electrons or holes. These ions create an internal electric field called a **contact potential** fig.1.66.

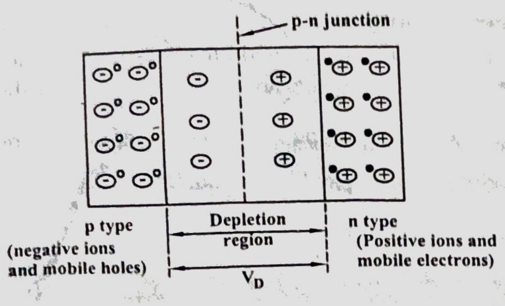


Fig. 1.66

The magnitude of the contact potential depends on the doping levels and temperature. This field is characterized by depletion voltage V_D.

These p-n junctions are used in the fabrication of LED, photodiodes and photovoltaic.

When an electron combines with a hole, two types of recombination process can take place. i.e.,

1. Non-radiative recombination
2. Radiative recombination

In non-radiative recombination process no light radiation is given out. But a radiative recombination process releases a quantum of energy called a **photon.**

Hence to make a semiconductor radiate light energy it is necessary to maintain electron-hole recombinations. But the depletion voltage prevents electrons and holes from penetrating into a depletion region. Therefore external energy must be supplied to overcome this voltage barrier fig.1.67.

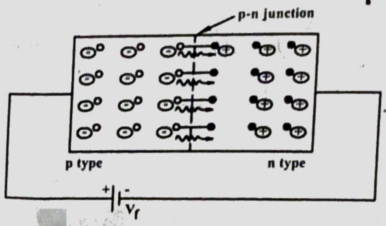


Fig. 1.67

This external voltage is called forward biasing voltage V_f and this must be greater than the barrier voltage V_D.

Hence to produce permanent light radiation, mobile electrons from the n-side attracted by the positive terminal of V_f must enter the depletion region. Simultaneously mobile holes from the p-side attracted by the negative terminal of V_f enter the some depletion region. Hence electron-hole recombination within this depletion region produces light.

> **Note:** *In a p-n junction, if p-type crystal is connected with positive end of the power supply and n-type crystal is connected with negative end of the power supply, now the p-n junction is generally referred as a forward biased p-n junction.*

1.37 LIGHT EMITTING DIODE (LED)

Definition: *An LED is a semiconductor p-n junction diode which converts electrical energy to light energy under forward biasing. It emits light in both visible and IR region.*

Theory: It is known that only the direct band gap semi conductors emit light in the p-n junction and the indirect band gap semiconductors emit the light by recombination via traps.

We know the forbidden band gap energy is given by

$$E_g = E_c - E_v = h\nu$$

since $\nu = \frac{c}{\lambda}$

$$E_g = \frac{hc}{\lambda} \text{ Joules}$$

Since $1 \text{ eV} = 1.602 \times 10^{-19}$ J

$$E_g = \frac{hc}{\lambda \times 1.602 \times 10^{-19}} \text{ eV}$$

Substituting for Plancks constant $h = 6.625 \times 10^{-34}$ Jsec

Velocity of light $c = 3 \times 10^{8}$ m/s

We get $\lambda = \frac{12406.7}{E_g} \text{Å} \approx \frac{12400}{E_g} \text{Å}$

Therefore the wavelength of the light emitted purely depends on the band gap energy expressed in electron volts.

1.38 LED MATERIALS

We know, the visible wavelength region lies between 4000 A and 7200 A.

We have $E_g = \frac{12406.7}{\lambda}$ eV

For $\lambda = 4000$ Å, $E_g = \frac{12406.7}{4000} \Rightarrow 3.101$ eV

For $\lambda = 7200$ Å, $E_g = \frac{12406.7}{7200} \Rightarrow$ eV

Therefore, if the wavelength of the light to be emitted has to lie in visible wavelength, the energy band gap should be between 3.101 and 1.723 eV. Thus, the intermediate compounds of group III and Group V, which has the energy band between 1.72 and 3.1 eV are choosen for the manufacturing of LED's.

Examples

(i) Gallium Arsenide (GaAs) (doped with silicon)

» It is a direct band gap semiconductor.

» The energy band gap $E_g = 1.43$ eV

» Wavelength emitted $(\lambda) = \frac{12406.7}{1.43} = 8616.01$ Å

» This wavelength lies in *IR region.*

(ii) Gallium phosphide (GaP) (doped with N (or) Bi)

» It is an indirect band gap semiconductor.

» The energy band gap $E_g = 2.26$ eV.

» Therefore, the wavelength emitted $= 5514.08$ A.

» This wavelength lies in *Green region* (i.e.) the LED made of this material emits *green colour.*

(iii) Gallium Arsenide phosphide ($GaAs_{0.15}\,P_{0.85}$) (doped with Nitrogen)

» It is a direct band gap semiconductor.

» Energy band gap $E_g = 2.106$ eV

» Wavelength emitted $= 5891.12$ A.

» Thus it emits *yellow colour.*

(iv) Gallium arsenide phosphide ($GaAs_{0.6}\ P_{0.65}$) (Doped with Nitrogen)

» It is a direct band gap semiconductor

» Energy band gap $E_g = 1.962$ eV

» Wavelength emitted $= 6320.35$ A

» Thus it emits orange colour.

(v) Gallium phosphide (GaP) (doped with zinc, oxygen)

» It is an indirect band gap semiconductor.

» Energy band gap $= 1.772$ eV.

» Wavelength emitted $= 7001.52$ A

» Thus it emits *Red colour.*

1.39 TYPES OF LED

There are two types of LED's, viz.,

(i) Planer LED (ii) Dome shaped LED

Planer LED

Since the light is emitted from a plane surface it is called planer LED (or) Surface emitting LED.

Principle: ***Injection luminescence****, which is the phenomenon of emitting light due to* ***minority carrier injection*** *is used as the principle in LED's.*

Construction: The surface emitting LED is as shown in fig.1.68. Here the p-n junction is formed by diffusion or epitaxial techniques.

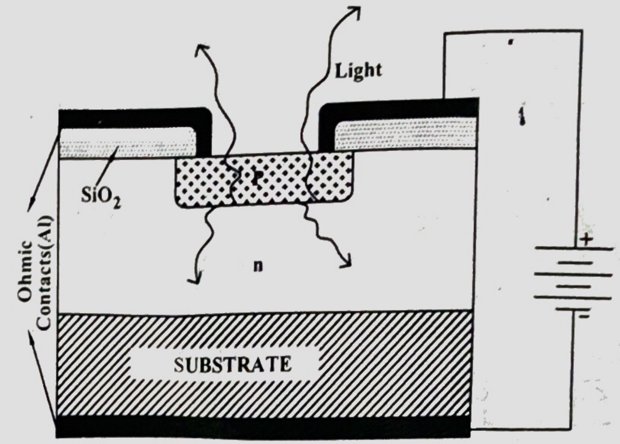


Fig. 1.68

The p-n junction is made by doping silicon with GaAs crystal. Since silicon can act both as donar (when it replaces Gallium) and acceptor (when it replaces arsenide) it is used as the impurity atom (or) dopent. Therefore a shallow p-n junction is formed on GaAs substrate such that p-layer is formed by diffusion on 'n' layer.

In order to increase the probability of radiative recombination, the thickness of the 'n' layer is taken higher than that of the thickness of the 'p' layer.

Ohmic contacts are made with the help of aluminium in such a way that top layer of the 'p' material is left uncovered, for the emission of light. Biasing can be applied at the ohmic contacts. The whole p-n junction is surrounded by plastic material so that the losses due to reflection can be minimised.

Working

The diode is forward biased. Due to forward bias, the majority carriers from 'n' and 'p' regions cross the junction and become minority carriers in the other junction (i.e)

Electrons, which are majority carriers in 'n' region cross the junction and go to 'p' region and become minority carriers in p-region as shown in fig.1.69.

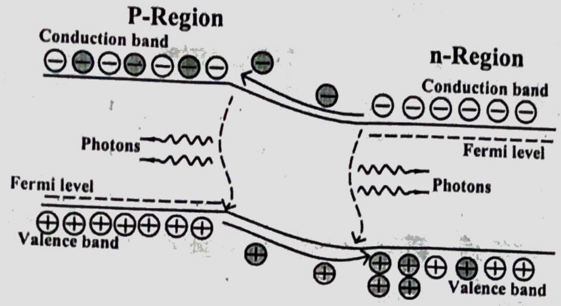


Fig. 1.69

Similarly, holes which are majority carries in 'p' region cross the junction and go to 'n' region and become minority carriers in 'n' region.

By the similar process, excess of minority carriers are injected in both 'p' and 'n' regions and this phenomenon is called ***minority carrier injection.***

Now if the biasing voltage is further increased, these *excess minority carriers diffuse away from the junction and they directly recombine with the majority carriers.* (i.e.) the electrons, which are excess minority carriers in p-region recombine with the holes which are the majority carriers in 'p' region and emit light. Similarly, the holes which are excess minority carriers in 'n' region recombine with the electrons which are majority carriers in 'n' region and emit light.

Therefore electron-hole *recombination process occurs more and more and thereby light (photons) is emitted through the top layer of the p-material* which is left uncovered as shown in fig.1.68.

Disadvantage

(i) The reflection losses will be more.

Dome-shaped LED

In the planer LED, the reflection loss is more because most of the emitted light strikes the material interface at an angle greater than the critical angle. Therefore they are totally internally reflected and will not come out of the interface. Thus the light is lost.

This loss of light due to internal reflection can be minimised by two ways. *viz.,*

(i) By making the 'p' material in the shape of a hemispherical dome (fig.1.70). The angle at which the light strikes the interface can be made less than the critical angle and hence the light will not be lost by total internal reflection.

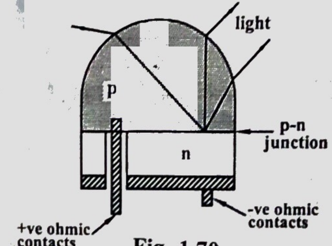


Fig. 1.70

(ii) By covering the p-n junction by a plastic medium of higher refractive index in the shape of hemispherical dome (fig.1.71), total internal reflection can be reduced. This LED is used for commercial purpose. Hence usually dome shape hemispherical LED is prepared than planer LED's.

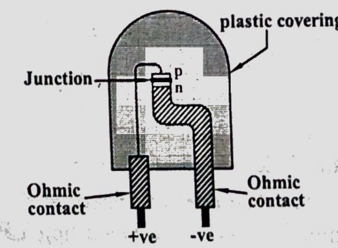


Fig. 1.71

Advantages of LED

(i) They are smaller in size.

(ii) Its cost is very low.

(iii) It has long life time.

(iv) LED's are available in different colours at low cost.

(v) It operates even at very low voltage.

(vi) Response time of LED is very fast in the order of 10^{-9} seconds.

(vii) Its intensity can be controlled easily.

(viii) It can be operated at a wide range of temperatures, (0 – 70°C)

1.40 MATERIALS USED IN COMPUTERS AND COMMUNICATION SYSTEMS

The materials which are designed earlier plays an important role in the field of computers and communications.

The materials are classified into various branches, viz.,conducting materials, semiconducting materials, insulatingmaterials, magnetic materials, superconducting materials, optical materials, non-linear optical materials etc.

They provide the basis for manufacturing, fabrication, operation, construction etc., which are used to generate electricity, transmit a message, store computer datas etc.

These are used to construct the most powerful devices such as LED, LCD, photodiode, PIN photo diode, avalanche photo diode, photo transistor etc.

For example, magnetic tapes and thin films, ferrites and metallic glasses find special application in the memory of the computer cores, magnetic shielding and recording devices.

Similarly metals, non-metals, ceramics, composites, metallic compounds and alloys are belonging to the category of super conducting materials which are widely used in

computer fields, such as switching elements, flip-flop devices, very strong magnets, magnetic detectors etc.

The materials that are widely used in computers and communications, are listed in the given table.

In communication

S.No.	Materials	Applications
1.	Carbon Graphite	Telecommunication equipments
2.	Polyacrylate, polymide	Used to make communication equipments
3.	Phenolics	Used to make telephone receivers.
4.	Copper alloys	Printed circuit boards
5.	Teflon, rexolite, rubber	Connectors
6.	Single crystal Silicon chips, hybrid chips of GaAs and Si	Integrated circuits
7.	Se, Pbs, CdS	Photo cells
8.	Nichrome	Sensor

In computers

S.No.	Materials	Applications
1.	Synthetic resin	Used to insulate computer components.
2.	Polymeric composites	Used to make computer body.
3.	Ferrites	Computer memory core.
4.	AlGaAs chips	Microprocessor
5.	Iron garnet, ferrites Mn-Mg	Memory devices
6.	Magnetic mylar plastics, Polyvinyl cinammnate	Compact disk
7.	Phenolics Gold	Input devices
8.	Fluorescent coated plastics	Display screen (output devices)

2.11 LIQUID CRYSTAL DISPLAY (LCD) [PASSIVE DISPLAY DEVICE]

Liquid crystal display is not a semiconductor device as LED. LCD's display the light, it doesn't radiate light energy. Therefore, LCD's require an external (or) Internal source of light so that it can either transmit (or) reflect the incident light.

Definition: *It is a digital display unit used in watches, calculators etc. in which the digits are displayed by the **transmission (or) reflection** of the incident light, with a very low power consumption (in the order of microwatts).*

Theory: Liquid crystals are the intermediate phases between liquid and the crystal. It has fluidity and anisotropic properties. The liquid crystals are organic fluids. The individual molecule has a minute cigar-shaped appearance. *The molecules will have a prefered orientation (or) direction called **director.***

Based on the orientation of the molecules there are three phases in liquid crystals.

1. Smectic2. Nematic and 3. Cholestric

Out of the three phases the last two phases are very important.

Nematic phase: In this phase the molecules are orderly arranged (i.e) the directors are aligned parallel to each other as shown in fig.2.16(a).

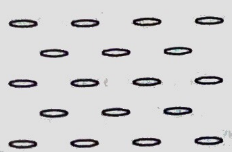
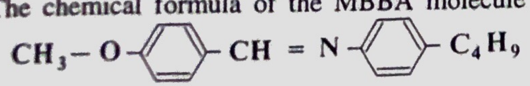


Fig. 2.16a

*The nematic liquid crystal is made of **MBBA** molecule (i.e.) **4-methoxy-Benzylidene,4-butylaniline** in which two benzene rings are linked in a single group.*

The chemical formula of the MBBA molecule is



Cholestric phase: In cholestric phase the molecules are orderly arranged similar to nematic phase, but in planes. Here the only difference is the orientation (directors) will differ from one plane to another as shown in fig.2.16(b).

*The distance between the similar planes (i.e.) the planes in which the molecules has same director, is called **pitch.***

The cholestric liquid crystal has a special property that, if white light is allowed to pass through the crystal it appears coloured.

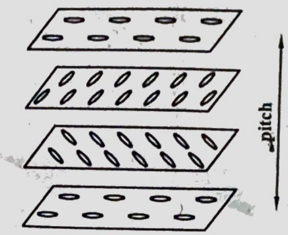


Fig. 2.16b

2.12 TYPES OF LCD'S

Nematic phase is widely used for displays. There are two types of LCDs in use.

1. Dynamic Scattering Displays
2. Twisted nematic displays (or) Field effect displays

1. Dynamic Scattering Display

In the case of dynamic scattering display in the absence of an applied voltage, the device is transparent. But, when the voltage is applied, the liquid crystal becomes an efficient scatterer of white light.

Construction: It consists of a pure nematic liquid crystal in which *impurities are added to increase its conductivity,* due to ions in them. The liquid crystal is filled in between two glass plates which are coated with transparent tin oxide and can act as electrodes as shown in fig.2.17. The spacer and scaler help in filling of liquid and to change the liquid level.

Working: In the normal state, without application of electric **field,** all the molecules in the nematic liquid crystal are parallel to the glass plate. The material is transparent (Fig.2.17.)

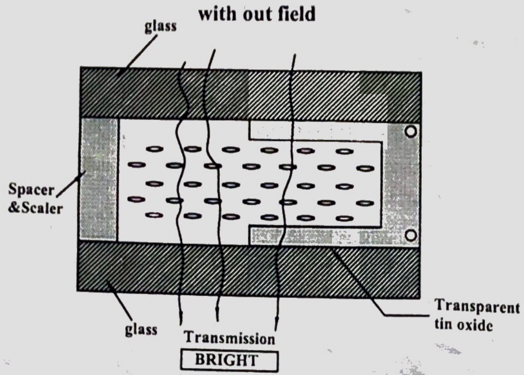


Fig. 2.17.

When the electric field is applied, the dipoles of the molecules are rotated into alignment in the direction, exactly perpendicular to field direction. Now, the ions are pulled by the electrodes and hence the positive ions will go towards negative potential and viceversa.

Therefore these ions (impurity) disrupt the molecules which are orderly arranged and create a small turbulence. Due to turbulence the negative charges are gathered as crests and positive charges are gathered as troughs, with respect to the field direction as shown in fig.2.18.

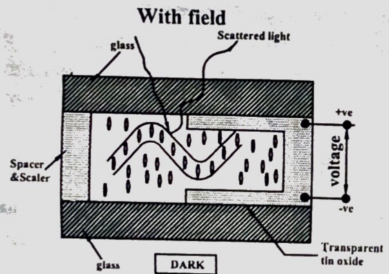


Fig. 2.18.

When the applied voltage is at critical value, the turbulance becomes more, which results in the variation of refractive index of the medium of the crystal. So, the light falling on them is scattered and hence liquid appears dark in the white background.

When the field is switched off the molecules are locally rearranged and material becomes transparent and the display is erased.

Disadvantages

1. It has large operating voltage (15 volts)
2. It consumes large power (20 milliwatt)
3. Lifetime is very small.

2. The twisted nematic display

Construction

In this nematic phase, liquid crystal molecules are kept between two transparent glass plates. The top glass plate and the bottom glass plates are coated with a transparent electrode. *The polariser and analyser are arranged in the **crossed** position, above and below the glass plates respectively as shown in fig.2.19.*

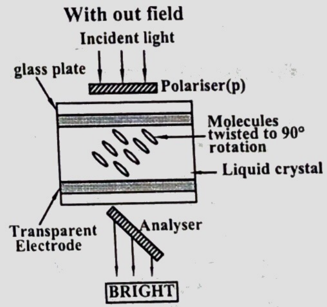


Fig. 2.19.

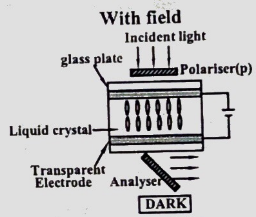


Fig. 2.21.

Working

The top glass plate is rotated through 90° and hence the molecules are also twisted through 90° (fig.2.19).

Without field

The light is passed through the polariser, then through the molecules and finally through the analyser.

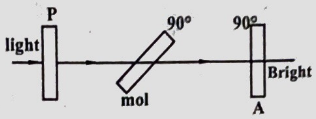


Fig. 2.20.

Here, the field of view appears *bright*, because the plane of polarisation is rotated through 90° by the crossed position of polariser and analyser and another 90° by twisted nematic molecules. (fig.2.20).

With field

Now, when the field is applied, the twisted molecules come to normal position as shown in fig.2.21 and there is only 90° rotation of plane of polarisation between polariser and analyser (Fig.2.22). Therefore, there is no transmission of light and the display appears black in white back ground.

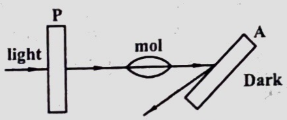


Fig. 2.22.

When the electric field is switched off, once again the molecules return back to their twisted position and so display is bright and erased.

Note: *This mode of display is widely used because of its low power consumption, low operating voltage etc.*

2.13 MERITS AND DEMERITS OF LED AND LCD

S.No.	L E D	L C D
	Demerits	**Merits**
1.	Cost is high compared to LCD	Cost is very low.
2.	Not suitable for large area display	Suitable for large area display
3.	High power consumption (milliwatts)	Low power consumption (microwatts)
	Merits	**Demerits**
4.	Operating temperature is 0° to 70°C.	Operating temperature is 10°C to 47°C
5.	Response time is in nano seconds (10^{-9} sec)	Response time is in microseconds 10^{-6} sec)
6.	Intensity of light can be controlled.	Intensity of light cannot be controlled
7.	Different colour displays are available at low cost.	Colour displays will not be available at low cost.

2.14 APPLICATIONS OF LCD

1. They are used in wrist-watches, clocks.
2. They are used in calculators, measuring instruments like digital multimeter.
3. Digital balance also has application of display devices.
4. They are used in measuring the temperature (Digital thermometers).
5. They are used in Digital Guass meters.
6. They are used in large display units.