photoresistor*** because it operates on the principle of photoresistivity.

(*a*) Theory

The resistivity (and, hence, resistance) of a semiconductor depends on the number of free charge carriers available in it. When the semiconductor is not illuminated, the number of charge carriers is small and, hence, resistivity is high. But when light in the form of photons strikes the semiconductor, each photon delivers energy to it. If the photon energy is greater than the energy band gap of the semiconductor, free mobile charge carriers are liberated and, as a result, resistivity of the semiconductor is decreased.



(*a*) (*b*)

Fig. 53.11

(*b*) Construction and Working

Photoconductive cells are generally made of cadmium compounds such as cadmium sulphide (CdS) and cadmium selenide (CdSe). Spectral response of CdS cell is similar to the human eye, hence such cells are often used to simulate the human eye. That is why they find use in light metering circuits in photographic cameras.

The construction of a typical photo conductive cell and its two alternative circuit symbols are shown in Fig. 53.11 (*a*) and (*b*) respectively. As seen, a thin layer of photosensitive semiconductor material is deposited in the form of a long strip zig-zagged across a disc-shaped ceramic base with protective sides. For added protection, a glass lens or plastic cover is used. The two ends of the strip are brought out to connecting pins below the base.

The terminal characteristic of a photoconductive cell is shown in Fig. 53.12. It depicts how the resistance of the cell varies with light intensity. Typically, the dark resistance of the cell is 1 MΩ or larger. Under illumination, the cell resistance drops to a value between 1 and 100 kΩ depending on surface illumination.

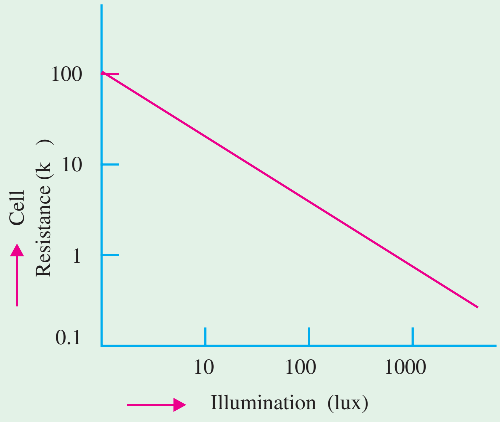


Fig. 53.12

(*c*) Applications

A photoconductive cell is an inexpensive and simple detector which is widely used in OFF/ON circuits, light-measurement and light-detecting circuits.

Example 53.1. *A relay is controlled by a photoconductive cell which has resistance of 100 kΩ when illuminated and 1 kΩ when in the dark. The relay is supplied with 10 mA from a 30-V supply when cell is illuminated and is required to be de-energized when the cell is in the dark. Sketch a suitable circuit and calculate the required series resistance and value of dark current.*

(Optoelectronic Devices, Gujarat Univ. 1993)

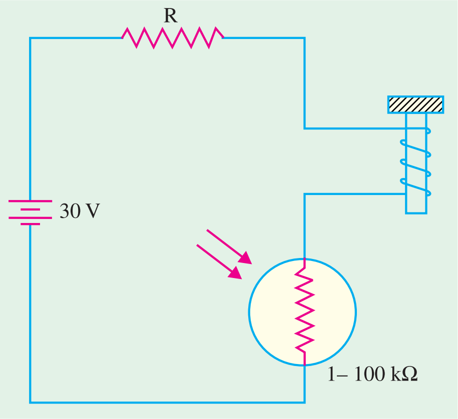


Fig. 53.13

Solution. The circuit is as shown in Fig. 30.13 where *R* is a current-limiting resistor.

$$I = 30/(R + r)$$

—where *r* is cell resistance

$$\therefore \quad R = (30/I) - r$$

When illuminated

$$R = (30/10 \times 10^{-3}) - 1 \times 10^3 = 2 \times 10^3 = \mathbf{2\ k\Omega}$$

Dark current is given by

$$I_d = 30/(2 + 100) \times 10^3 = 0.3 \times 10^{-3}\ \text{A} = \mathbf{0.3\ mA}$$

53.8. Phototransistor

It is light-sensitive transistor and is similar to an ordinary bipolar junction transistor (BJT) except that it has no connection to the base terminal. Its operation is based on the photodiode that exists at the *CB* junction. Instead of the base current, the input to the transistor is provided in the form of light as shown in the schematic symbol of Fig. 53.14 (*a*).

Silicon NPNs are mostly used as photo transistors. The device is usually packed in a TO-type can with a lens on top although it is

Phototransistor

sometimes encapsulated in clear plastic. When there is no incident light on the *CB* junction, there is a small thermally-generated collector-to-emitter leakage current I_{CEO} which, in this case, is called dark current and is in the *nA* range.

When light is incident on the *CB* junction, a base current I_λ is produced which is directly proportional to the light intensity. Hence, collector current $I_C = \beta\, I_\lambda$

Typical collector characteristic curves of a phototransistor are shown in Fig. 53.14 (*b*). Each individual curve corresponds to a certain value of light intensity expressed in mW/cm^2. As seen, I_C increases with light intensity.

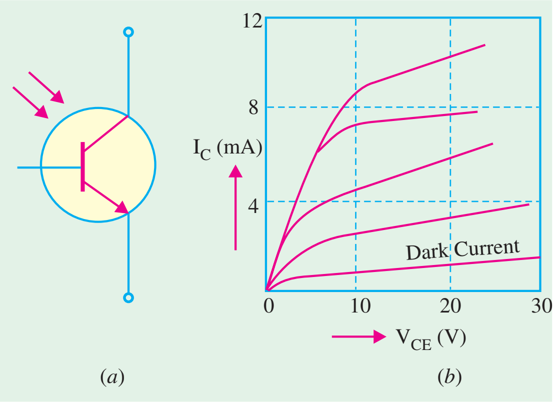


Fig. 53.14

The phototransistor has applications similar to those of a photodiode. Their main differences are in the current and response time. The photo-transistor has the advantages of greater sensitivity and current capacity than photodiodes. However, photodiodes are faster of the two, switching in less than a nanosecond.

53.9. Photodarlington

As shown in Fig. 53.15 a photodarlington consists of a phototransistor in a Darlington arrangement with a common transistor. It has a much greater sensitivity to incident radiant energy than a phototransistor because of higher current gain. However, its switching time of 50 μs is much longer than the phototransistor (2 μs) or the photodiode (1 ns). Its circuit symbol is shown in Fig. 53.15.

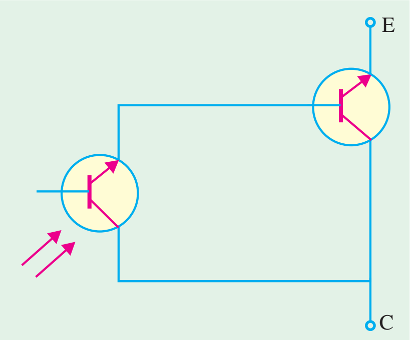


Fig. 53.15

Applications

Photodarlingtons are used in a variety of applications some of which are given below.

A light-operated relay is shown in Fig. 53.16 (*a*). The phototransistor T_1 drives the bipolar transistor T_2. When sufficient light falls on T_2, it is driven into saturation so that I_C is increased manifold. This collector current while passing through the relay coil energizes the relay.

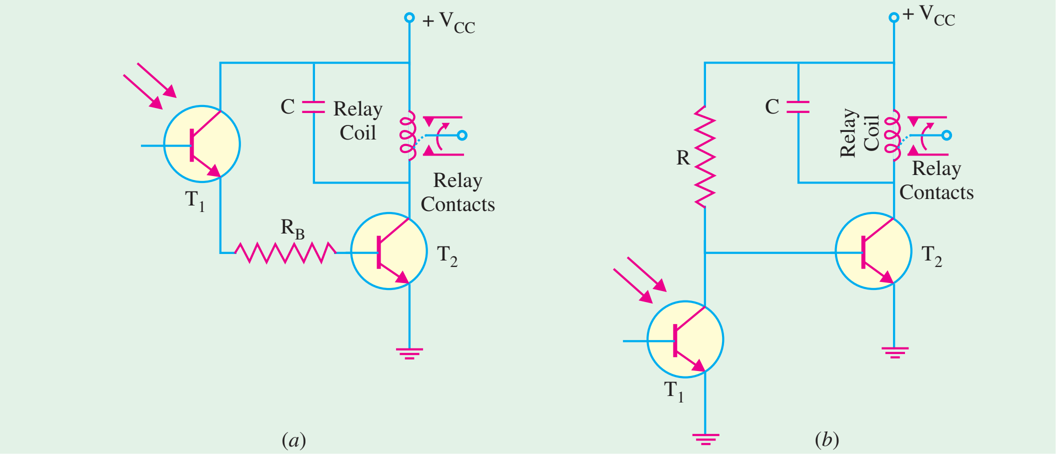


Fig. 53.16

Fig. 53.16 (*b*) shows a dark-operated relay circuit *i.e.* one in which relay is deenergized when light falls on the phototransistor. Here, T_1 and R form a potential divider across V_{CC}. With insufficient light incident on T_1, transistor T_2 is biased ON thereby keeping the relay energized. However, when there is sufficient light, T_1 turns ON and pulls the base of T_2 low thereby turning T_2 OFF and hence, deenergizing the relay.

Such relays are used in many applications such as ***(i)*** automatic door activators, ***(ii)*** process counters and ***(iii)*** various alarm systems for smoke or intrusion detection.

53.10. Photo voltaic or Solar Cell

Such cells operate on the principle of photovoltaic action *i.e.* conversion of light energy into electrical energy. This action occurs in all semiconductors which are constructed to absorb energy.

(*a*) Construction

As shown in Fig. 53.17 (*a*), a basic solar cell consists of *P*-type and *N*-type semiconductor material (usually, silicon or selenium) forming a *P*-*N* junction. The bottom surface of the cell (which is always away from light) covered with a continuous conductive contact to which a wire lead is attached. The upper surface has a maximum area exposed to light with a small contact either along the edge or around the perimeter. The surface layer of *P*-type material is extremely thin (0.5 mm) so that light can penetrate to the junction.

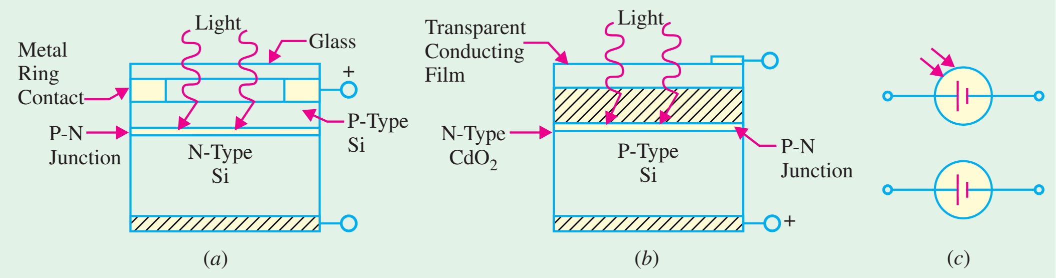
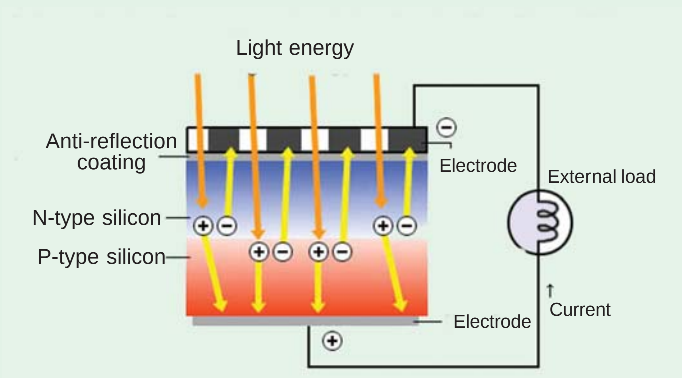


Fig. 53.17

Although silicon is commonly used for fabricating solar cells, another construction consists of *P*-type selenium covered with a layer of *N*-type cadmium oxide to form *P*-*N* junction as shown in Fig. 53.17 (*b*). Two alternative circuit symbols are shown in Fig. 53.17 (c). Power solar cells are also fabricated in flat strips to form efficient coverage of available surface area. Incidentally, the maximum efficiency of a solar cell in converting sunlight into electrical energy is nearly 15 per cent at the present.

(*b*) Theory



A photovoltaic cell generates electricity when irradiated by sunlight

When the *P*-*N* junction of a solar cell is illuminated, electron-hole pairs are generated in much the same way, as in photovoltaic cell. An electric field is established near the *P*-*N* junction by the positive and negative ions created due to the production of electron-hole pairs which leads to the development of potential across the junction. Since the number of electron-hole pairs far exceeds the number needed for thermal equilibrium, many of the electrons are pulled across the junction by the force of the electric field. Those that cross the junction contribute to the current in the cell and through the external load. The terminal voltage of the cell is directly proportional to the intensity of the incident light. The voltage may be as high as 0.6 V depending on the external load. Usually a large number of cells are arranged in an array in order to obtained higher voltages and currents as shown in Fig. 53.18.

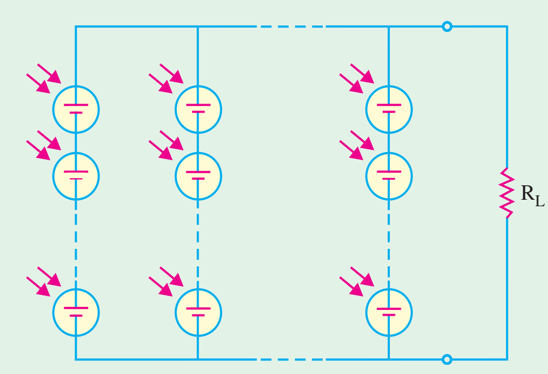


Fig. 53.18

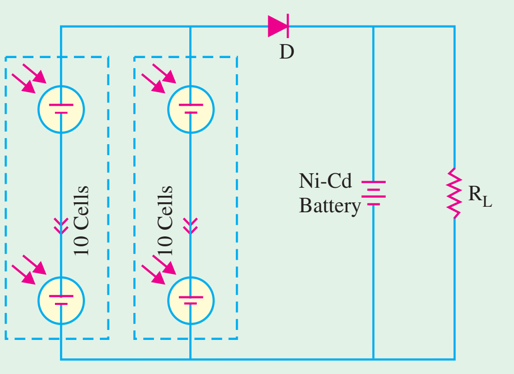


Fig. 53.19

Solar cells act like a battery when connected in series or parallel. Fig. 53.19 show two groups of 10 series cells connected in parallel with each other. If each cell provides 0.5 V at 150 mA, the overall value of the solar bank is 5 V at 150 mA. The two parallel solar banks provide 5 V at 300 mA. This solar power source supplies the load and also charges the Ni-Cd battery. The battery provides power in the absence of light. A blocking diode *D* is used to isolate the solar cells from the Ni-Cd battery otherwise in the absence of light, the battery will discharge through the cells thereby damaging them.

A solar cell operates with fair efficiency, has unlimited life, can be easily mass-produced and has a high power capacity per weight. It is because of these qualities that it has become an important source of power for earth satellites.

Example 53.2. *An earth satellite has on board 12-V battery which supplies a continuous current of 0.5 A. Solar cells are used to keep the battery charged. The solar cells are illuminated by the sun for 12 hours in every 24 hours. If during exposure, each cell gives 0.5 V at 50 mA, determine the number of cells required.* **(Optoelectronics Devices, Gujarat Univ. 1994)**

Solution. The solar cell battery-charging circuit is shown in Fig. 53.20. The cells must be connected in series to provide the necessary voltage and such groups must be connected in parallel to provide the necessary current. The charging voltage has to be greater than the battery voltage of 12 V. Allowing for different drops, let the solar bank voltage be 13.5 V.

Number of series connected solar cells = 13.5/0.5 = 27

The charge given out by batteries during a 24 hour period = 12 × 0.5 = 6 Ah. Hence, solar cells must supply this much charge over the same period. However, solar cells deliver current only when they illuminated *i.e.* for 12 hours in every 24 hours. Necessary charging current

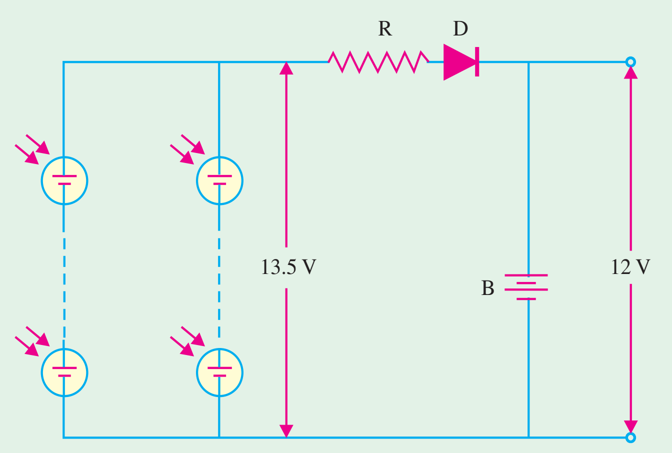


Fig. 53.20

required from the solar cells = 6 Ah/12 h = 0.5 A.

Total number of groups of solar cells required to be connected in parallel is

= output current / cell current = 0.5 / 50 × 10^3 = 10

∴ total number of solar cells required for the earth satellite = 27 × 10 = **270**

53.11. Laser Diode

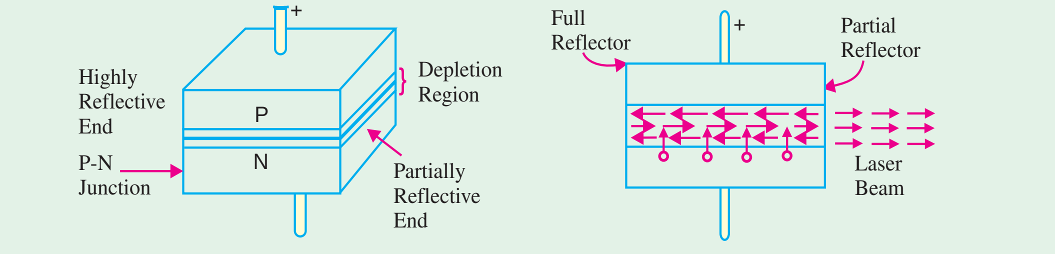
Like LEDs, laser diodes are typical *PN* junction devices used under a forward-bias. The word LASER is an acronym for ***Light Amplification*** by ***Stimulated Emission of Radiation.*** The use of laser is (becoming increasing common) in medical equipment used in surgery and in consumer products like compact disk (CD) players, laser printers, hologram scanners etc.

(*a*) Construction

Broadly speaking, the laser diode structure can be divided into two categories :

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

Fig. 53.21 (*a*) shows the structure of an edge-emitting laser diode. This type of structure is called Fabry-Perot type laser. As seen from the figure, a *P-N* junction is formed by two layers of doped gallium arsenide (GaAs). The length of the *PN* junction bears a precise relationship with the wavelength of the light to be emitted. As seen, there is a highly reflective surface at one end of the junction and a partially reflective surface at the other end. External leads provide the anode and cathode connections.

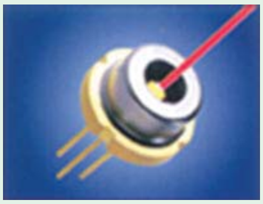


(*a*) (*b*)

Fig. 53.21

(*b*) Theory

When the *P-N* junction is forward-biased by an external voltage source, electrons move across the junction and usual recombination occurs in the depletion region which results in the production of photons. As forward current is increased, more photons are produced which drift at random in the depletion region. Some of these photons strike the reflective surface perpendicularly. These reflected photons enter the depletion region, strike other atoms and release more photons. All these photons move back and forth between the two reflective surfaces. [Fig. 53.21 (*b*)] The photon activity becomes so intense that at some point, a strong beam of laser light comes out of the partially reflective surface of the diode.



Laser diode

(*c*) Unique Characteristics of Laser Light

The beam of laser light produced by the diode has the following unique characteristics :

1. It is coherent *i.e.* there is no path difference between the waves comprising the beam;
2. It is monochromatic *i.e.* it consists of one wavelength and hence one colour only;

3. It is collimated *i.e.* emitted light waves travel parallel to each other.

Laser diodes have a threshold level of current above which the laser action occurs but below which the laser diode behaves like a LED emitting incoherent light. The schematic symbol of a laser diode is similar to that of LED. Incidentally, a filter or lens is necessary to view the laser beam.

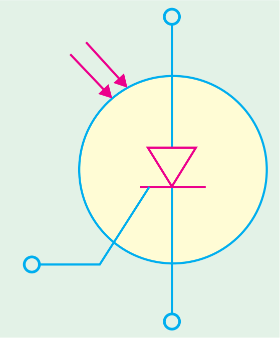


Fig. 53.22

(*d*) Applications

Laser diodes are used in variety of applications ranging from medical equipment used in surgery to consumer products like optical disk equipment, laser printers, hologram scanners etc. Laser diodes emitting visible light are used as pointers. Those emitting visible and infrared light are used to measure range (or distance). The laser diodes are also widely used in parallel processing of information and in parallel interconnections between computers. Some of these applications are discussed in the following articles.

53.12. Optical Disks

The major application field for laser diodes is in optical disk equipment. This equipment is used for reading or recording information and can be broadly divided into two groups :

1. Reading-only and **2.** Recording-and-reading type.

The optical disk equipment of either type make use of a laser diode, lenses and photodiodes. During recording, it changes electrical information into optical information and then records the information on the optical disk. During reading (or playback), the head optically reads the recorded information and changes the optical information into electrical information. Fig. 53.22 shows the different types of optical disks used in practice. The commercial systems make use of disks that are 90, 120, 130 and 300 mm in diameter. A mini disk, 64 mm in diameter is also used for digital audio.

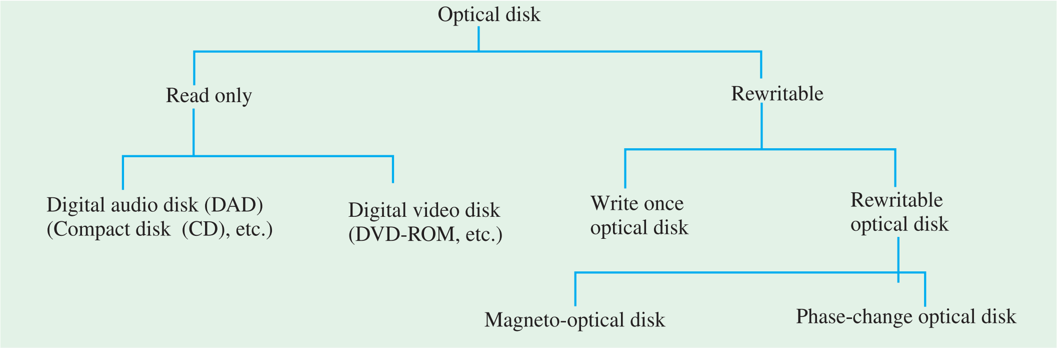


Fig. 53.23

The optical disks have several advantages over semiconductor memories. Some of these include their larger data storage capacity, shorter access time and smaller size. Therefore they are used in terminal equipment of computers as well as in audio visual equipment.

53.13. Read-only Optical Disks Equipment

Fig. 53.24 shows an optical equipment for reading data from digital audio (compact) disks. Compact disks (CDs) which are 120 mm in diameter are typical digital audio disks. Compact disks usually means digital audio compact disk, but it also includes the read-only memory (CD-ROM) for data memory and interactive compact disk (CD-I) for multimedia use.

Audio information (*i.e.* sound) is digitally recorded in stereo on the surface of a CD in the form of microscopic "pits" and "flats". As seen from Fig. 53.24, the light emitted from the laser diode passes through the lens and is focussed to a diameter of about 1 μm on the surface of a disk. As the CD rotates, the lens and beam follow the track under control of a servo motor. The laser light which is altered by the pits and flats along the recorded track is reflected back from the track through the lens and optical system to infrared photodiodes. The signal from the photodiodes is then used to reproduce the digitally recorded sound.

A CD-Rom

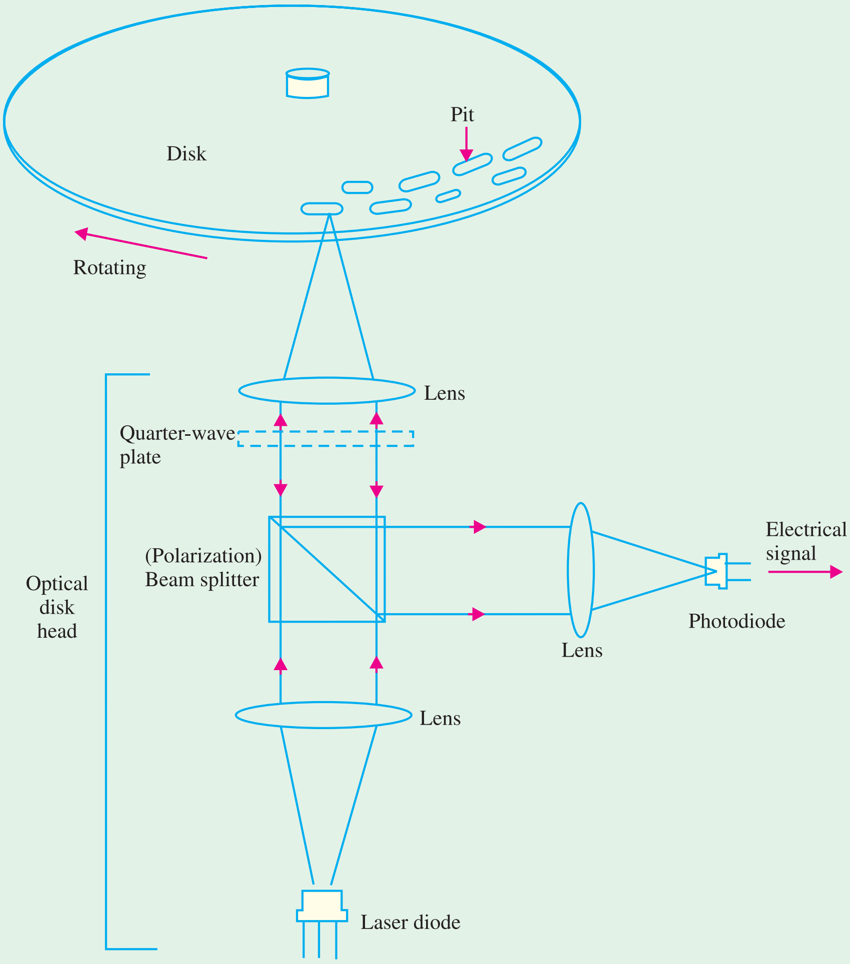


Fig. 53.24

53.14. Printers Using Laser Diodes

There are two types of optical sources usually used in printers ; **(1)** laser diodes and **(2)** LED arrays. The printers using laser diodes are called laser beam printers (or simply laser printers). These are one of the most attractive type of equipment in office automation in today's world. Words and figures can be printed rapidly and clearly more easily by a laser printer than by other types of printers.

(Courtesy optical semiconductor devices by M.Fukuda published by John Weliy & Sons Inc.)

Fig. 53.25 shows a simplified diagram of a laser printer. As seen the laser diode is driven by modulated signals from the computer. The optical beam after passing through the lens is reflected by the rotating polygon mirror and scanned on the photosensitive drum. The drum is homogeneously charged when it passes through the charging unit consisting of an LED array. The homogeneous electrification is partially erased in accordance with the scanned optical beam. This is because of the fact that the electrical resistance at the light-irradiated part decreases and the electric charge is released. This causes the signals (*i.e.* data) from the computer to be written on to the drum. At the developing unit, an electrically charged powder (called toner) is electrostatically attached to the written parts. At the transcribing unit, the powder is transferred to the paper. Next, the transferred pattern is fixed by heating and pressing at the fixing unit. The data from the computer is thus printed on the paper.

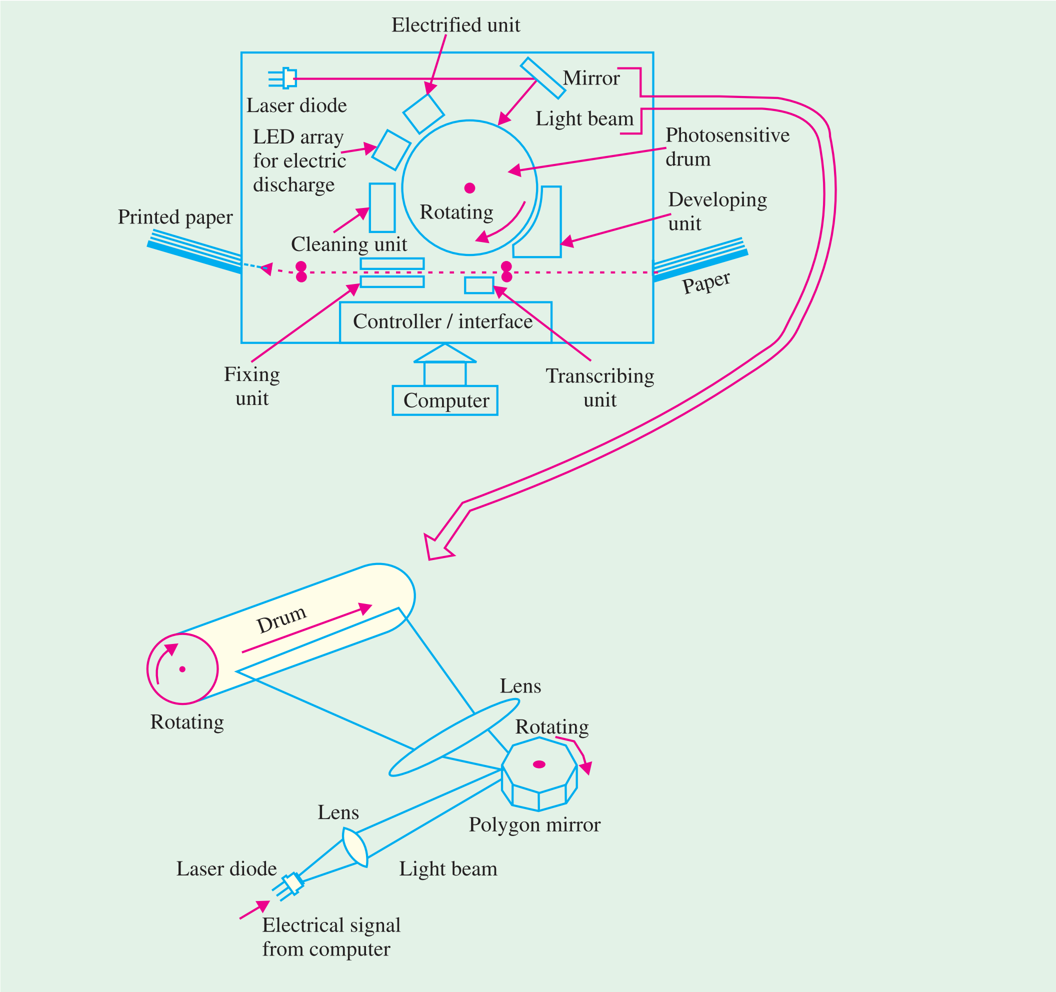


Fig. 53.25

53.15. Hologram Scanners

The hologram scanner is widely used in various equipment and is ordinarily used in bar-code readers in point-of-sale systems (such as super marked checkout counters). It is also used in laser printers for scanning the laser beam on the drum precisely.

Fig. 53.26 shows a simplified schematic of a hologram scanner. As seen, the optical beam for reading the bar-code is focussed by a lens through the hologram disk and scanned on the bar-code by rotating the hologram disk. Gratings with coaxial circles are formed on the hologram disk. This causes the incident laser beam to bend at the grating by an amount determined by the grating pitch. The reflected light modulated according to the bar-code is reflected by the mirror and monitored by the photodiode. The monitored optical signal is then translated into an electrical signal.

Hologram scanners

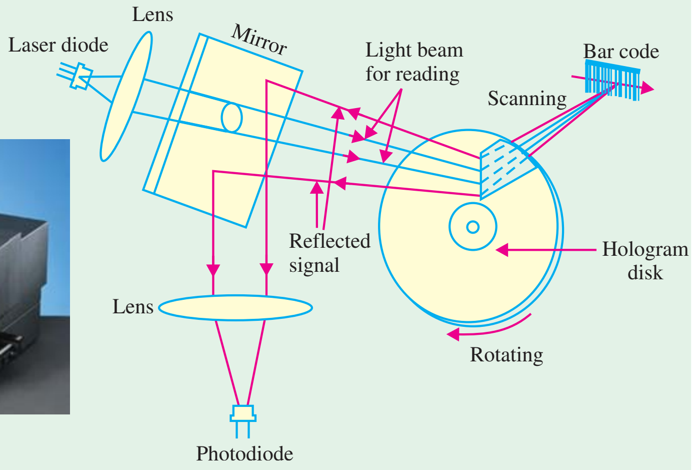


Fig. 53.26

53.16. Laser Range Finder

The laser diodes along with photodiodes can be used to measure the range (*i.e.* a distance) of an object. Fig. 53.27 shows a simple schematic of a laser range finder. As seen, the laser diode is modulated with high current pulses. The pulsed high-power beam is emitted in the direction of an object. The beam is reflected from the object. The reflected beam is detected with a photo detector (or photodiode). The range is calculated as the difference between the time the light was emitted from the laser diode and the time it was detected by the photodiode.

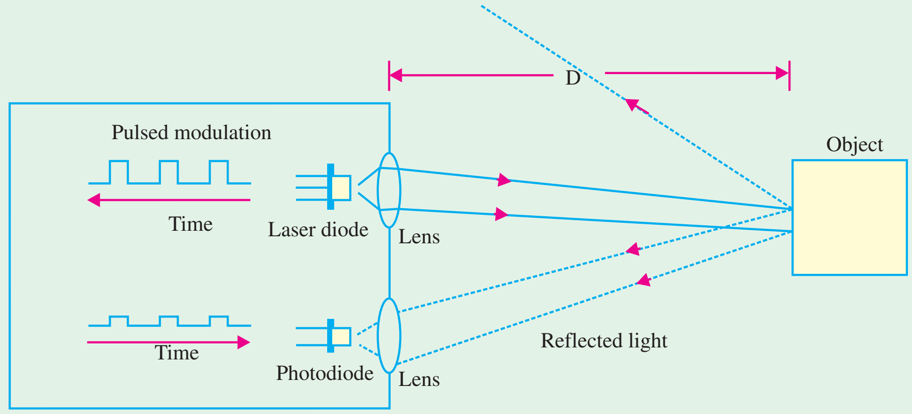


Fig. 53.27

Let D = distance between the laser range finder and the object.

ΔT = Time difference between the instance when the light was emitted from the laser diode and the instance when it was detected by the photo-diode

Then $D = \dfrac{1}{2} \times \text{speed of light} \times \Delta T$

A 2-dimensional array of laser diodes and photodetectors can be constructed. Such a system is used to obtain 3-D images of an object.

53.17. Light-activated SCR (LASCR)

The operation of a LASCR is essentially similar to that of a conventional SCR except that it is light-triggered (Fig.53.28). Moreover, it has a window and lens which focuses light on the gate junction area. The LASCR operates like a latch. It can be triggered ON by a light input on the gate area but does not turn OFF when light source is removed. It can be turned OFF only by reducing the current through it below its holding current. Depending on its size, a LASCR is capable of handling larger amount of current that can be handled by a photodiode or a photo-transistor.

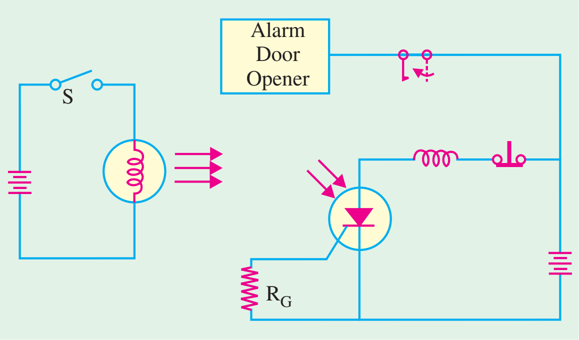


Fig. 53.28

Fig. 53.28 shows how a LASCR can be used for energizing a latching relay. The input dc source turns on the electric lamp and the resulting incident light triggers the LASCR into conduction. The anode current energizes the relay and closes the contact. It is seen that the input dc source is electrically isolated from the rest of the circuit.

53.18. Optical Isolators

Optical isolators are designed to electrically isolate one circuit from another while allowing one circuit to control the other. The usual purpose of isolation is to provide protection from high-voltage transients, surge voltages and low-level electrical noise that could possibly result in an erroneous output or damage to the device. Such isolators allow interfacing of circuits with different voltage levels and different grounds etc.

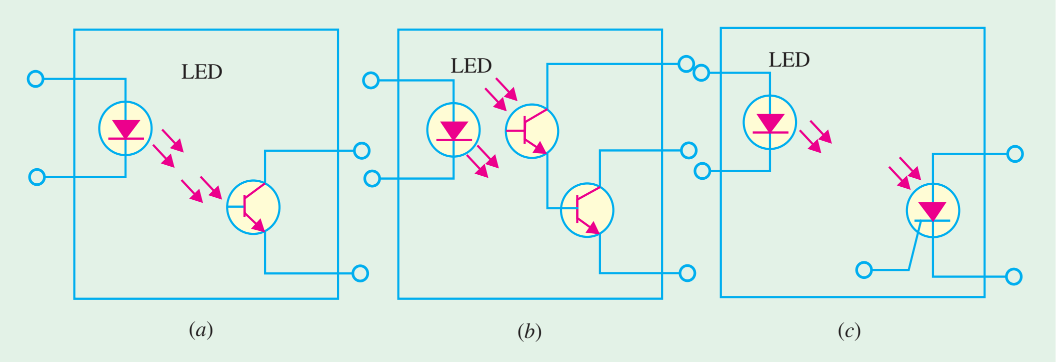


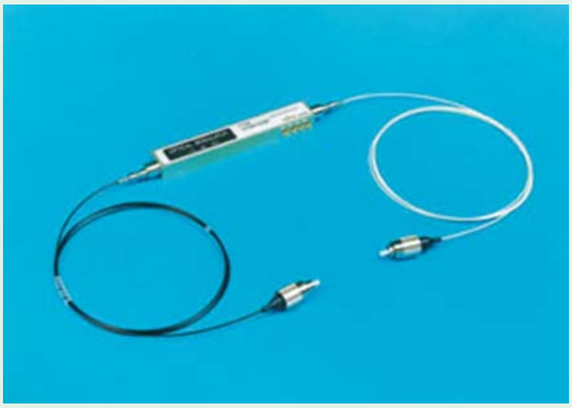
Fig. 53.29

An optical isolator (or coupler) consists of a light source such as LED and a photodetector such as a photo transistor as shown in Fig. 53. 29 (*a*) and is available in a standard *IC* package.

When LED is forward-biased, the light produced by it is transferred to the phototransistor which is turned ON thereby producing current through the external load.

Fig. 53.29 (*b*) shows a Darlington transistor coupler which is used when increased output current capability is needed beyond that provided by the phototransistor output. The LASCR output coupler of Fig. 53.29 (*c*) can be used in applications where a low-level input voltage is required to latch a high voltage relay for activating some kind of electro-mechanical device.

53.19. Optical Modulators



Optical modulator

Light emitting *PN* junction devices such as LEDs and laser diodes are easily modulated by superimposing signals on to the injected current. This is **direct modulation.** Laser diodes in high-bit rate and long-span optical communication systems are frequently used under direct modulation.

However direct modulation results in ***chirping*** which limits transmission quality because of ***dispersion*** in optical fibres. An optical modulator can modulate the light output from laser diodes with little or no chirping. There are two types of optical modulators :

1. The semiconductor optical modulators
2. Optical modulators composed of dielectric materials such as ***lithium nitrate*** ($LiNO_3$)

The semiconductor optical modulators are *PN* junction diodes and can further be subdivided into two types :

1. Devices used under forward bias (as LEDs and laser diodes are used). The optical modulation in these devices is carried out by changing gain or loss within the modulators.
2. Devices used under reverse bias (*i.e.*, as photodiodes are used). Most high-performance semiconductor optical modulators are used under reverse bias. The reverse bias is needed to generate strong electric field. Optical modulation is basically performed by modulating the ***refractive index or optical absorption coefficient*** of the modulators. The devices which make use of refractive index phenomenon for modulation are called phase modulation type devices while those that use optical absorption coefficient phenomenon are called intensity modulation type devices.

There are several different types of optical modulators available today. But the waveguide type optical modulator is more common in use. Further there are several different waveguide type optical modulator structures possible. Fig. 53.30 shows a mesa type optical modulator structure.

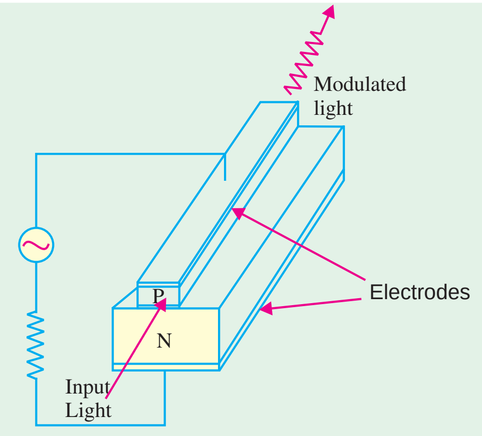


Fig. 53.30

It may be noted that although we have shown the structure making use of a simple *N*- and *P*-layer but in reality each layer (*N*-type or *P*-type) is made up of several different semiconductors.

53.20. Optical Fibre Communication Systems

The optical fibre communication systems (such as public communication networks and data links) are the basic infrastructure of the information hungry society. There are several advantages of the optical fibre system over metallic transmission systems as listed below :

1. Data can be transmitted at a very high-frequency over longer distances without much loss.
2. Electromagnetic induction (EMI) noise is never induced during transmission through optical fibre cables.
3. Optical fibre cable is light, flexible and economical.

Fig. 53.31 shows the public optical fibre communication system broadly divided into two groups: (1) Submarine systems, and (2) Land systems. Submarine systems have already been used to connect countries all over the world. The submarine systems help people to talk overseas without any time delay.

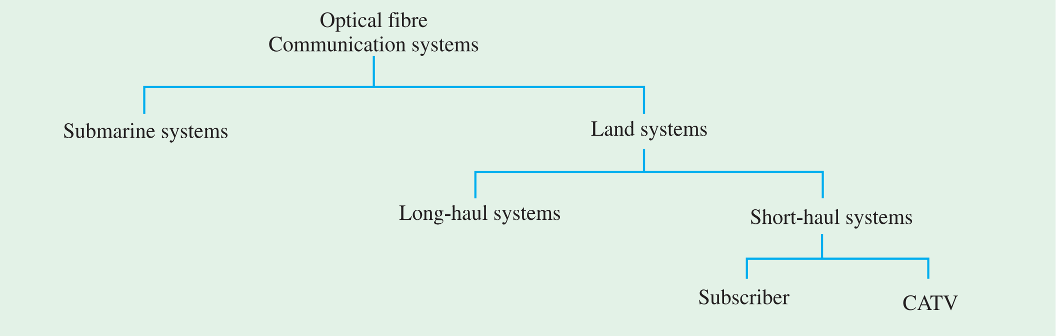


Fig. 53.31

In land systems, long-haul systems have been connected between large cities. The land systems also include systems such as subscriber systems and CATV (*i.e.* community or common antenna television, cable and telecommunication television system, or cable television system).

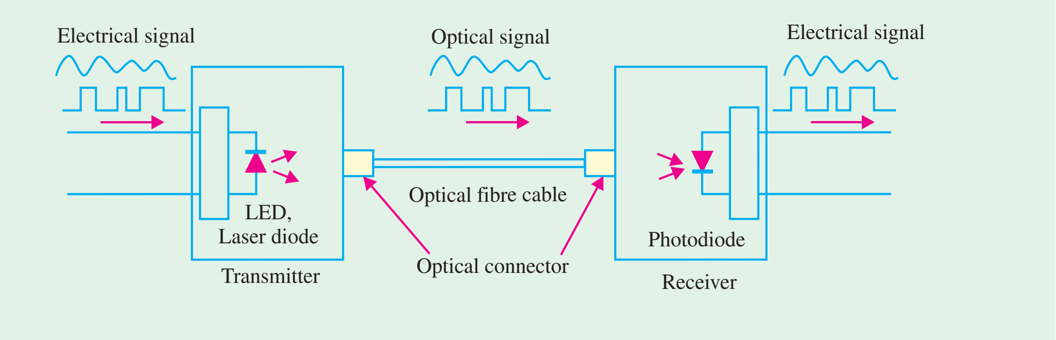


Fig. 53.32

Fig. 53.32 shows an application of LEDs, laser diodes and photodiodes in a simplified optical fibre communication systems. The LEDs and laser diodes emit light modulated with a signal. The optical signal is then transmitted through the optical fibre and is received with photodiodes on the destination side. In this type of a system LEDs or laser diodes emit the light directly through the optical fibre and therefore is referred to as direct modulation type systems. But in more recent systems, the **optical modulators** modulate the light emitted from the laser diodes and then the modulated light is transmitted through the optical fibre [refer to Fig. 53.33].

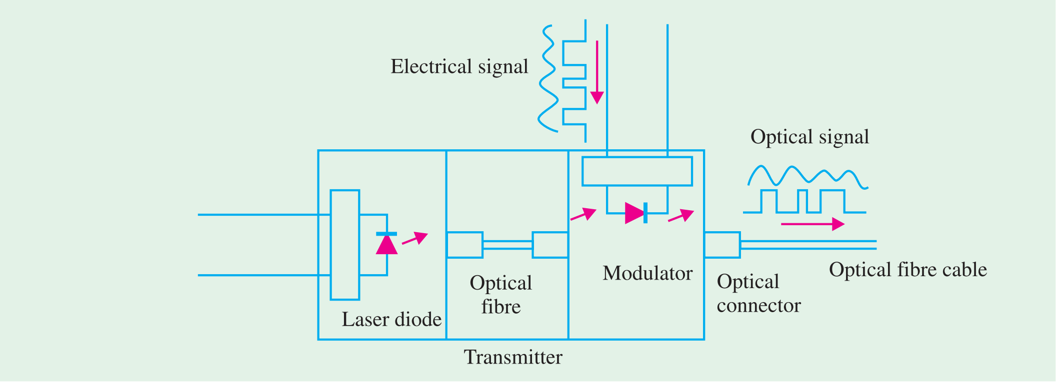


Fig. 53.33

In long-haul systems, **repeaters** (which include photodiodes and laser diodes and electronic circuits) are inserted. In the repeater, the weak optical signal being transmitted through the optical fibre is detected by the photodiode. The detected signal is reformed and amplified by the electronic circuits. The amplified signal is converted again into an optical signal by a laser diode and transmitted again through the optical fibre cable. Fig. 53.34 shows a simple schematic of a repeater.

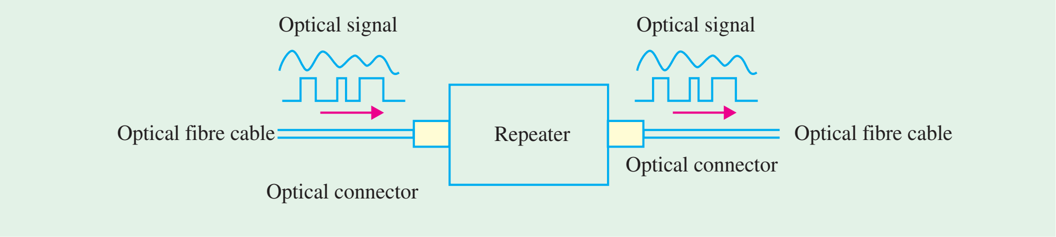


Fig. 53.34

From the modulation point of view, the optical fibre communication systems can be divided into ***digital systems*** and ***analog systems.*** Most long-haul and large capacity optical fibre communication systems are digital systems. The analog systems are used for transmitting information over a short distance.

53.21. Optical Fibre Data Links

The use of optical fibre data links has wide spread in the past few decades. Its application ranges from local area networks (LANs) to the computer, digital audio and mobile fields. Several different types of LEDs and laser diodes emitting light at wavelengths ranging from visible to the infrared are used as optical sources. The transmission data rate is a function of transmission distance and varies from application to application. For computer links where the distance varies from 1 m to 100 m, the data transmission rate varies from 1 M bits/s to 100 M bits/s. For local-area-networks used in factory, office and building automation, the data transmission rate varies from 10 K bits/s to 5 M bits/s. In digital audio field, where the distance is below 1 m the data transmission rate varies from 500 bits/s to over 10 M bits/s. Similarly in mobile fields (such as ship, aircraft, train and automotive applications) where the distance could vary from 1 m to 100 m, the data transmission rate varies from 1 K bits/s to 1 M bits/s.

1. Optical fibre local area networks. The optical fibre local area networks (LANs) are similar to the public communication systems. Some of their advantages over the systems using metallic cables are : **(1)** high transmission capacity and bit rate and **(2)** longer transmission distance. However, the range of LANs is restricted. They are more commonly used within factories, offices, buildings etc. Computers, printers, facsimile machines and other office equipment are connected with each other by optical fibre cables as shown in Fig. 53.35.

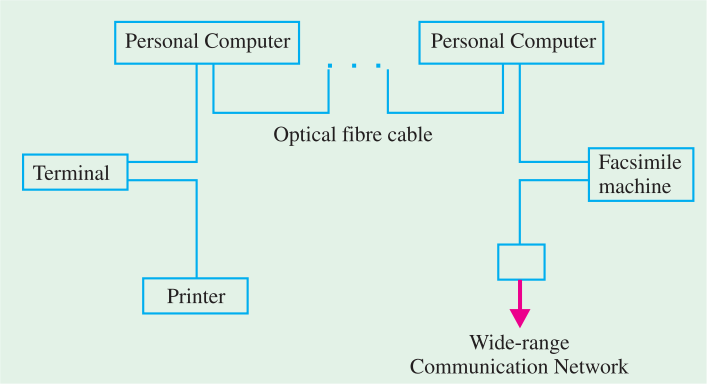


Fig. 53.35

The LEDs and laser diodes are used to transmit data through the optical fibre cable and photodiodes are used to receive data. The different types of equipment connected in the LAN could be one of the following two types : (1) An optical ethernet having a radial-shape network as shown in Fig. 53.36 (*a*) or (2) a fibre-distributed data interface (FDDI) having a ring-shape network as shown in Fig. 53.36 (*b*).

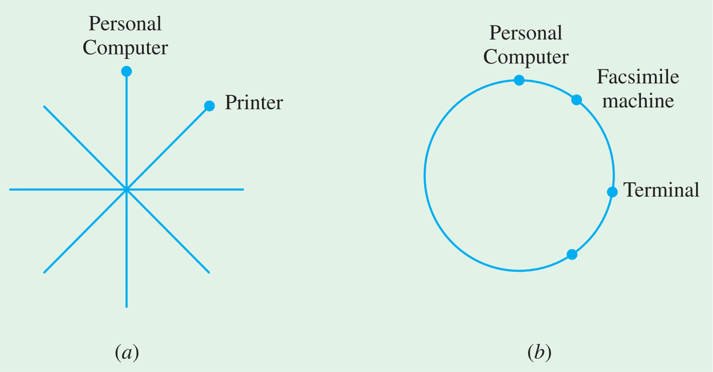


Fig. 53.36

2. Digital audio field. Fig. 53.37 shows an example of a data link in digital audio field. As seen, the optical fibre cable is used to connect compact disk (CD) player, laser disk (LD) player, digital audio tape (DAT) and tuner with the amplifier and speaker. The connection between the amplifier and everything except DAT is unidirectional. The audio digital signals from CD, LD player, DAT and tuner are converted into optical signals by LEDs or laser diodes at one end of the fibre optic cable and then transmitted through the cable to the opposite end. At the opposite end, the signals are received by photodiodes and converted into an electrical signal for amplification and finally speaker for reproduction to a sound.

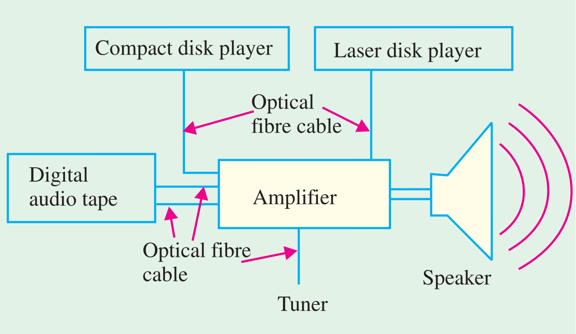


Fig. 53.37

3. Mobile fields. The optical data links are very suitable in mobile fields such as ship, aircraft, train, automotive etc. The reason is that optical data links are very compact, and light in weight than metallic data links. In addition to this, the optical data links are not subjected to noise induced by electromagnetic induction.

OBJECTIVE TESTS – 53

1. LEDs are commonly fabricated from gallium compounds like gallium arsenide and gallium phosphide because they
(*a*) are cheap
(*b*) are easily available
(*c*) emit more heat
(*d*) emit more light.

2. A LED is basically a .... P-N junction.
(*a*) forward-biased
(*b*) reverse-biased
(*c*) lightly-doped
(*d*) heavily-doped.

3. As compared to a LED display, the distinct advantage of an LCD display is that it requires
(*a*) no illumination
(*b*) extremely low power
(*c*) no forward-bias
(*d*) a solid crystal

4. Before illuminating a P-N junction photodiode, it has to be
(*a*) reverse-biased
(*b*) forward-biased
(*c*) switched ON
(*d*) switched OFF.

5. In a photoconductive cell, the resistance of the semiconductor material varies .... with the intensity of incident light.
(*a*) directly
(*b*) inversely
(*c*) exponentially
(*d*) logarithmically.

6. A photoconductive cell is known as .... cell.
(*a*) phototransistor
(*b*) photoresistor
(*c*) photovoltaic
(*d*) both (*a*) and (*b*).

7. A phototransistor excels a photodiode in the matter of
(*a*) faster switching
(*b*) greater sensitivity
(*c*) higher current capacity
(*d*) both (*a*) and (*b*)
(*e*) both (*b*) and (*c*).

8. A photodarlington comprises of
(*a*) a phototransistor
(*b*) a transistor
(*c*) a photodiode
(*d*) both (*a*) and (*b*).

9. A solar cell operates on the principle of
(*a*) diffusion
(*b*) recombination
(*c*) photo voltaic action
(*d*) carrier flow.

10. Solar cells are used as source of power in earth satellites because they have
(*a*) very high efficiency
(*b*) unlimited life
(*c*) higher power capacity per weight
(*d*) both (*b*) and (*c*)
(*e*) both (*a*) and (*b*).

11. The device possessing the highest sensitivity is a
(*a*) photo conductive cell
(*b*) photovoltaic cell
(*c*) photodiode
(*d*) phototransistor

12. The unique characteristics of LASER light are that it is
(*a*) coherent
(*b*) monochromatic
(*c*) collimated
(*d*) all of the above

13. The LASCR operates like a
(*a*) latch (*b*) LED
(*c*) photodiode (*d*) phototransistor.

14. Optical couplers are designed to .... one circuit from another.
(*a*) control (*b*) isolate
(*c*) disconnect (*d*) protect.

15. The main purpose of using optical isolators is to provide protection to devices from
(*a*) high-voltage transients
(*b*) surge voltages
(*c*) low-level noise
(*d*) all of the above.

16. A LED emits visible light when its ....

(*a*) P-N junction is reverse-biased
(*b*) depletion region widens
(*c*) holes and electrons recombine
(*d*) P-N junction becomes hot.

17. In LED, light is emitted because

(*a*) recombination of charge carriers takes place
(*b*) diode gets heated up
(*c*) light falling on the diode gets amplified
(*d*) light gets reflected due to lens action.

18. GaAs, LEDs emit radiation in the

(*a*) ultraviolet region
(*b*) violet-blue green range of the visible region
(*c*) visible region
(*d*) infra-red region

19. Phototransistors respond much like a conventional transistor except that, in their case, light energy is used to ....

(*a*) alter leakage current
(*b*) change base voltage
(*c*) switch it ON
(*d*) alter emitter current.

ANSWERS

1. *(d)* **2.** *(a)* **3.** *b* **4.** *(a)* **5.** *(b)* **6.** *(d)* **7.** *(e)* **8.** *(d)* **9.** *(c)* **10.** *(d)* **11.** *(d)* **12.** *(d)*
13. *(a)* **14.** *(b)* **15.** *(d)* **16.** *(c)* **17.** *(a)* **18.** *(d)* **19.** *(c)*

GO To FIRST